UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

AGE AND TECTONIC SIGNIFICANCE OF VOLCANIC ROCKS ON ST. MATTHEW ISLAND, BERING SEA, ALASKA

By

William W. Patton, Jr., Marvin A. Lanphere,

Thomas P. Miller, and Richard A. Scott

Menlo Park, Calif., Anchorage, Alaska, Denver, Colo.

Open-file report 75-150

1975

AGE AND TECTONIC SIGNIFICANCE OF VOLCANIC ROCKS ON ST. MATTHEW ISLAND, BERING SEA, ALASKA

By WILLIAM W. PATTON, JR., MARVIN A. LANPHERE,

THOMAS P. MILLER, and RICHARD A. SCOTT

Menlo Park, Calif., Anchorage, Alaska, Denver, Colo.

Abstract.-- Reconnaissance investigations of the heretofore little known volcanic assemblage on St. Matthew Island provide significant information on the tectonic history of the Bering Sea shelf. St. Matthew Island is made up of approximately 500 m of subaerial calc-alkaline volcanic rocks ranging in composition from high-alumina basalt to rhyolite. Four K-Ar analyses of samples from this volcanic sequence give Late Cretaceous ages of 65-77 m.y., and intercalated carbonaceous tuff layers yield Cretaceous pollen assemblages. Along the northeast coast of St. Matthew Island the volcanic rocks are intruded by granodiorite that gives an early Tertiary K-Ar age of 61 m.y.

Correlations with on-land geology in northeast Siberia and marine geophysical data from the western Bering Sea strongly suggest that St. Matthew Island represents a southeastward extension of the Okhotsk-Chukotsk belt, a Late Cretaceous and early Tertiary volcanic arc that borders the Pacific margin of Siberia for 3,000 km. The apparent continuation of this volcanic arc along the margin of the Bering shelf at least as far east as St. Matthew Island supports suggestions by Burk and by Scholl and others that in late Mesozoic time the Pacific plate margin coincided with the present-day Bering shelf margin and did not shift to the Aleutian trench until the end of Cretaceous or the beginning of Tertiary time.

During the summer of 1971 the U.S. Geological Survey conducted a reconnaissance expedition to St. Matthew Island in the central Bering Sea aboard the Survey research vessel Don J. Miller II. The purpose of the expedition was to obtain basic geologic information on the age and lithologic character of the volcanic rocks on St. Matthew as part of a broad program of onshore and offshore investigations of the energy and mineral resources of the Bering Sea shelf. St. Matthew Island had not been mapped previously and available geologic information was confined to brief notes from early exploratory surveys of the Bering Sea region published more than 50 years ago (Dawson, 1894; Emerson, 1910).

St. Matthew Island together with two small neighboring islands, Hall and Pinnacle, is situated 400 km west of mainland Alaska on the broad continental shelf that connects Alaska and Siberia (fig. 1).

Figure 1 near here.

Although these islands have a combined area of only 350 km^2, they are important because they provide a rare subaerial exposure of the geology of the shelf and furnish new information on the tectonic history of the Bering Sea region.

This report briefly describes the geology of the island and suggests how the island fits into the tectonic framework of the Bering Sea region.

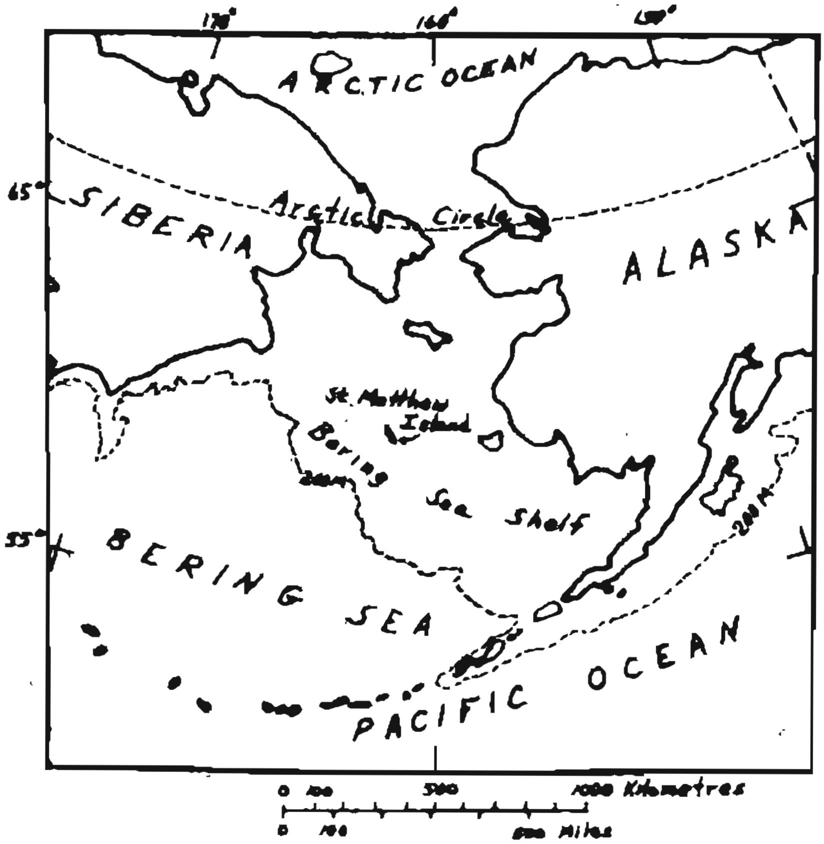


Figure 1.--Index map showing St. Matthew Island and Bering Sea shelf.

DESCRIPTION OF ROCK UNITS

St. Matthew and nearby Hall and Pinnacle Islands are made up almost entirely of an assemblage of flat-lying to gently folded subaerial calc-alkaline volcanic rocks of Late Cretaceous and earliest Tertiary age (fig. 2)

Figure 2 near here.

(Patton and others, 1975). The exposed thickness of the volcanic sequence is at least 500 m. Along the north coast of St. Matthew the volcanic rocks are intruded and thermally altered by small stocks of granodiorite of early Tertiary age. A small, fault-bounded block of contorted volcanic graywacke and argillite of unknown age and uncertain affinities occurs near the center of the island.

Volcanic assemblage

The lower part of the volcanic assemblage consists chiefly of andesite, dacite, and rhyolite tuffs with minor andesitic and dacitic flows, dikes and plugs. This predominantly pyroclastic succession underlies virtually all of St. Matthew Island and also is exposed in a small area along the east side of Hall Island (fig. 2). Pollen, identifiable as Cretaceous in age, was collected from these rocks at two localities along the southwest coast of St. Matthew Island. No samples of the tuffs and breccias suitable for isotope dating were found on St. Matthew Island because of pervasive alteration by granodiorite intrusions. An unaltered sample of the breccia from Hall Island, however, gave mineral pair dates of 74.1 ± 2 m.y. and 74.4 ± 2 m.y. (Late Cretaceous) for biotite and hornblende, respectively. Analytical data for the K-Ar ages have been published previously (Patton and others, 1975).

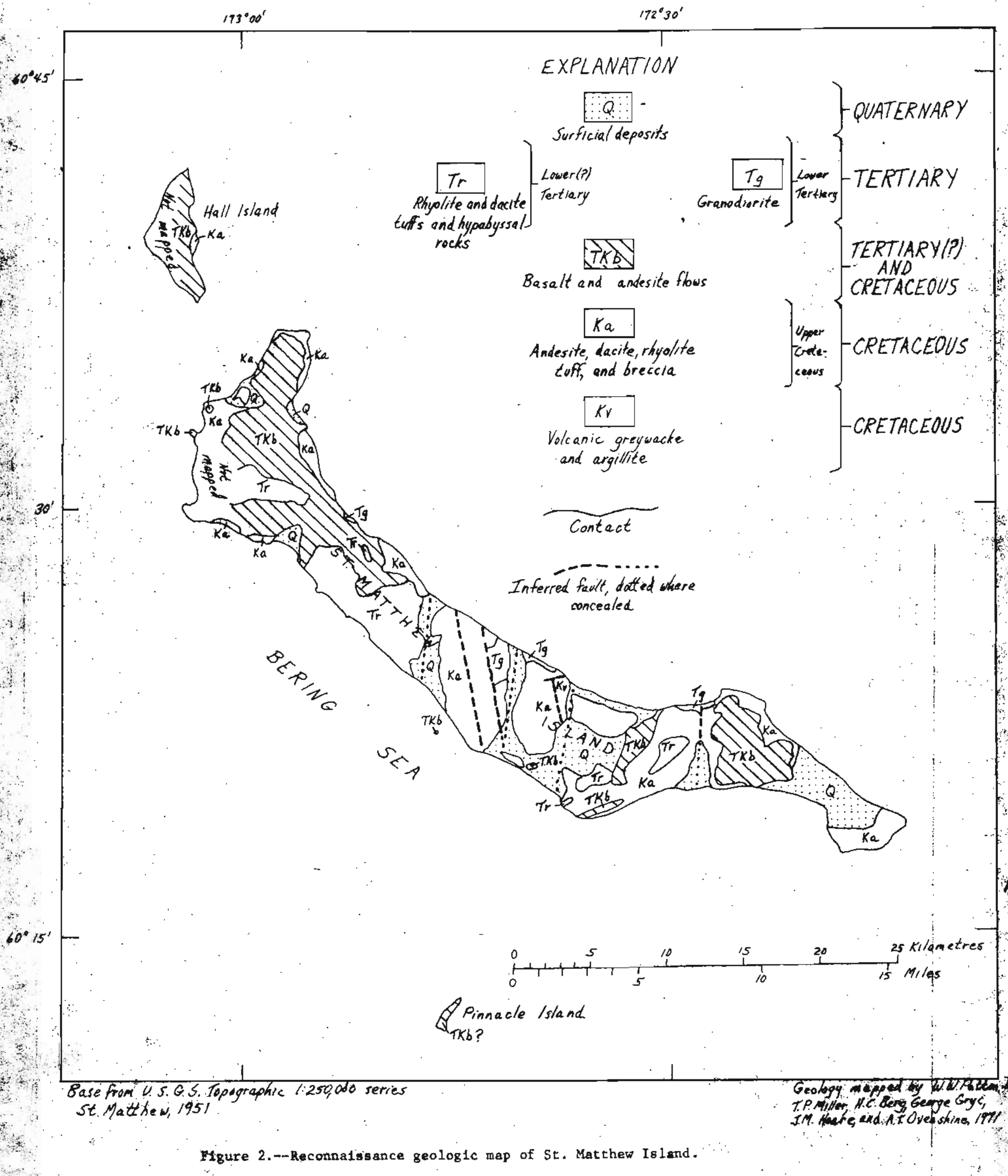


Figure 2.--Reconnaissance geologic map of St. Matthew Island.

The pyroclastic rocks are capped by flows of high-alumina basalt and andesite that are at least 250 m thick at the north end of St. Matthew Island and on Hall Island. On Hall Island these flows are interlayered with andesitic tuffs and conglomerate. Potassium-argon ages of 76.8±2 m.y. and 64.8±2 m.y. (Cretaceous and Tertiary?) were obtained from two whole-rock samples of the flows at the north end of St. Matthew Island.

The youngest volcanic rocks are dacite and rhyolite welded tuffs and fine-grained hypabyssal rocks that appear to be, at least in part, cogenetic with granodiorite. These felsic volcanic rocks have not been dated isotopically but are assigned a Tertiary (probable earliest Tertiary) age on the basis of their apparent consanguinity with the granodiorite.

Granodiorite

Fine-grained leucocratic hornblende granodiorite crops out in seacliffs at several localities along the north-facing coast of St. Matthew Island (fig. 2). The total exposed area of the granodiorite is small, but the volume of these intrusive rocks may be considerably greater in the subsurface. This is suggested by the relatively large area of thermal alteration of the pyroclastic host rock extending well beyond the small area of exposure of the granodiorite. A greater subsurface volume is also suggested by a broad 10 mGal positive gravity anomaly over the coastline which, according to Barnes and Estlund (1975), can be accounted for by the density contrast between a large granodiorite body at shallow depth and the less dense pyroclastic host rocks.

A potassium-argon age of 60.7±2 m.y. (earliest Tertiary) was obtained from hornblende from a sample of the granodiorite collected on the central part of the island.

Volcanic graywacke and argillite

A puzzling section of highly deformed and thermally altered marine volcanic graywacke and argillite occurs in a small fault-bounded block in the central part of St. Matthew Island (fig. 2). These sedimentary rocks show small-scale crossbedding and convolute laminations suggesting that they are the distal facies of a turbidite. No other exposures of these rocks were found and their age and stratigraphic relationships are uncertain. The structural complexity of these rocks indicates that they probably are older than the Upper Cretaceous volcanic rocks of the island. However, the proximity of St. Matthew to the probable Cretaceous margin of the Bering shelf and correlations with on-land geology in northeast Siberia make it appear likely that they are Cretaceous.

CHEMICAL ANALYSES AND NORMS

The volcanic-plutonic assemblage on St. Matthew Island shows a typical calc-alkaline trend on an AFM plot of 34 representative samples (fig. 3).

Figure 3 near here.

The alkali-lime index for the samples is 58 and well within the calc-alkali field of Peacock (1931). The analyzed samples (Patton and others, 1975) include high-alumina basalt flows; andesite, dacite, and rhyolite tuffs, flows, and hypabyssal rocks; and granodiorite. All of the samples are quartz and hypersthene normative, and some of the more silicic andesite contains sufficient excess of Al_2O_3 so that corundum appears in the norm with the consequent exclusion of diopside.

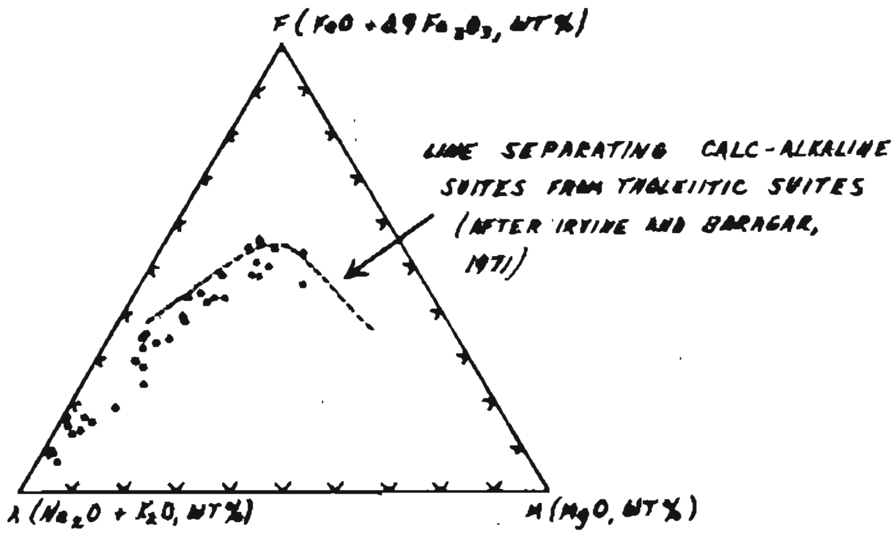


Figure 3.—AFM plot of 34 representative samples of volcanic and plutonic rocks on St. Matthew Island.

LATE CRETACEOUS AND EARLIEST TERTIARY VOLCANISM AND TERRIGENOUS DEPOSITION IN THE BERING SEA

The broad distribution of volcanism and terrigenous deposition in the Bering Sea region during Late Cretaceous and earliest Tertiary (~80 to 55 m.y.) time is shown in figure 4. During this time, thick terrigenous

Figure 4 near here.

sediments were deposited along the continental margins of both northeast Siberia and Alaska. At the same time volcanism occurred behind the continental margin along a relatively narrow belt in northeast Siberia and over a somewhat broader belt in western Alaska. The northern limit of large-scale volcanic and plutonic activity was the pre-Late Cretaceous miogeosynclinal Verkhoyansk-Chukotsk belt in Siberia and the Seward Peninsula-Brooks Range belt in Alaska. Between Alaska and Siberia, the belt of miogeosynclinal rocks appears to bow southward through St. Lawrence Island (Patton and Tailleur, 1972).

Volcanism

In northeast Siberia volcanic and associated plutonic activity was confined largely to the Okhotsk-Chukotsk belt, a relatively narrow but continuous tectonic feature that parallels the Pacific margin in Siberia for nearly 3,000 km (Belyi, V. F., 1973, Tilman and others, 1969). In the vicinity of the Gulf of Anadyr, the Okhotsk belt turns abruptly to the southeast and extends along the south side of the Chukotsk Peninsula.

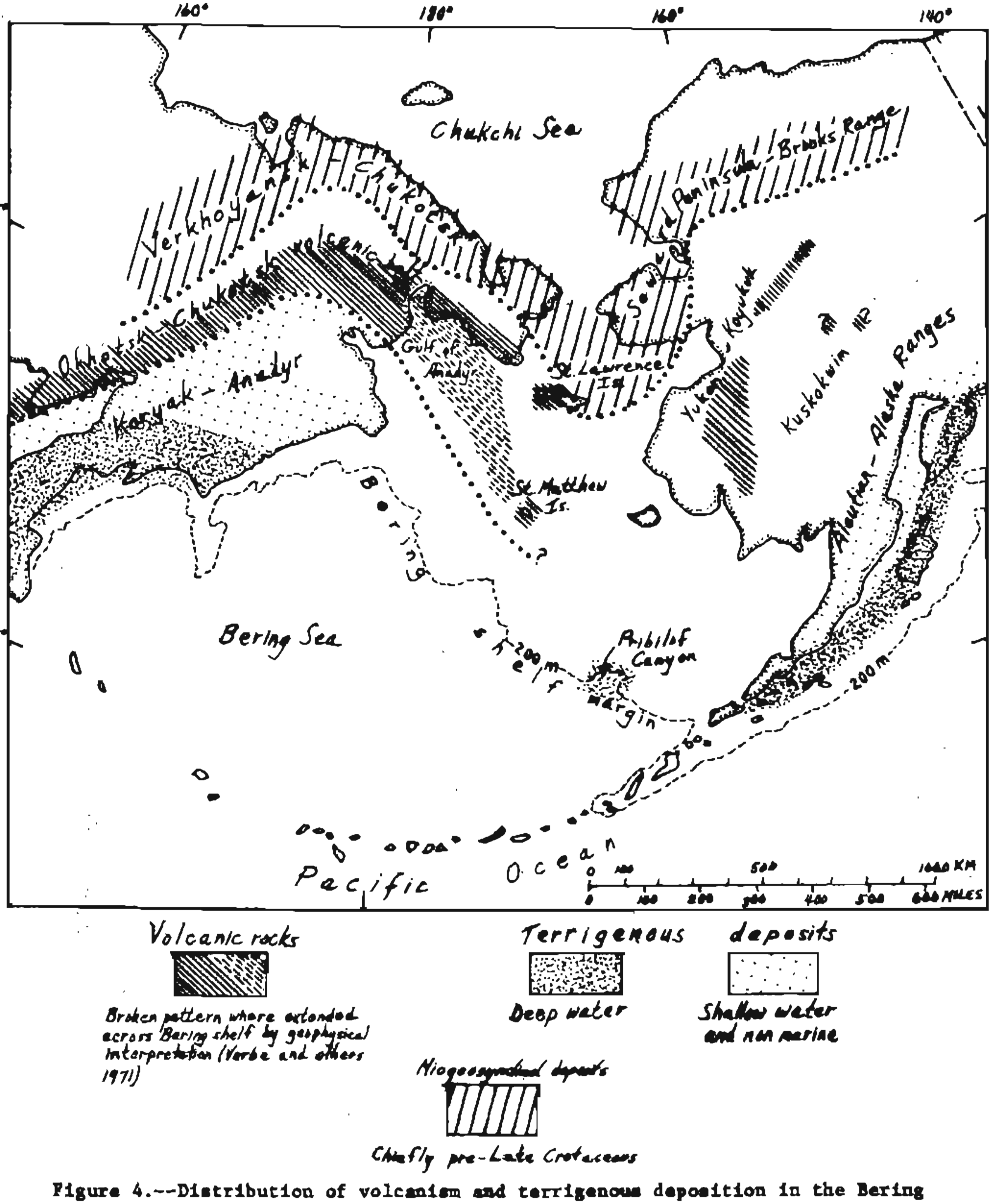


Figure 4.--Distribution of volcanism and terrigenous deposition in the Bering Sea region during Late Cretaceous and earliest Tertiary (~80 to 55 m.y.) time.

Recent offshore geophysical investigations and onshore geologic mapping on St. Matthew and St. Lawrence Islands suggest that the Okhotsk belt continues southeasterly across the Bering shelf at least as far as St. Matthew Island (fig. 4). In the Gulf of Anadyr and on the western Bering shelf Soviet geologists believe that they can trace the volcanic rocks of the Okhotsk belt along a broad Cenozoic high from the Chukotsk Peninsula nearly to St. Matthew Island (Verba and others, 1971). On St. Lawrence Island subaerial calc-alkaline volcanic rocks similar to those on St. Matthew Island have been mapped on the western and central part of the island (Patton and Csejtey, 1971). Three K-Ar ages have been reported for the volcanic rocks on St. Lawrence Island: 62.8 and 60.5 m.y. on sanidine and hornblende, respectively, from a trachyte (Patton and Csejtey, 1971) and 62.2 m.y. on a dacite (Dalrymple and Lanphere, 1971).

The extent and distribution of volcanic rocks on the Bering shelf east of St. Matthew Island are not known. However, in western Alaska a major belt of subaerial calc-alkaline volcanic rocks can be traced for about 800 km northeastward from the lower Kuskokwim River valley to the Arctic Circle. Six K-Ar ages ranging from 58-69 m.y. (Patton and Miller, 1973; Hoare and Condon, 1966; Hoare, unpub. data; and Patton, Lanphere, and Brosgé, unpub. data) have been obtained from these volcanic rocks. Two smaller areas of similar volcanic rocks also have been mapped in the upper Kuskokwim-Yukon region, but no isotopic ages have been measured on these rocks (Cass, 1959; Eakin, 1918).

In addition to the known areas of volcanism shown in figure 4 the broad region of western Alaska south and east of the Seward Peninsula-Brooks Range belt also contains many large granitic plutons, some of which may represent roots of former volcanic terranes. Only a few of these plutonic bodies have been dated isotopically, but these ages are sufficient to show that magmatism was widespread in Late Cretaceous and earliest Tertiary time. For example, in the northern Koyukuk region along the Hogatza trend a major plutonic event has been dated at about 80 m.y. (Miller and others, 1966). An age of 79 m.y. has been measured on a large granitic pluton at Cape Romanzof in the Yukon delta (Hoare and Condon, 1968), and a similar pluton in the central Kuskokwim has yielded an age of 65 m.y. (Hoare, unpub. data). In southern Alaska, Reed and Lanphere (1973) have documented a major intrusive phase in the Alaska-Aleutian Range batholith between 58 and 83 m.y. on the basis of 70 K-Ar mineral ages.

Terrigenous deposition

In Alaska, a belt of highly folded deep-water flysch deposits containing a sparse Maestrichtian fauna has been traced from the Chugach Mountains through Kodiak and the Shumagin Islands (Jones and Clark, 1973). At the southwest end in the Shumagin Islands, Moore (1972) found evidence that this belt did not continue southwestward along the Aleutian Arc but crossed the trend of the Alaska Peninsula and extended northwestward along the margin of Bering Sea shelf. These deep-water deposits are bordered on the north by a band of fossiliferous shallow-water sedimentary deposits that stretches from the Wrangell Mountains to the lower Alaska Peninsula.

In the Koryak-Anadyr region of Siberia (fig. 4), Soviet geologists (Avdeiko, 1971; Gladenkov, 1964) also recognize an outer belt of deep-water flysch deposits with mafic volcanic rocks and an inner belt of shallow-water and nonmarine sedimentary deposits.

Along the Bering shelf margin acoustical profiling and dredging by Scholl and others (in press) and Hopkins and others (1969) have shown that highly deformed flysch deposits underlie the shelf edge beneath a thick cover of poorly consolidated Neogene sediments. Fossils of late Mesozoic or earliest Tertiary age occur in samples of the flysch dredged from the walls of Pribilof Canyon. This was a particularly important discovery because it appears to bear out earlier suggestions of Burk (1965) that the late Mesozoic continental margin deposits of the Alaska Peninsula and Koryak-Anadyr region were connected by way of the Bering shelf margin. It also is significant because it establishes the contemporaneity of calc-alkaline volcanism on St. Matthew Island and the deposition of flysch sediments on the continental margin.

PLATE TECTONIC INTERPRETATION

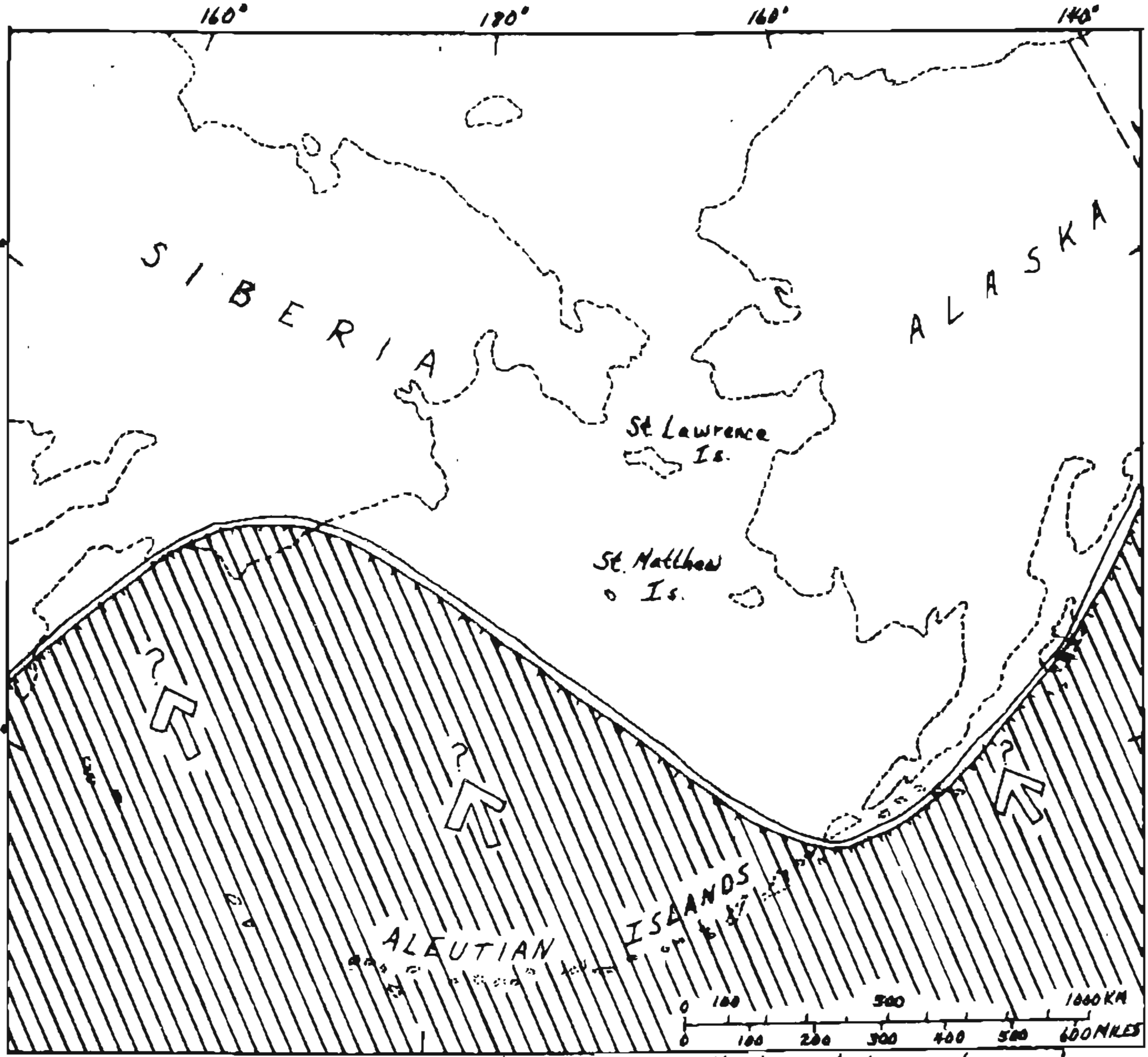
Figure 5 shows the plate model for the Bering Sea region proposed by

---

Figure 5 near here.

Scholl, Buffington, and Marlow (in press). Their model suggests that the late Mesozoic boundary between the North American-Eurasian continental plate and the Kula oceanic plate extended from Siberia to Alaska along the present Bering shelf margin. At the end of the Mesozoic or in the early Tertiary the boundary either jumped or migrated to its present position at the Aleutian Trench, isolating the deep Bering Sea basin behind the Aleutian arc.

This model is supported by the discovery of extensive calc-alkaline volcanism of Late Cretaceous and earliest Tertiary age on St. Matthew Island within a few hundred kilometres of the shelf edge and by the correlation of this volcanism with flysch deposition at the shelf margin.



From Scholl, Buffington, and Marlow (in press)

Figure 5. Boundary and relative plate motion between Kula Plate (shaded) and North American–Eurasian Plate in the Bering Sea region in late Mesozoic time.

The relative motion of the Kula plate in this proposed model appears to have been at a small convergence angle with the Bering shelf margin, leading to the suggestions that the margin was a transform fault. Our evidence for an extensive belt of calc-alkaline volcanism parallel to the margin, however, seems to argue for subduction, even though the convergence angle may have been small.

REFERENCES CITED

Avdeiko, G. P., 1971, Evolution of geosynclines on Kamchatka: Pacific Geology, v. 3, p. 1-14.

Barnes, D. G., and Estlund, M. B., 1975, Gravity map of St. Matthew and Hall Islands, in Patton, W. W., Jr., Miller, T. P., Berg, H. C., Gryc, George, Hoare, J. M., and Ovenshine, A. T., 1975, Reconnaissance geologic map of St. Matthew Island, Bering Sea, Alaska: U.S. Geol. Survey Misc. Field Studies Map MF-642.

Belyi, V. F., 1973, Okhotsk-Chukotsk fold belt and the problem of volcanic arcs in northeast Asia. Am. Assoc. Petroleum Geologists Mem. 19, p. 252-258.

Burk, C. A., 1965, Geology of the Alaska Peninsula—island arc and continental margin: Geol. Soc. America Mem. 99 [in 3 parts].

Cass, J. T., 1959, Reconnaissance geologic map of the Ruby quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-289.

Dalrymple, G. B., and Lanphere, M. A., 1971, $^{40}Ar/^{39}Ar$ technique of K-Ar dating; A comparison with the conventional technique: Earth and Planetary Sci. Letters, v. 12, p. 300-308.

Dawson, G. M., 1894, Geological notes on some coasts and islands of the Bering Sea and vicinity: Geol. Soc. America Bull., v. 5, p. 117-146.

Eakin, H. M., 1918, The Cosna-Nowitna region, Alaska: U.S. Geol. Survey Bull. 667, 54 p.

Emerson, B. K., 1910, Notes on stratigraphy and igneous rocks, in Harriman Alaska Expedition, 1899, v. 4, Smithsonian Institution, p. 32-38.

Gladenkov, Iu. B., 1964, O tektonike vostochnoi chasti Koryakskogo Nagor'ya: Trudy, Geologicheskii Institut, Akad. Nauk. SSSR, v. 113, p. 7-23 [Tectonics in the eastern part of the Koryak Uplands].

Hoare, J. M., and Condon, W. H., 1966, Geologic map of the Kwiguk and Black quadrangles, western Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-469.

______1968, Geologic map of the Hooper Bay quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-523.

Hopkins, D. M., Scholl, D. W., Addicott, W. D., Pierce, R. L., Smith, P. B., Wolfe, J., Gershanovich, D., Kotenev, B., Lohman, K. E., Lipps, J. H., and Obradovich, J., 1969, Cretaceous, Tertiary and early Pleistocene rocks from the continental margin in the Bering Sea: Geol. Soc. America Bull., v. 80, p. 1471-1480.

Irvine, T. N., and Baragar, W. R. A., 1971, A guide to the chemical classification of common volcanic rocks: Canadian Jour. Earth Sci., v. 8, p. 523-548.

Jones, D. L., and Clark, S. H. B., 1973, Upper Cretaceous (Maestrichtian) fossils from the Kenai-Chugach Mountains, Kodiak and Shumagin Islands, southern Alaska: U.S. Geol. Survey Jour. Research, v. 1, no. 2, p. 125-136.

Miller, T. P., Patton, W. W., Jr., and Lanphere, M. A., 1966, Preliminary report on a plutonic belt in west-central Alaska: U.S. Geol. Survey Prof. Paper 550-D, p. D158-D162.

Moore, J. C., 1972, Uplifted trench sediments--southwest Alaska-Bering shelf edge: Science, v. 175, no. 4026, p. 1103-1105.

Patton, W. W., Jr., and Csejtey, Béla, Jr., 1971, Preliminary geologic investigations of western St. Lawrence Island, Alaska: U.S. Geol. Survey Prof. Paper 684-C, p. C1-C15.

Patton, W. W., Jr., and Miller, T. P., 1973, Bedrock geologic map of Bettles and southern part of Wiseman quadrangles, Alaska: U.S. Geol. Survey Misc. Field Studies Map MF-492.

Patton, W. W., Jr., Miller, T. P., Berg, H. C., Gryc, George, Hoare, J. M., and Ovenshine, A. T., 1975, Reconnaissance geologic map of St. Matthew Island, Bering Sea, Alaska: U.S. Geol. Survey Misc. Field Studies Map MF-642.

Patton, W. W., Jr., and Tailleur, I. L., 1972, Evidence in the Bering Strait region for differential movement between North America and Eurasia [abs.]: Geol. Soc. America Abs. with Programs, v. 4, no. 7, p. 623.

Peacock, M. A., 1931, Classification of igneous rock series: Jour. Geology, v. 39, no. 1, p. 54-67.

Reed, B. L., and Lanphere, M. A., 1973, Alaska-Aleutian Range batholith; Geochronology, chemistry, and relation to circum-Pacific plutonism: Geol. Soc. America Bull., v. 84, p. 2583-2610.

Scholl, D. W., Buffington, E. C., and Marlow, M. S., In press, Plate tectonics and the structural evolution of the Aleutian-Bering Sea region, _in_ Forbes, R. B., ed., The geophysics and geology of the Bering Sea region: Geol. Soc. America Mem. 151.

Tilman, S. M., Belyi, V. F., Nikolaevskii, A. A., and Shilo, N. A., 1969, Tektonika Severo-vostoka SSSR: Trudy Severo-Vostochnogo Kompleksnogo Nauchno-Issledovatelskogo Instituta, Sibirskoe Otdelenie Akademii Nauk SSSR, Vyiusk 33, 78 p., Magadan, SSSR [Tectonics of northeast of USSR].

Verba, M. L., Gaponenko, G. I., Ivanov, S. S., Orlov, A. N., Timofeev, V. I., and Cherenkov, Iu. F., 1971, Glubinnoe stroesue i perspektivy neftigazonosnosti severo-zapadnoi chasti beringova moria-V. sb: Geofizicheskie metody razvedki v Arktike L, Niiga, vyp 6, p. 70-74 [Deep structure of northwestern part of the Bering Sea and the prospects of finding oil and gas].