Geology of the Delarof and Westernmost Andreanof Islands Aleutian Islands, Alaska

By GEORGE D. FRASER and H. FRANK BARNETT

INVESTIGATIONS OF ALASKAN VOLCANOES

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PREFACE

The U. S. Geological Survey, in response to the October 1946 request of the War Department (now Department of the Army), made a reconnaissance during 1946–54 of volcanic activity in the Aleutian Islands-Alaska Peninsula area. Results of the first year's research, field, and laboratory work were hastily assembled as two administrative reports to the War Department. Some of the early findings, as recorded by Robert R. Coats, were published in Bulletin 974–B (1950), "Volcanic Activity in the Aleutian Arc," and in Bulletin 989-A (1951), "Geology of Buldir Island, Aleutian Islands, Alaska."

Unpublished results of the early work and all data gathered in later studies are being published as separate chapters of Bulletin 1028.

The investigations of 1946 were financed principally by the Military Intelligence Division of the Office, Chief of Engineers, U. S. Army. From 1947 until 1955 the Departments of the Army, Navy, and Air Force jointly furnished financial and logistic assistance.

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GEOLOGY OF THE DELAROF AND WESTERNMOST ANDREANOF ISLANDS, ALEUTIAN ISLANDS, ALASKA

By GEORGE D. FRASER and H. FRANK BARNETT

ABSTRACT

The layered rocks of the Delarof and westernmost Andreanof Islands are divisible into five units, generally younger from south to north. Unit 1, the rocks of Amatignak Island, is composed of altered, well-bedded tuffaceous rocks including thick, finely banded, penecontemporaneously deformed argillite. These rocks apparently grade northward into unit 2, the altered pillow lavas and pyroclastic deposits of Ulak Island which are interpreted as a near-source facies of unit 1. The age of these two units is unknown but presumably is Tertiary. Unit 3 is a composite sequence of almost unaltered shallow marine and subaerial volcanic rocks composed of tuff-breccia, lava, pillow lava, and subordinate sedimentary rocks. This units extends in a belt across the central Delarof Islands and the southern parts of Tanaga and Kanaga Islands. Upper Tertiary fossils are found in the rocks on Tanaga and Kanaga; the rocks of the central Delarofs are correlated with these because of lithologic similarities. The rocks in unit 3 may be partly equivalent, extreme facies of the Amatignak rocks, or they may be younger. The contact is not exposed. Unit 4 is composed of Pleistocene precaldera lava that forms fragments of old shield volcanoes near the presently active cones. This lava, younger than most of unit 3, apparently intertongues in places with the upper part of the older sequence. Unit 5 comprises the composite cones of presently active Gareloi, Tanaga, and Kanaga Volcanoes. All five bedrock units are andesitic to basaltic in composition.

Units 1, 2, and 3 are cut by many dikes, dike swarms, and sills of andesitic or basaltic composition. One limburgite intrusive mass and one light rhyodacite dike represent divergent compositions.

The older units are also cut by coarse-grained sills, dikes, and plutons, mostly of granodioritic composition. Ilak Island is part of a granodiorite pluton cut by aplite and andesite dikes; none of the invaded rock is exposed and the age is unknown.

None of the rocks have been regionally metamorphosed; even low-grade foliated rocks, such as slate and phyllite, are absent.

Submarine contours reveal a major trench and ridge structure for the Aleutian arc. Islands are actually peaks of a great arcuate mountain range. In this area the range rises 25,000 feet from a foredeep on the Pacific side and 13,000 feet from a deep on the north. The main ridge is apparently

an arch bounded on the south by a north-dipping thrust zone and on the north by a high-angle fault zone, downthrown to the north. Volcanoes are located along the inferred fault on the north. A group of transverse submarine and subaerial linear elements suggests further that the area has been segmented by high-angle faulting. An Aleutian island arc was probably formed in this general area as early as Miocene time, but the present volcanoes and the island locations and shapes were formed much later, probably in Pleistocene time.

Several stages of late Tertiary or Quaternary wave planation and subsequent differential tilting characterize the late history of the area; sporadic central-type volcanism at its north edge began in early Pleistocene and has continued to the present time. Widespread deposition of Recent ash, and historic eruptions from Gareloi, Tanaga, and Kanaga Volcanoes, are the most recent volcanic events. Glaciers were active on Tanaga and Amatignak during the Pleistocene, and ice patches are now present near dormant east Tanaga volcanoes and on the high slopes of Gareloi Volcano.

INTRODUCTION

Most of the western Aleutian Islands here described were mapped in reconnaissance (fig. 44) during the field season of 1952 as part of a general study of the geology of the Aleutian Islands. The Geological Survey's motorship Eider transported the field parties during the frequent changes of base camps. Those who participated in the field study were: R. E. Wilcox (geologist-in-charge), H. F. Barnett, B. H. Bieler, G. D. Fraser, E. H. Meitzner, W. H. Nelson, R. A. Robie, and G. L. Snyder.

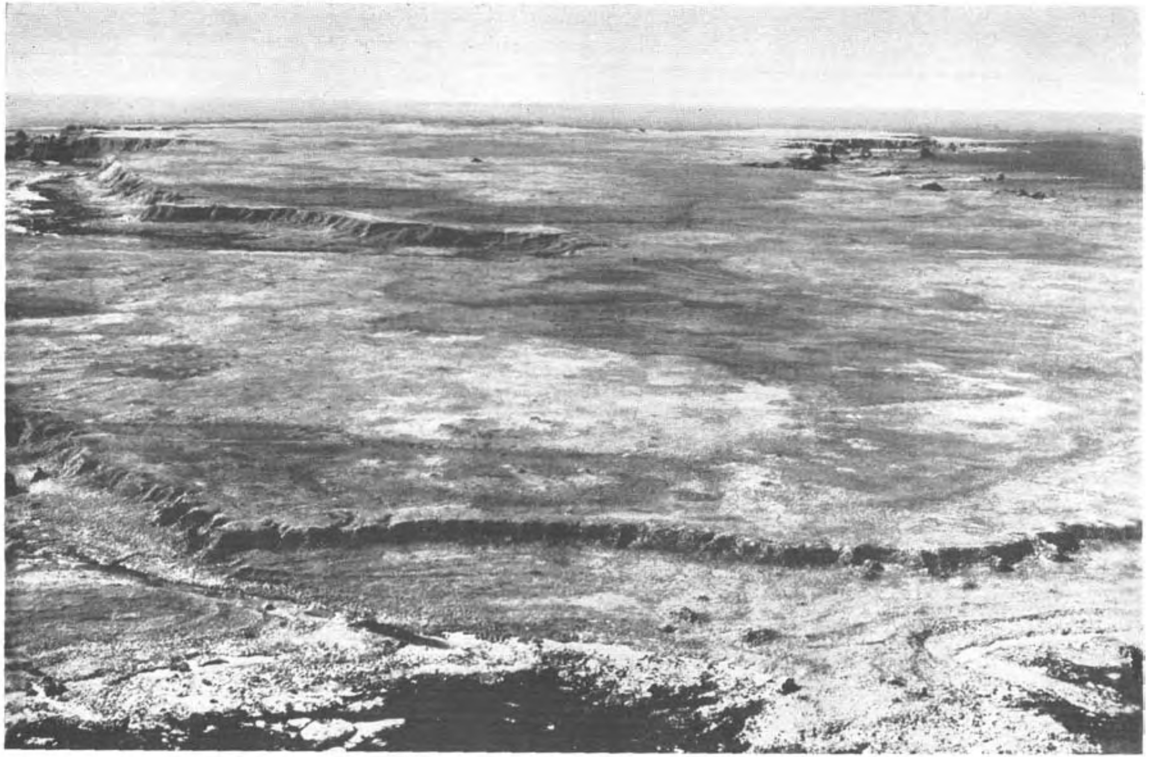
Two-man traverses were made on foot from base camps established along the coasts. Coverage is summarized as follows: Kanaga (south of latitude 51°54′) 7 camps, 34 traverses; Tanaga (south and southeast coasts) 4 camps, 8 traverses; Amatignak (east coast) and Ulak, 3 traverses each; Kavalga, 2 traverses; Unalga, Ilak, Skagul, Ogliuga, 1 traverse each. Traverses ranged from 4 to 12 miles, and averaged about 7.

Contour maps prepared in 1943 by the Corps of Engineers, U. S. Army, at a scale of 1:25,000 were available for Kanaga Island. The Delarof Islands were mapped on Coast and Geodetic Survey topographic manuscript sheets, scale 1:20,000. For southern Tanaga the only maps available were forrn-line Coast and Geodetic Survey topographic hydrographic charts (Nos. 9145, 9146), scale, 1:40,000. High-altitude aerial photographs cover most of the area.

Data included here for northern Kanaga are based upon the reconnaissances of Robert R. Coats, who also touched briefly at some of the Delarof Islands and part of Tanaga (Coats, 1950, 1952, 1956b, c; written communication, 1954).

AERIAL PHOTOGRAPH OF GARELOI VOLCANO FROM SKAGUL ISLAND

Wave-planed surface of Skagul Island contrasts with volcanic cane 15 miles northwest. Note small mounds in foreground. Skagul and Ogliuga (not shown) are unique among the Delarof Islands in that the usual sea cliff is not well developed. Air Force Photo Air Photographic and Charting Service (MATS), United States Air Force.



AERIAL PHOTOGRAPH OF KAVALGA ISLAND, LOOKISG WEST

Note wave-planed upper surface, sea cliff, partly covered storm beach, and present day rock bench (tidal flat). Small mounds on upper surface may have originated as boulders and irregularities on wave-cut surface; compare with features on present wave-cut surface. Air Force Photo Air Photographic and Charting Service (MATS), United States Air Force.

GEOGRAPHY

LOCATION

The 10 islands discussed lie along the Aleutian Islands arc between longitude 177°03′ and 179°09′ W., and between latitude 51°13′ and 51°56′30″ N. (fig. 44). The two large islands of Kanaga and Tanaga have areas of about 100 and 160 square miles, respectively, and are the westernmost of the Andreanof group. Four of the eight Delarof Islands, Skagul, Ogliuga, Kavalga, and Unalga, constitute a narrow projection which extends 35 miles west of the larger islands and is separated from them by Tanaga Pass. Ulak and Amatignak form a spur trending southwestward from this westerly projection and from the general curvilinear trend of the Aleutian chain. Ilak and Gareloi are, respectively, 5 and 15 miles south and north of the line between Skagul and Unalga. The total area of the scattered Delarof group is about 65 square miles.

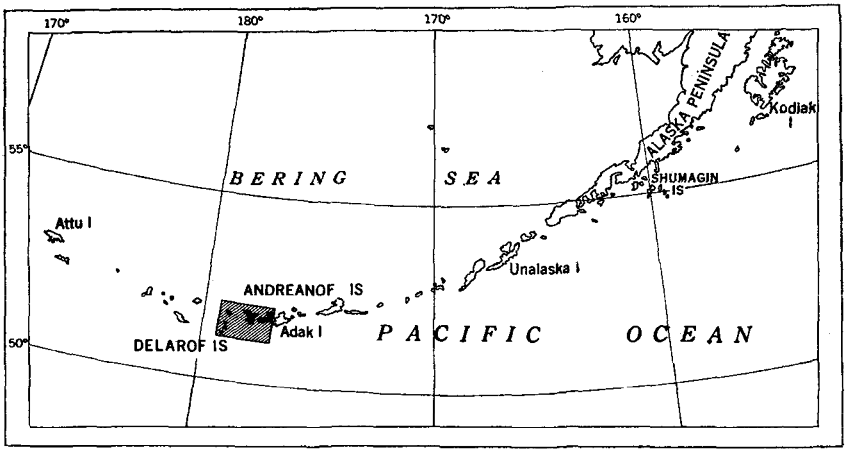


FIGURE 44.—Index map of the Aleutian Islands, Alaska, showing location of the Delarof and westernmost Andreanof Islands.

CLIMATE AND VEGETATION

Weather in the Aleutian Islands varies locally and is related to the interaction of ocean currents, moving air masses, and island topography. Winds, clouds, rain, and fog generally prevail the year around. Low heavy fogs often limit visibility to 100 feet for days at a time, particularly in the summer, and traverses must often be completed solely by compass and aneroid barometer observations. Annual precipitation is about 40–50 inches.

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In the western Andreanofs summer winds originate mostly from the southeast, south, and southwest. Average velocities are about 25 miles per hour; during sudden storms velocities increase to 70 miles per hour. From October to March prevailing winds are from the north and west. Excessively strong, gusty down-slope winds, sometimes exceeding 100 miles per hour, result from the rapid spilling over of air masses dammed against the windward sides of mountains or ridges.

The North Pacific drift from the southwest warms the cold waters brought south from the Bering Sea. Winter temperatures seldom fall as low as 0°F. The mean temperature of the warmest month (usually August) is about 55°; the daily temperature ranges in summer from 46° to 75°F. Total annual snowfall, falling mostly from December through March, averages 70 inches, but little accumulates except at higher mountain altitudes.

Vegetation is abundant as a consequence of the temperate humid marine environment. Mosses, grasses, fungi, and a wide variety of flowering plants (many with edible parts) blanket the slopes to a thickness of 2 or 3 feet. The only trees are a few stunted recumbent willows.

Except at gullies and cliffs the plant cover is unbroken on the flat or gently rolling uplands below 1,500 feet altitude. The irregular, hummocky, springy surface makes walking slow—less than 2 miles per hour is an average rate. Rock outcrops in the interiors of all the flat islands are rare and widely separated. Geologic investigations in such islands were largely confined to the sea-cliff and rock-bench zone around the island perimeters.

LANDFORMS

The landforms among the western Andreanof Islands vary greatly. Kanaga and Tanaga Islands exhibit compound landforms. Lofty volcanic heights at the north give way southward and westward to poorly drained lowlands surrounded by sea cliffs. The highest, least eroded, and most recently active volcanic areas are at the extreme north of both islands. Like several of the larger Aleutian Islands, Kanaga has a narrow low-lying westward extension.

Gareloi Island is a conical volcano which rises abruptly from the ocean floor a few thousand feet below sea level to a summit 5,160 feet in altitude (pl. 31). Two small glaciers hang on the steep, slightly gullied slopes. The shoreline is precipitous along most of its length. An eruption in 1929 opened a series of vents; it spilled dark lava from a rift zone southeast of the summit vent and spread pyroclastic materials over the southern face of the volcano. This recently active, elevated mass is north of lower lands, paralleling the arrangement on Kanaga and Tanaga.

Amatignak Island is a dissected glaciated upland marked by cirques, sharp arêtes, troughlike valleys, and small intermontane depressions. The island has 1,875 feet of relief. No constructional volcanic landforms were seen.

The other islands of the Delarof group are low, flat-topped featureless platforms bounded mostly by sheer cliffs and sea-level rock benches; they resemble the southern parts of Kanaga and Tanaga Islands. Small ponds commonly dot the poorly drained surfaces. Ulak has a somewhat higher relief than the low Delarofs.

The flat Delarof Islands are dotted with small conical mounds (pls. 31, 32) generally only a few feet high and too small to show on a topographic map. A few larger mounds are visible as closed contours (pl. 30); dense vegetation, possibly the result of fertilization by birds, gives some credence to the idea that the mounds are "bird perches." Some of the structures may have begun as irregularities on the wave-planed surface (pl. 32).

GEOLOGY

LAYERED ROCKS

AMATIGNAE ISLAND

Character.—Sedimentary rocks composed of volcanic detritus make up most of the bedrock on Amatignak Island (pl. 27). The rocks are of dark-gray, greenish-gray, olive-green, bluish-gray, and light-brown tuffaceous argillite and siltstone, tuffaceous sandstone, and tuffaceous breccia. Greenish colors are most common. Grain sizes less than one-half inch predominate, but volcanic bombs are visible in a few beds, and altered volcanic glass is seen in thin section; accordingly many of these rocks have been classified as volcanic wacke (Williams, Turner, and Gilbert, 1954). Generally the rocks are well indurated, chloritized, pyritized, and silicified. Cryptocrystalline quartz veinlets are common.

A common rock of the island is a finely laminated argillite, banded green and gray. The rock is brittle, breaks with a conchoidal fracture, and often shows structures recording penecontemporaneous deformation. Similar argillite has been found on Ulak Island and elsewhere in the Aleutian Islands in association with altered pillow lavas and marine pyroclastic deposits.

Microscopic examination of specimens in the sand- and silt-size range confirmed their origin as tuffaceous sediments. One specimen had fragments (< 0.04 mm) of green chloritic material, oligoclase-andesine, and augite cemented by carbonate. Another, with zeolitic(?) cement had particles (< 0.2 mm) of chloritized volcanic glass containing feldspar laths and other crystals, and crystal fragments of unaltered augite and albitized plagioclase (< 0.09 mm). Most of these rocks are of andesitic or basaltic composition.

Many andesitic or basaltic dikes and small sills intrude the sedimentary rocks along the eastern and southern coast. Small dioritic or diabasic sills are also found; a large quartz diorite sill forms Knob Point on the east coast. Shipboard observations and study of aerial photographs suggest large areas of massive rock, perhaps plutonic, in the northwest quadrant of the island.

Age.—No precise age can be assigned to the rocks of Amatignak Island. Parts of some formations on Attu, Agattu, Adak, and Unalaska dating from late Paleozoic to early Miocene have similar lithology. The two oldest stratigraphic units in the Rat Islands, generally coarser grained than the rocks of Amatignak, have been altered and intruded by quartz diorite. Fossils from the Rat Islands indicate an Eocene(?) to Miocene age for the younger sequence intruded by quartz diorite, but the older unit is not fossiliferous. Mesozoic fossils have been found only on Atka Island; Paleozoic fossils have been found in one small area on Adak (Coats, 1956a). Tertiary fossils have been found on Attu, Agattu, and Unalaska in rocks resembling those of Amatignak. On Amatignak, structures resembling worm tubes were found in two outcrops; one unidentifiable foraminifer, probably post-Cretaceous, was found in thin section. The rocks of Amatignak are provisionally assigned to the Tertiary and are probably Miocene or older.

The rocks on Amatignak have been tentatively correlated with those on nearby Ulak Island, and both are probably at least as old as those on the central Delarof Islands which have not been regionally altered or invaded by plutonic rocks (p. 217).

ULAK ISLAND

The rocks of Ulak Island resemble those of Amatignak. They are greener and more altered than those of the central Delarofs. The layered sequence is composed of altered palagonite breccia and tuff, basaltic pillow lavas, and tuffaceous sedimentary rock. Those rocks are intruded by andesite and basalt dikes and sills. In contrast with the well-bedded sedimentary section on Amatignak, the rocks of Ulak are dominantly igneous and pyroclastic.

Pillow lavas, abundant on Ulak, were not observed on Amatignak. The rocks of Ulak are chloritized, but the pillow lavas and tuff are apparently not spilitic.

A 2-foot thick layer like the distinctively banded argillite found on Amatignak lies between altered tuff-breccia layers on the west coast of Ulak. This suggests a correlation of the rocks of the two islands, and possible facies change from fine-grained, well-bedded sedimentary rocks on Amatignak to more dominantly volcanic rocks on Ulak.

Bedding on the south half of Ulak Island dips toward Amatignak, and beds on northeast Amatignak dip steeply east, suggesting either a syncline beneath the straits between Amatignak and Ulak or drag on an interisland fault (pl. 27). If there is a fault between Amatignak and Ulak, and if the relative altitudes indicate relative movement, then the apparent facies change may be better explained as a change upward in the section toward Ulak. The rocks on Ulak are believed to be about the same age as the rocks on Amatignak.

CENTRAL DELAROF ISLANDS AND SOUTHERN PARTS OF TANAGA AND KANAGA ISLANDS

Character.—Unaltered pyroclastic rocks and lava make up the bulk of the other islands of the area (pls. 27-30). Tuff-breccia and tuff are interlayered with black, gray, or brown andesitic and basaltic flows, pillow lava, and flow breccia. Tuff-breccia is most common, lava flows are abundant, and tuff is somewhat less common. Sedimentary rocks are least abundant, except on southeastern Tanaga. Plates 28, 29, and 30 show proportions of the rock types in selected areas.

Volcanic centers have not been found. The relative scarcity of reworked volcanic material and the abundance of coarse debris suggest that the volcanic centers were nearby. Fossils (table 1) indicate that many of the beds are of shallow marine origin and some of them are subaerial.

The composition of these rocks, as revealed by field mapping, brief petrographic study, and four chemical analyses seems to be consistently basaltic and andesitic, with no representatives of more siliceous types of lava. Table 2 presents chemical analyses of nine samples from Kanaga, Tanaga, and the Delarof Islands. The first four analyses are of rocks considered in this section. The main differences between rocks of the sequence apparently are textural and structural rather than chemical. All sections studied under the microscope fall in the basaltic and andesitic groups

TABLE 1.—*Fossils from Kanaga and Tanaga Islands*

[Identification of fossils: F. S. MacNeil, megafossils (locs. 1–9, 12); Ruth Todd, Foraminifera (locs. 2–5, 7, 12); P. E. Cloud, algae (loc. 10); C. W. Cooke, echinoids (loc. 13); E. S. Barghoorn, pollen and spores (loc. 14); R. W. Brown, fossil wood (loc. 15)]

Locality	Identification	Age	Remarks
	Kanaga [1]		
1. On W. side of Kanaga Bay 0.6 mile N. of mouth of bay.	Pelecypoda: *Ostrea* sp. (large) *Cardium* (*Cerastoderma*) n. sp.? aff. C. (C) *ciliatum* Fabricins Cirripedia: *Balanus* sp. (a small, strongly ribbed species)	Late Tertiary, possibly Miocene	Opinion on age based largely on size of oyster. Pliocene to Recent species normally less ponderous.
2. North coast of Kanaga at long 177°33′30″. In bedded gravel deposit about 50 ft above beach.	Pelerypoda: *Pecten* n. sp. *B*. fragment [2] *Cardita* (*Cyclocardia*) sp. aff. *C. alaskana* Dall Cirripedia: *Balanus* sp. (a large, irregularly ribbed species) - - - - - - - - - Foraminifera: *Huperammina*? sp. milliolid? *Elphidium* sp. *Elphidiella arctica* (Parker and Jones) *Uvigerina cushmani* Todd *Cassidulina limbata* Cushman and Hughes? sp.	Late Tertiary (Pliocene?) - - - - - - - - -	*Pecten* same as species loc. 4.
3. In valley of large stream 2.1 miles NNW. of head of Kanaga Bay. Coarse tuffaceous conglomerate.	Unidentifiable molds of gastropods and pelecypods		
4. On W. coast N. of coastal lakes 4.5 miles SSW. of Kanaga Volcano in green, tuffaceous sandstone layers. Conspicuous *Peckn* coquina here.	Pelecypoda: *Pecten* n. sp. B aff. *P. albidus* Dall [2] Brachiopoda: Single valve, gen. and sp. indet. - - - - - - - - - Foraminifera: *Cassidulina*? sp. *Cibicidina* sp.	Pliocene(?) - - - - - - - - -	An internal mold of a *Pecten*, probably identical with *Pecten* n. sp. B, is in the collection from St. George Island associated with a large fauna believed to be Pliocene. This *Pecten* also present on northern Adak. Belongs to *Pecten hastatus* group.
5. About 50 yds S. of loc. 4 in bedded, semiconsolidated pumiceous sediments interbedded with volcanic breccia.	Gastropoda: *Buccinum* sp. *Natica* sp.	Possibly Pliocene	All mollusks are poorly preserved and except for *Pecten*, *Saxicava*, and *Mya* are internal molds.

	Pelecypoda: *Pecten* n. sp. C. Fragments [3] *Astarte* sp. aff. A. *actis* Dall Macoma sp. indet. *Saxicava* cf. *S. pholadis* Linnaeus *Mya* cf. *arenaria* Linnaeus Unidentifiable pelecypod molds Brachiopoda: Gen. and sp. indet. but having same microsculpture as specimen from loc. 4 *Hemithyris psittacea* (Gmelin) Bryozoa: 2 species Cirripedia: *Balanus?* Molds only		*Pecten* n. sp. C resembles a specimen from Middleton Is., Gulf of Alaska, from be6 believed to be Pliocene. Belongs to *Pecten islandicus* group.
	Foraminifera: *Gaudryina* sp. *Quinqueloculina* spp. *Triloculina* spp. *Astacolus* sp. *Lagena* acuticosta Reuss *williamsoni* (Alcock) *Sigmomorphina* spp. *Nonionella?* sp. Nonion *labradoricum* (Dawson) Elphidium *alaskense* Cushman and Todd *frigidum* Cushman sp. *Elphidiella arctica* (Parker and Jones) Fissurina marginata (Montagu)? sp. *Uvigerina* cf. *cushmani* Todd *Angulogerina fluens* Todd *Buccella frigida* (Cushman)? *Eponides columbiensis* (Cushman) *Cassidulina californica* Cushman and Hughes *limbata* Cushman and Hughes *Pullenia salisburyi* R. E. and K. C. Stewart Cibicides *lobatulus* (Walker and Jacob)	Pliocene or Pleistocene	Similar to fauna on Amchitka Is. (Cushman and Todd, 1947) but lacking planktonic.?. The Kanaga Foraminifera were deposited in shallow water, probably not less than 6 fathoms nor more than 100, more likely toward shallower end of this range. The fauna is characteristic of cold water, similar to those known in Alaska, northern Canada, and Greenland in Recent seas.
6. In limestone breccia fragments from volcanic sediment beds along the beach 1.7 miles N. of Cape Chunu.	Pelecypoda: Acila cf. A. *castrensis* (Hinds) *Macoma* sp. *Mya* sp.	Probably late Tertiary	*Acila castrensis* ranges from early Pliocene to Recent.

See footnotes at end of table.

TABLE 1.—*Fossils from Kanaga and Tanaga Islands*—Continued

Locality	Identification	Age	Remarks
	Kanaga[1]**—Continued**		
7. In sand lens in conglomerate 0.9 mile N. of Cape Chunu.	Pelecypoda: Unidentifiable fragment Cirripedia: Unidentifiable fragment		
	Foraminifera: *Gyroidina* sp. *Eponides?* sp. *Cibicides* sp. *Cibicidina* sp. sp.		
8. In massive, poorly consolidated unbedded tuff 2.2 miles NE. of Western Pt.	Pelecypoda: *Acila*, fragment *Lucina acutilineata* Conrad *Macoma*, fragment	Late Tertiary	*Lucina acutilineata* ranges from mid-Tertiary to Recent.
9. In massive, poorly consolidated unbedded tuff NE. shore of Monroe Bay (bay E. of Western Pt.).	Gastropoda: *Natica* sp. Pelecypoda: Fragment of large shell, unidentifiable		
10. On west shore of N. Kanaga 3.8 miles SSW. of Kanaga Volcano.	Algae: Genus similar to *Lithophyllum* may be new genus or subgenus	Late Tertiary or Pleistocene	In same stratigraphic sequence as loc. 4 and 5.
	Tanaga[3]		
11. South shore of point (Trunk Point) on S. margin of Hot Springs Bay. From bedded tuff breccia layer (30-ft thickness exposed) dipping gently southward.	Pelecypoda: *Saxicava pholadis* Linnaeus	Late Tertiary to Recent	
12. Lat 51°41′25″ N., long 177°50′30″ W., in 5–20 ft lens of tuffaceous coquina conglomerate over andesite flow.	Gatropoda: *Acmaea* n. sp. An uncommonly large, heavy species Pelecypoda: *Ostrea* n. sp.?	Late Tertiary, possibly Miocene	Large, heavy oysters are more characteristic of Miocene than later deposits. Apparent predominance of undescribed forms' almost precludes a very late Tertiary or post-Tertiary age. A heavy concave oyster having small radial ribs resembling those of some species of *Spondylus* or *Hinnites*.

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	Pecten n. sp. E [2] *Platyodon*? sp. Mold with a deep muscle scar on the posterior end Other unidentifiable pelecypod molds **Cirripedia:** *Balanus* n. sp.? **Cirratulids:** A mass of colonial worms probably identical with ?*Serpula octoforis* Dall from Miocene of Coos Bay, Oreg. Foraminifera: *Elphidiella arctica* (Parker and Jones) *Planulina* sp. *Cibicides* sp.		A fragment having sculpture similar to that of left valve of P. *hindsii*, but the valve is more concave. Large *Balanus* [illegible] (*fide* Henderson) possibly of [illegible] Packard questioned that Dall's specimen really came from Tertiary racks because it resembles so closely a Pleistocene and Recent species from the Pacific Coast. There is no doubt that the present specimen was enclosed in the tuffaceous conglomerate.
13. W. coast Cape Sasmik peninsula, from talus on beach.	**Echinoidea: (Spatangoidia)** Two specimens, probably same species. May be *Macropneustes* or *Linthia*, but lack diagnostic features	Possibly Eocene or Late Cretaceous	The writers find no field evidence for assigning Cape Sasmik rocks to a sequence significantly older than rocks in locs. 12 and 14. Because of generic assignments, [illegible] dating may be in error. There is a [illegible] of *Linthia* in Miocene Monterey [illegible] of California.
14. Long 177°59′10″ W., lat 51°39′05″ N. from conglomerate and tuff layers rich in carbonized plant debris. Slump block from sea cliff.	Tree pollen (No. of grains): *Picea* (spruce), 3 Abics (fir), 2 *Pinus* (pine), 14 *Alnus* (alder), 52 *Quercus* (oak)? (poorly preserved), 2 Nontree pollen (No. of grains): *Alisma* (water plantain), 8 Ericaoeae. 3 Orchidaceae. 3 Nymphaeaceae (water lily), 7 Unknown diverse herbaceous pollen, 10 distinctly different sporomorphs, 32 grains Spores (No. of grains): Sphagnum, 2 Polypodiaceae (3 types), 13	Late Pliocene or Pleistocene (interglacial)	The sediments were apparently deposited in a basin [illegible]ljacent to [illegible] allow, probably [illegible] water. There were extensive alder [illegible] in the region, spruce and fir forests at considerable distance, and limited pine cover in the area. A varied herbaceous flora probably existed along margins of the sedimentary basin. Climatic conditions were probably somewhat milder than those found today in same area. There are no trees in area today. Three possibilities of geologic age are suggested: late Pliocene, Pleistocene, and postglacial optimum. Degree of consolidation of sediments would tend to refute third possibility.
15. Long 177°55′45″ W., lat 51°39′14″ N. in tuffaceous sandstone and conglomerate. Fragments of fossil wood.	*Abies* sp. (fir)	Post-Mesozoic	

[1] Kanaga localities from scale 1:25,000 U. S. Army, Corps of Engineers maps, 19[illegible].
[2] N. sp. for *Pecten* designated by letters B, C, E (other letters in series for n. sp. [illegible] Aleutian Islands).
[3] Tanaga localities from U. S. Coast and Geodetic Survey charts 9145 and 9146.

TABLE 2.—*Chemical composition* of rocks *from the Delarof* and *westernmost Andreanof Islands*

[Analyst, E. J. Tomasi]

Constituents	Locality, name, and occurrence of specimens								
	Aphanitic rocks							Phaneritic rocks	
	Unalga	Skagul	Ogliuga	S. Tanaga	NW. Kanaga	S. Kanaga		Ilak	
	Augite andesite, flow	Augite andesite, flow	Labradorite-augite andesite, flow	Andesine basalt, flow or sill	Dark rhyodacite, dike	Rhyodacite, dike	Labradorite dacite, sill	Granodiorite, pluton	Aplite, dikelet in pluton
	52-N-64	52-W-64	52-W-70	52-Fs-94	52-Sn-37	52-Sn-100	52-W-38	52-Sn-167	52-Sn-181
SiO_2	53.29	56.56	48.04	61.75	58.03	71.21	56.76	66.99	72.71
Al_2O_3	18.49	18.96	18.88	16.01	17.16	12.65	17.89	15.77	14.72
Fe_2O_3	3.76	4.52	4.49	4.89	2.85	.40	2.85	1.49	.31
FeO	3.79	3.16	6.27	6.84	3.87	.45	3.65	1.71	.44
MgO	4.48	270	6.09	COO	3.16	.32	2.91	1.87	.90
CaO	9.08	8.09	10.37	8.73	6.95	.99	8.10	3.55	1.64
Na_2O	3.55	3.96	2.98	3.71	3.77	3.93	3.40	3.99	4.28
K_2O	.68	.78	.47	.70	2.07	2.28	.61	3.26	3.76
H_2O-	.78	.62	.53	.79	.08	3.28	.47	.06	.08
H_2O+	.60	.37	.64	.82	.74	3.59	.29	.42	.46
TiO_2	.93	.60	.95	1.89	.76	.08	.52	.42	.21
CO_2	.12	.01	.03	.01	.03	.05	1.86	.02	.02
P_2O_5	.22	.40	.22	.53	.30	.17	.25	.13	.06
Cl	.00	.05	.01	.08	.13	.01	.04	.06	.03
F	.03	.03	.03	.06	.04	.03	.02	.05	.02
S	.00	.00	.00	.01	.00	.02	.00	.01	.16
MnO	.12	.18	.18	.21	.16	.13	.16	.08	.01
	99.93	89.98	100.08	100.02	100.10	[a] 99.73	99.78	99.88	99.81
Less O	.01	.02	.01	.04	.05	.02	.02	.03	.10
Total	99.92	99.96	100.07	99.98	100.05	99.71	99.76	99.85	99.71
Powder density				2.82		2.29	2.72		

[a] Includes 0.14 percent BaO, not shown.

whether the rock is pyroclastic or lava, and the sedimentary rocks appear to have been derived from similar rocks. Significant variations within the basaltic and andesitic groups are indicated by a wide variation in type and frequency of mafic phenocrysts, and it seems probable that a few of the lighter colored rocks, in particular the pyroclastic deposits, would fall in the dacite or rhyodacite groups of the chemical classification of Rittmann (1952). No rocks as light colored as the rhyodacite dike (specimen 52-Sn-100) were found in the layered sequence, and at least 90 percent of the sequence is probably more basic than dacite.

The root names (andesite, basalt) used in this report for analysed aphanitic rocks are those appearing in the chemical classification of Rittmann. In the text the full Rittmann name is given parenthetically for each analysed rock. Pigeonite appears in the calculated Rittmann name for specimens 52-N-64, 52-W-64, and 52-W-70, but no pigeonite was found in the modes. Moreover, pigeonites, as used by Rittmann (1952, p. 78) are "mixed crystals of diopside and clinohypersthene" not further defined by optic angle and may, therefore, include augite and other clinopyroxenes as defined by others.

Specimen 52-N-64 is a dark, greenish-gray augite andesita (Rittmann: pigeonite andesite). Phenocrysts of augite, magnetite, and zoned (oscillatory) calcic plagioclase are set in a groundmass of plagioclase microlites ($\approx An_{50}$) and opaque oxides. The larger plagioclase phenocrysts are often poikilitic and usually contain several zones of dusty inclusions.

Specimen 52-W-64 (Rittmann: pigeonite andesite) is a light-gray porphyritic augite andesite. The phenocrysts (<2 mm) are progressively zoned calcic plagioclase, augite, magnetite, and one ghost crystal of hornblende ("opacite"). The groundmass contains microphenocrysts of plagioclase, clinopyroxene, and opaque oxide in a cryptocrystalline matrix.

Specimen 52-W-70 is dark-gray labradorite-augite andesite (Rittmann: pigeonite labradorite andesite) with numerous black, subangular to rounded cryptocrystalline inclusions (0.1–1.3 cm) of unknown composition, but possibly altered basaltic glass or tuff. The inclusions are opaque on the borders and are crowded with opaque dust throughout; small crystals of plagioclase and clinopyroxene have begun to form within the inclusions. The igneous matrix for these inclusions is markedly porphyritic with zoned, poikilitic crystals of calcic plagioclase (wide dusty zones and areas within the crystals), augite, and corroded olivine in a groundmass of labradorite microlites and opaque oxides. There is a marked flow structure in the groundmass.

Specimen 52-Fa-94 (Rittmann: andesine basalt) is a black, very fine grained rock. About 1 percent consists of scattered phenocrysts of plagioclase, clinopyroxene, and pseudomorpha after olivine. The groundmass has a strong flow structure and consists of microlites of calcic andesine, clinopyroxene, and opaque oxides.

Other rocks of this group are generally similar. Augitic pyroxene, hypersthene, oxyhornblende, and olivine are common mafic phenocrysts. Phenocrystic plagioclase is usually labradorite or more calcic and strongly zoned. Andesites with both clinopyroxene and orthopyroxene are perhaps the most common rocks, but many fall close to the andesite-basalt boundary and are difficult to classify without chemical analyses.

Throughout the islands areas of bleached and iron-stained rocks, believed to result from fumarolic activity, are common; one large, poorly defined area contains abundant epidote stringers which probably indicate a different type of alteration. This area extends from Kanaga Bay to Cape Chlanak and northward toward Naga Point on the east coast of Kanaga Island. An andesitic dike swarm and at least one granodioritic dike invade the volcanic complex in this area and may be related to the epidotization.

Plates 28, 29, and 30 show typical areal distributions of the rocks. Outcrops are confined largely to coastal areas; many major lithologic changes occur across and along strikes. Bedding attitudes vary greatly and in thick, coarse pyroclastic deposits or massive tuff layers are often impossible to obtain; local unconformities exist in many outcrops. Key beds have not been found; consequently, mapping of structures and separating even large areas into broad map units is not possible in reconnaissance. Much more field and laboratory detail is necessary before an adequate generalized map of the area can be made.

Age.—Fossils were found on Kanaga and Tanaga Islands. Rocks of the central Delarof Islands are grouped with the fossiliferous rocks because of lithologic similarities and geographic proximity. Table 1 is a summary of the paleontologic evidence for dating rocks on Kanaga and Tanaga. The rocks are believed to be largely Miocene and Pliocene but may include some Pleistocene.

Similar paleontologic evidence for rocks older than Miocene is lacking. The epidotized rocks between Kanaga Bay and Naga Point resemble Finger Bay volcanies known to be, in part, Paleozoic (Coats, 1956a); but upper Tertiary fossils were found in the altered area on Kanaga (table 1, loc. 1). A basal contact with older rocks has not been found. The upper contact with lava of the precaldera shield volcanoes is apparently unconformable in some areas and gradational elsewhere (p. 225).

EARLY SHIELD VOLCANOES

The radially dipping lava flows of partially destroyed early shield volcanoes on northern Kanaga and Tanaga Islands have been mapped separately on plate 27, although the contact with rocks farther south is probably transitional in part. Coats (1956b) has described those rocks for northern Kanaga and mapped them in more detail than is shown here. In one area on the northwest coast of Kanaga Island, lava flows of ancient Mount Kanaton (Coats, 1956b, p. 72), which predate caldera subsidence, overlie the fossiliferous beds (locs. 4, 5, and 10 in table 1) with apparent angular discordance. The time interval between deposition of these contrasting rock types may be very short. Because the fossiliferous sedimentary rocks are characterized by variable initial dips and local unconformities, an apparent unconformity here may lack significance. Lava indistinguishable from that of the shield volcano is intercalated farther south with pyroclastic debris and sediment typical of southern Kanaga. A break in topographic slope separates ancient Mount Kanaton from planed southern Kanaga; this critical area is covered by a thick ash, soil and tundra mantle. On the northeast coast of Kanaga Island, 6.6 miles south of Kanaga Volcano, lava flows of ancient Mount Kanaton(?) are interlayered with pyroclastic deposits, and a gradational contact is suggested.

The corresponding contact on Tanaga Island where the topographic break is even less well developed than on Kanaga, was not visited.

The upper contact on both Kanaga and Tanaga is based largely on topography and location of undissected volcanoes within caldera remnants.

Age.--Goats (1956b, p. 78) has assigned a late Tertiary and Pleistocene age to the lava of ancient Mount Kanaton and associated precaldera volcanic centers on Kanaga Island. He has postulated a late Pleistocene date for caldera formation. Corresponding rocks on Tanaga Island are assumed to be about the same age.

RECENT VOLCANIC CONES

Gareloi, Tanaga, and Kanaga Volcanoes, which have relatively undissected composite cones with records of historic activity (Coats, 1950), and dormant remnants of slightly older volcanoes on Tanaga Island are of Recent age. Relations of Recent volcanoes with the early shield volcanoes on Tanaga have not been determined. The rocks composing the three active cones have initial dips as steep as 35° and rest unconformably on older rocks in

Kanaga and Tanaga. The younger cones are built within calderas formed in older volcanoes.

Gareloi and Kanaga Volcanoes and parts of northern Tanaga have been studied by Coats (1950, 1952, 1956b, c; 1954, written communication). The rocks of Kanaga Volcano and ancestral Mount Kanaton are basaltic or andesitic and their lime and alkali parameters show the province to be calc-alkaline (Coats, 1952, p. 485). Basaltic and (or) andesitic rocks occur on Gareloi Volcano, and presumably exist on Tanaga Volcano. The strikingly similar chemical composition of these rocks and those farther south indicates that this sector of the Aleutian arc has been dominated by basaltic and andesitic rocks since Miocene time and perhaps longer.

The material which forms the present surfaces of these conical volcanic mountains is largely postglacial. That glaciation was followed by volcanic eruptions is evident on northern Tanaga Island where an older glaciated cone is capped by lava extruded from a reactivated volcanic vent.

SURFICIAL DEPOSITS

Deposits of volcanic ash and soil covered by heavy tundra vegetation (without permafrost) mantle the islands inland from the sea cliffs. Locally the ash on northern Kanaga, which contains thin layers of pumiceous lapilli and reddish-brown soil zones, reaches a maximum thickness of 20 feet and sometimes forms dunes. The ash blanket is continuous on the low, flat islands of Unalga, Kavalga, Ogliuga, and Skagul, but quite thin and discontinuous on Ulak and Amatignak. Quaternary volcanoes nearby were probably the source. Because of abundant loose, fresh pumiceous lapilli in the deposits of the central Delarofs, the ash layer there may be younger than the stratified sequences with intercalated soil layers on Kanaga and Tanaga Islands. A thin dark-gray soil is usually formed on the surface of the ash. Peaty deposits have formed in some boggy areas.

On several islands, notably Ogliuga, Skagul, and Kanaga, extensive sand dunes are stabilized by vegetation (pls. 28, 30). Stream-transported alluvium, mostly fine pyroclastic material, locally fills small basins and valleys. Deltas form at protected bay heads.

Discontinuous gravel, cobble, and boulder beaches fringe all the coves and bays of the islands, commonly with a wave-cut bench offshore. Abandoned beach deposits at higher level are sometimes preserved. Coats (1956c, p. 92) reports that southern Tanaga is mantled by marine gravels resting on a wave-cut platform, and he also reports that similar boulder gravels on Ogliuga are overlain by coarse volcanic cinders.

Glacial debris was recognized in cirques and cols at higher altitudes on Amatignak and on northern Tanaga Island. Ulak Island presents a scoured appearance, but no morainal material was found.

Coats (1956b, pl. 15) has mapped an andesitic ash layer of caldera age on northern Kanaga Island. This layer, conspicuous as coarse and fine pyroclastic debris on the surface of Kanaton Ridge, is buried beneath more extensive layers of younger ash south of ancient Mount Kanaton. On the south bank of a large lake 6.4 miles south of Kanaga Volcano the older ash is beneath about 20 feet of the finer Recent ash as a decomposed zone of coarse pumice one foot thick. Neither the younger ash nor the buried ash are mapped in this report.

FINE-GRAINED INTRUSIVE ROCKS

Many shallow intrusive rocks, usually andesitic or basaltic, either porphyritic or aphyric, cut the bedrock units south of Recent volcanic cones and older shield volcanoes. Nearly vertical dikes are usual, either as single units or as dike swarms.

The most conspicuous dike swarm is in the area on southeastern Kanaga Island extending 2½ miles north of Cape Chlanak. The dikes are andesitic and contain needle hornblende. Most trend northwest, but several at Cape Chlanak trend west.

Basalt.—Many basalt dikes, most trending northwest, are on the north coast of Kanaga Island about 5 miles northwest of Kanaga Bay. Several domelike masses of basalt, as much as 400 yards in greatest dimension, are visible along the coast in the same area. One basalt mass, with a radius of 150 to 200 yards, in cross section is steep sided, bulbous, and concentrically divided into layers about 10 feet thick. Each concentric layer has a separate set of radial columnar joints.

These rocks contain conspicuous, sporadically large inclusions of dark gabbroic rocks rich in anorthite, olivine, clinopyroxene, and chromite. Many of the inclusions have been stretched into vague schlieren. One of the inclusions covers a surface area of 400 square feet or more. Less abundant angular inclusions of tuffaceous(?) siltstone, apparently derived from the sedimentary and pyroclastic rocks, are also found.

The basalt is characterized by a strong fluidal structure of calcic plagioclase microlites. A great variety of dark minerals—olivine, orthopyroxene, clinopyroxene, and oxyhornblende—may appear in the same slide. Some of the mafic minerals are probably xenocrysts from gabbroic inclusions. Elongate vesicles filled with secondary minerals are present in several outcrops.

These intrusions may be one of the many types of volcanic domes usually found in and near volcanic vents (Williams, 1932), but more probably they are bulbous developments in shallow sills. Evidence of doming was found at one contact with overlying tuff-breccia; basalt dikes as much as 60 feet wide also invade the tuff-breccia. Although the sill-like character of the Kanaga structures is not certain, the joint patterns do suggest tabular masses (either sills or flows) and this origin seems more likely than plugs or domes within vents.

Limburgite.—A half mile inland from the coastal area which shows domed sills (?) and dikes, a fragmental rock with abundant olivine-rich inclusions as much as a foot in diameter forms an isolated outcrop about 10 by 50 feet. The olivine inclusions, both rounded and tabular, are mixed with less abundant, very angular inclusions of tuffaceous limestone in a limburgite matrix. Ross and others (1954, p. 701) examined some of these inclusions and reported that chromium diopside, enstatite, and chromium spinel are associated with dominant olivine in the ultrabasic inclusions. Possibly this outcrop is a petrographically extreme development of the inclusion-rich, domelike structures just described. The abundance, size, and angularity of the inclusions and their association with sedimentary inclusions suggest a shallow nearby source (cf. Ross and others, 1954, p. 693).

Andesite.—On southwestern Kanaga (pl. 28) thick, coarsely porphyritic sills of andesite comprise the sea cliff for long distances. One of these sills has vertical columns 10 feet across and at least 100 feet high. Topography on the headland 1 mile southeast of Western Point suggests a thickness greater than 300 feet. Top and bottom contacts were not observed, but nearly vertical end contacts at two locations and one exposure of contact breccia suggests either postemplacement faulting or forceful transgressive intrusion.

These rocks are characterized by ragged phenocrysts of biotite and (or) oxyhornblende with "opacite" rims. The rocks also contain abundant phenocrysts of zoned plagioclase (labradorite-oligoclase) with or without dusty zones. Progressive, oscillatory, and reversed zoning occur. Clinopyroxene and orthopyroxene, magnetite, and a few rounded quartz grains are also present. The rocks are probably siliceous andesite, but chemical analyses would be required to classify them exactly.

Specimen 52-W-38 (Rittmann: labradorite **dacite)** is **from a** light-gray columnar sill 2.5 miles northwest of Cape Tusik on southern Kanaga. This sill is finer grained and megascopically less porphyritic than the sills on southwest Kanaga. Phenocrysts, mostly less than 1 millimeter in diameter, make up 25 percent of the rock as follows: abundant zoned labradorite-bytownite with thin rims of oligoclase-andesine and, commonly, oscillatory zoning; less abundant oligoclase-andesine crystals surrounded by a zone crowded with dark inclusions, then a rim of labradorite-oligoclase with strong oscillatory zoning (included here are many phenocrysts of labradorite with center parts showing patchy extinction); clinopyroxene and orthopyroxene, both rare (<0.5 mm); abundant subhedral opaque oxides (<0.2 mm); rare sphene; ghost hornblende (<2 mm) now composed of fine pyroxene, opaque oxide, and feldspar; rounded quartz relics (<0.6 mm) surrounded by rims of granular **clinopyroxene** in a brown, weakly anistropic matrix. The strongly fluidal groundmass is composed of: abundant lath- and blocky-shaped crystals of zoned oligoclase-andesine (<0.2 mm); many stubby crystals of **clino**pyroxene (<0.15 mm); many blocky crystals and grains of opaque oxide (<0.07 mm); irregular grains and masses of carbonate, some within pyroxene crystals and some within plagioclase crystals; abundant interstitial isotropic, material having a low index of refraction and a fracture pattern suggestive of cristobalite or **opal.**

Both the western and southern Kanaga sills are complex rocks. Feldspars of several types showing internal zones crowded with inclusions and oscillatory or reversed compositional zones, rounded quartz relics, and hornblende ghosts all suggest hybridization or at least a very complex cooling history.

***Rhyodacite.*—Specimen** 52-Sn-100 (Rittmann: rhyodacite) is from a very light-colored **podlike** body about 200 yards wide, exposed 4.8 miles west of the mouth of Kanaga Bay on the south coast of Kanaga Island. This was the only light rhyodacite found in the Delarof-Kanaga area. Quartz, oligoclase, and biotite are present in the white to light-green glassy matrix ($n \approx 1.476$) which makes up about 85 percent of the rock.

Specimen 52-Sn-37 (Rittmann: dark rhyodacite) is of quite different composition (table 2) and would be classified **microscopically** as vitrophyric labradorite dacite. This specimen is a dark-gray rock from the chill border of a small dike on northwest Kanaga. Its texture is porphyritic ($\approx$35 percent phenocrysts) with a **hyalo-felty** ground mass and strong flow structure. Phenocrystic plagioclase (<4 mm) is occasionally uniform, but usually shows either progressive or distinct oscillatory zoning. Composition ranges from An_{72-46}, with most of the determinations about An_{54}. A few of the crystals contain dusty zones of glassy inclusions. Augite (often as an overgrowth on hypersthene), hypersthene, opaque oxides, and rare ghost hornblende with a rim of granular pyroxene are also present as phenocrysts; small grains of cristobalite(?) are less conspicuous, and these are all set in a brown glass (*n* between 1.506 and 1.510) containing numerous plagioclase (An_{32-43}) microlites. Potash, present in the analysis, is not expressed mineralogically and must be contained, along with occult quartz, in the low-index glass.

Summary and age.—Most of the aphanitic intrusions studied microscopically have a porphyritic texture with phenocrysts of zoned calcic plagioclase (rarely, more sodic types) and one or more of the following dark minerals: augitic pyroxene, orthopyroxene, oxyhornblende, olivine, and (rarely) biotite. The compositions and textures present in the dikes and sills are more variable than those found in the flows of the intruded sequence, but most of the small intrusive masses are andesite or basalt.

No single period of intrusion can be assumed. Dikes found in the chloritized rocks on Ulak Island are themselves altered; however, fresh-appearing andesite dikes cut the granodiorite pluton that constitutes Ilak Island, and most of the dikes in the Naga Point-Kanaga Bay altered area are fresh. If alteration is associated with subjacent plutonic invasion, diking probably both preceded and followed that event. Diking almost certainly accompanied extrusive volcanism throughout the Tertiary.

One dike which cuts the fossiliferous sequence on northwest Kanaga (specimen 52-Sn-37) stops at the contact with overlying Kanaton lava. The dike raises the lava flows slightly but does not cut them, suggesting that it failed to penetrate the massive flows; thus some of the dikes may be Quaternary.

COARSE-GRAINED INTRUSIVE ROCKS

Coarse-grained intrusive rocks are found in several areas. A thick sill of quartz diorite makes up the outer end of Knob Point (pl. 27) on Amatignak Island. Other sills of diabase or diorite and perhaps larger plutons exist on that island.

Ilak Island is composed of medium- to coarse-grained granodiorite (specimen 52-Sn-167) and quartz diorite cut by numerous small aplite dikes (specimen 52-Sn-181) and a few andesite dikes 10 to 200 feet wide. The largest andesite dike has a contact with the granodiorite indicating that both rocks may have been fluid at the same time. There are many rounded inclusions of coarse- and fine-grained material in the granodiorite, but contacts with the host rock are not exposed.

A granodiorite dike occurs on Kanaga Island between Cape Chlanak and Naga Point. Possibly the alteration (p. 224) and coarse dikes, together with the andesite dike swarm (p. 227), indicate a plutonic mass relatively close to the surface in that area.

Inclusions and boulders.—Inclusions ranging in composition from dunite to granite are found in the shallow intrusions and flows on Kanaga. Large rounded boulders of gabbroic to granitic composition and also boulders of schist and gneiss were found in association with inclusions of similar rock in the lava cropping out along the shore of an inland lake 400 feet above sea level. Near the southeast tip of Skagul boulders of diorite, coarse-grained granite gneiss, and fine-grained granite occur. Boulders of coarse-grained rocks, possibly of local derivation from sills known to exist on the island, were also found on Amatignak.

Some of these boulders undoubtedly are weathered-out inclusions; others may be ice-rafted from known plutonic areas. One boulder on Amatignak was locked in the roots of a driftwood tree. As there are no trees in the Aleutians, this boulder may have come from a great distance, probably from the west. Large areas of metamorphic rock are not necessary to account for these boulders of gneiss and schist. On Unalaska Island the foliated rocks are confined to sheared roof pendants and narrow border zones on large plutons. No large areas of regionally metamorphosed rocks of even slate grade are known in the Aleutian Islands, and them is no evidence for an oldland of metamorphic and igneous rocks. However, inclusions in late Tertiary aphanites indicate that plutonic rocks of diverse composition are present beneath the islands in some areas.

Age.—All dated plutons in the Aleutian Islands are Tertiary. The Ilak pluton and other coarse-grained rocks in the Delarof-Kanaga area cannot be dated, nor is it certain that they are all the same age. At least two episodes of coarse-grained intrusion are possible. The inclusions in lava of late Tertiary age on Kanaga indicate older rocks, and the dike there permits inference of intrusion after late Tertiary. However, it cannot be stated definitely that two episodes are required; apophyses from one intrusion could cut some upper Tertiary rocks, and the same intrusion could supply inclusions for slightly younger upper Tertiary lava flows.

A middle Tertiary episode of intrusion, in the southern parts of several islands or groups of islands, followed by general uplift, erosion, and late Tertiary, central-type volcanism along the north edge of the chain has been suggested for other areas (Gates, Fraser, and Snyder, 1954). Possibly the Ilak pluton is one of several roughly synchronous intrusions belonging to this episode. The coarse-grained sills on Amatignak may be connected with magma chambers that supplied andesitic lava at different times during the Tertiary, and may or may not be genetically related to the granodiorite on Ilak.

STRUCTURE

The Aleutian Islands may be considered as peaks of a submerged mountain range rising 25,000 feet from the floor of the Aleutian Trench and 13,000 feet from the deep on the concave side. Major configurations are apparent from regional studies of submarine contours (Murray, 1945). The Aleutian arc is single in its western part and therefore is probably simpler and younger than double arcs in the circum-Pacific belt (Umbgrove, 1947, p. 185).

Trend lines.—Most of the area is covered by the sea and many structures must be presented as interpretations (pl. 27) from fragmentary subaerial and submarine data (pls. 27–31). Structures interpreted by trend lines on plate 27 are of three types: (1) linear subaerial drainage basins, (2) straight shorelines, and (3) submarine scarps, troughs, and slopes. Most of these alinements probably reflect faults whose precise locations are not known. Some of the linear features may reflect folds. Individual trend lines offer no positive proof of structural control. Together the trend lines form a geometric pattern which would be difficult to obtain by nonstructural methods. We believe that the submarine topography is controlled by longitudinal, perpendicular transverse, and oblique transverse fractures, which apparently are geometrically and genetically related to the arc as a whole.

MAJOR STRUCTURES

In general the main ridge north of the Aleutian Trench probably is a complex arch bounded on both sides by faults. One thrust zone dipping north from its trace on the north side of the Aleutian Trench is indicated by seismic evidence and by comparison with better known arcs where the seismic data furnish compelling evidence for such a fault (Benioff, 1949; 1955).

A second major fault bounds the arch on the north. Alinement of volcanoes along the north edge of the islands has been noted by all workers in the area. Gates and Gibson (1956) and Snyder

(1957) have demonstrated by detailed submarine contouring that this alinement, in some areas, is coincident with a high-angle, normal(?) fault downthrown on the north side. A 1,200-foot submarine scarp is evident west of the Delarofs between Little Sitkin and Semisopochnoi Volcanoes. A similar fault or fault zone is probably buried beneath coalescing volcanic piles in the Delarof-Andreanof area.

This latter fault appears to have been offset by transverse faults. The Delarof sector shows southerly displacement relative to the Rat and Andreanof sectors, so that Gareloi Volcano lies south of lines connecting volcanoes on either side. Amchitka Pass, west of the Delarofs, and Tanaga Pass probably were formed by large transverse faults.

The Amchitka Pass area is unique for the Aleutian chain. Amatignak Island, east of the pass, is farther south than any other island of the chain and is bounded on the northwest by a 6,000-foot depression (pl. 27). Amchitka Island, west of the pass, and the Southern Delarof Islands appear to be dragged south with respect to adjacent parts of the chain. West of Amchitka Pass the trend of the arc is northwest rather than west. Most significant is the 345-mile arcuate ridge, Bowers Bank (Murray, 1945), that curves north and west of Amchitka Pass. The Amchitka Pass area, therefore, is the site of an intersection of two large mountain ranges, but an analysis of the structures is not possible with available data.

The trend of the main arch is shown on plate 27. Its crest passes north of the central Delarofs and south of Tanaga and Kanaga. Unfaulted segments of the south flank of the arch show a smooth slope more gentle than that to the north, where longitudinal faulting modified by volcanic deposition gives a different profile. How much of the movement on this arch is bending and how much is discontinuous movement on high-angle longitudinal faults similar to the north boundary fault is unknown. Abundant high-angle dikes on most of the islands may indicate a tensional environment (Anderson, 1951, p. 3). Dynamic metamorphism and tight folding are absent, possibly confirming the hypothesis of tension near the crest of the main arch. The entire arch may be a drag feature on the main underlying thrust zone, or it may be the anticlinal lip of a tectogene formed by plastic deformation (cf. Benioff, 1955; Vening Meinesz, 1955).

MINOR STRUCTURES

Folds.—In addition to the main arch, dip reversals indicate several smaller folds (pl. 27). Data are fragmentary, and local changes in dip resulting from conditions of deposition and faulting make all of these folds questionable.

Probable northeast-trending folds on Kavalga and Tanaga (and also on Adak Island 10 miles east of Kanaga) contrast with possible northwest-trending folds on Amatignak Island. Unusually steep beds on northeast Kavalga are probably dragged on a strong north-trending fault zone (pls. 27 and 29).

The large and poorly exposed area of central Kanaga shows many beds trending north and northeast; many have dips too steep or persistent to be attributed to chaotic deposition. A dome at Cape Tusik and northerly folds or faults elsewhere may explain some of these anomalous attitudes.

Faults.—The major longitudinal and transverse faults believed to exist beneath the sea have been mentioned. Probably some of the faults that cut the islands have not been found because of the lack of lithologic marker beds, erasure of scarps by wave planation, and cover by ash and tundra. Faults that have been recognized in the field are mostly high-angle shear zones, silicified and stained with iron oxides. North- and northwest-trending faults of this type are evident on Kavalga (pl. 29).

A small reverse fault on the south shore of Kanaga Island (pl. 27) shows apparent vertical displacement of 20 feet. A steaming fissure passing through Kanaga Volcano strikes N. 65°-70° W. On western Kanaga large andesite porphyry sills commonly end in steep side contacts that are probably faults (pl. 28). Small faults are shown on Ulak and Tanaga (pl. 27).

A possible north-trending fault between Ulak and Amatignak is suggested by the different attitudes of the beds on the two islands, and by the steepening of the beds on Amatignak. Relative altitudes of the two islands and the dragged beds suggest that the west side is upthrown (pl. 27).

Calderas.—Coats (1950, p. 43) found incomplete calderas on both Kanaga and Tanaga Islands, the northern sections presumably destroyed by faulting or marine erosion. These structures are approximately coincident with the east and south margins of coastal areas of volcanic rocks of Quaternary age shown on plate 27 for Kanaga and Tanaga Islands. Possibly the north rims of these structures were never completely formed. Arcuate normal faults, downthrown on the north and roughly alined with a larger east-west structural trend, may explain the calderalike rims better than the theory of partly eroded conventional calderas. (Williams, 1941, p. 242; van Bemmelen, 1954, p. 88–92.)

SUBMARINE TOPOGRAPHY

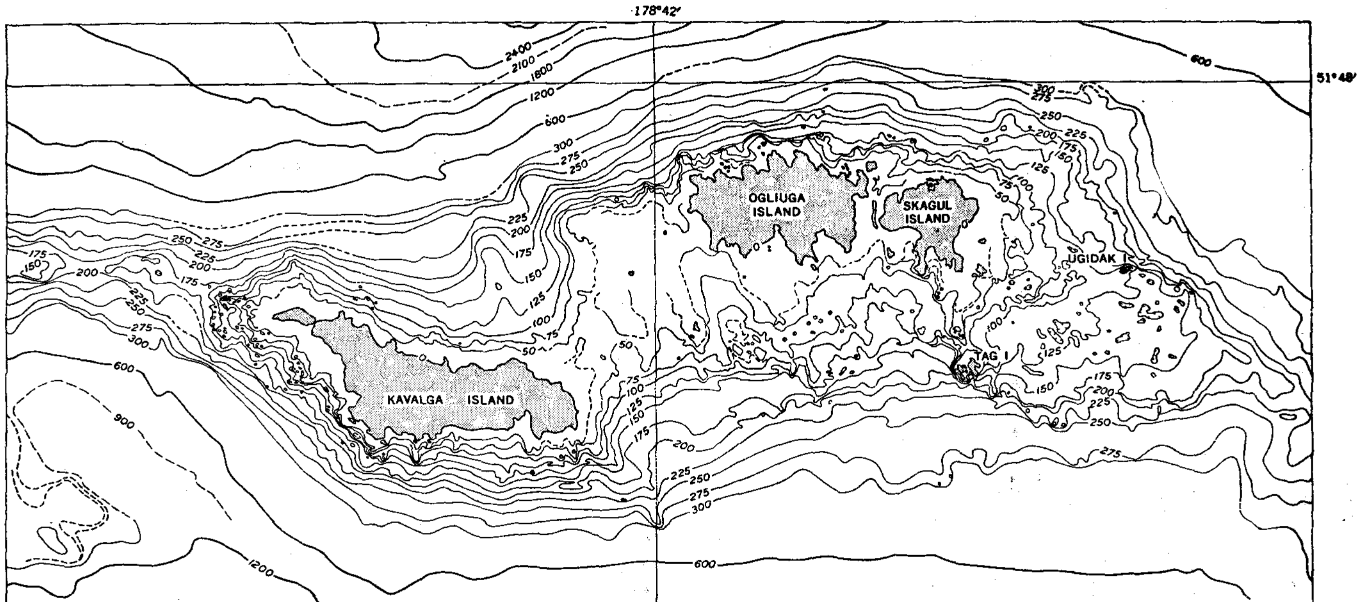
Submarine contours in most of the area from longitude 180° east to Adak Strait, and including northern Tanaga Island and Amatignak, are shown on plate 27. The map was prepared from U. S. Coast and Geodetic Survey boat sheets at several larger scales. The contour interval is 300 feet. The map scale and the density and precision of location of soundings give the contour lines the status of form lines. Figure 45 is a detailed map of the bottom topography around the central Delarof Islands.

Many sea valleys, ridges, scarps and passes show strong alinements miles in length. These alinements commonly trend in one of four directions: west, almost parallel with the terrestrial Aleutian Ridge line; obliquely northwest; obliquely northeast; or roughly north at right angles to the ridge. The linear character of ridges, valleys, and scarps, and the presence of blocklike seahighs suggest that much of the bottom topography reflects geologic structure.

The islands of Unalga, Kavalga, Ogliuga, and Skagul emerge from a shallow submarine platform orientated generally east-west along the Aleutian arc (pl. 27 and pl. 31). The platform extends west of the Delarofs across Amchitka Pass; east of this group of islands it appears to be offset to the north and presumably is coincident with the flat southern parts of Tanaga and Kanaga Islands.

The crest of the Aleutian Ridge between the 180th meridian and Skagul Island is bounded on the south by a steep slope at least 1,500 feet high. At the foot of the slopes just south of Kavalga and west of longitude 179°50′ W. the bottom flattens to form a shallow trough with seaknolls alined along its outer edge. The knolls are flat topped with a steep northern margin and a more gentle southern slope. Probably the trough was once continuous along the Delarof Islands and across Amchitka Pass, but it is now disrupted north of Amatignak by a 2,700-foot slope which drops into a large depression whose maximum depth is 6,000 feet. The depression is a triangular area between the Amatignak-Ulak Islands block, a seahigh 16 miles northwest of Amatignak, and the crest of the Aleutian Ridge. The greatest depths are at the southeast corner of the triangle.

The east-west, or longitudinal, trend is dominant along the central Delarofs and west to longitude 180°, but it is only generally evident east of Tanaga Pass as the boundary of the emergent Aleutian Ridge. The submarine topography north of the islands is only partly contoured, but additional evidence of U. S. Coast and Geodetic Survey hydrographic charts and analogy with the Kiska-



Hydrographic data from U. S. Coast and Geodetic Survey, 1944–52

Contouring by H. F. Barnett

CONTOUR INTERVALS
Occasional intermediate contours for detail

Depth (feet)	Interval (feet)
0–300	25
300–600	300
600–2400	600

2 0 6 Miles

ALTITUDE OF ISLANDS IN FEET

Kavalga	315
Ogliuga	73
Skagul	95

FIGURE 46.—Detailed submarine topography of central Delarof Islands area.

Arnchitka area (Gibson and Nichols, 1953, pl. 1) indicates the slopes are steeper than those south of the islands.

Tanaga Pass and the pass east of Kavalga Island (fig. 45) have features with strong northwesterly alinements (N. 35" W. to N. 50° W.). The east side of Ulak Island is the west edge of a parallel-sided, flat-bottomed trench trending northwest; the pass between Kavalga and Unalga apparently is an extension of this trend offset to the east. Other features with evident northwesterly trends intersect the seahigh 16 miles northwest of Amatignak and bound it on the northeast; they can be seen on central Ulak and southeast Tanaga as linear subaerial features. The north margin of Tanaga Bay trends northwest, in line with the linear zone on the island.

The most obvious northwesterly alinements of bottom topography are in the Delarof Islands-Amchitka Pass area; such alinements are largely absent east of Tanaga Pass.

A zone of closely spaced northeasterly trends (N. 25° E. to N. 50° E.) is apparent south of Ilak and Tanaga Islands, and may be the main structural control on Kanaga Pass. This trend also outlines the south margin of the Amatignak-Ulak Islands block. Submarine valleys and seaknolls oriented northeast are evident in Amchitka Pass to a lesser extent.

Northerly trends are also evident and two north-south scarps are particularly noticeable: one is south of Kanaga Island, in line with Adak Strait; the second is in Amchitka Pass, near the 180th meridian and intersects the Aleutian Ridge crest at the base of a steep west-facing slope. Amchitka Seavalley (Gibson and Nichols, 1953, pl. 1) also trends north. Skagul Pass (pls. 27, 31) is an example of this trend, and many smaller alinements have been contoured.

The southwest peninsula of Ulak Island is triangular. This shape is probably the result of the intersection of northwest-, northeast-, and north-trending structural breaks. In general, the orientation of long straight coastlines and interisland passes throughout the area shown on plate 27 is closely coincident with the four main directions of submarine alinements (p. 235), with the directions of subaerial trends, and with the strike of dikes.

PHYSIOGRAPHY

Kanaga Island.—Landforms on Kanaga Island illustrate the concept of constructive volcanism coupled with continual erosion. The symmetrical, complete cone of Kanaga Volcano at the north end of the island is the most recent constructional landform.

Steam issues from a vent near the summit, and flows of blocky lava in 1906 (Coats, 1947, p. 93) indicate present day volcanic activity. Continuing construction of the cone has inhibited dissection by streams. The shoreline is concentric around the volcano and is scarcely eroded by the sea.

The arcuate calderalike scarp of Kanaton Ridge south and east of Kanaga Volcano confines the younger deposits within a half-bowl depression (Coats, 1956b, p. 76). Many branching streams flow southward from the scarp lip. They are underfit in broad valleys which radiate from Kanaton Ridge, and are separated by almost continuous sharp interfluves of high relief. The valleys were developed upon the slopes of the ancient Kanaton Volcano. Cliff recession on the west shore has carved bluffs at least 400 feet high into the rocks of the old volcano and the underlying sedimentary rocks.

Planed surfaces on Kanaga Island.—About 3 miles south of the lip of Kanaton Ridge, the streams join a transverse drainage direction in the flatlands below 500 feet in altitude. This northwest-southeast drainage is the first expression of the older, wave-planed surfaces of the southern and western parts of Kanaga.

Five major levels of planation are inferred from the topographic profiles (fig. 46). Each level is continuous and bounded by distinct breaks in slope many feet high. Abundant ponds and lakes on the several levels emphasize their flatness. The irregularly dashed lines on the map, which indicate the levels, were drawn from drainage patterns and slope changes shown on topographic maps and aerial photographs.

The broad central area of the island is topped by the highest planar surface, level 1, which has an altitude of more than 500 feet on the northwest and 400 feet on the southeast. (On the map, level 1 includes a minor surface about 50 feet below the uppermost flatlands.) A steep scarp 100 to 150 feet high separates level 1 from level 2, at an altitude of 260 to 280 feet on the northwest and slightly more than 200 feet on the southeast side of the island. Level 2 is easily seen at the narrowed neck separating the northern volcanic highlands from the rest of the island. The highest flat ponded area west of the central area, along the narrow prolongation of the island, is correlated with level 2; presumably level 2 also can be correlated with the higher altitudes at the extreme west end of Kanaga, north and west of Cape Chunu. Level 3, mostly about 220 feet in altitude, is well defined near the west edge of the central area; it makes up much of the slender western extension of the island and may be present locally along the steep

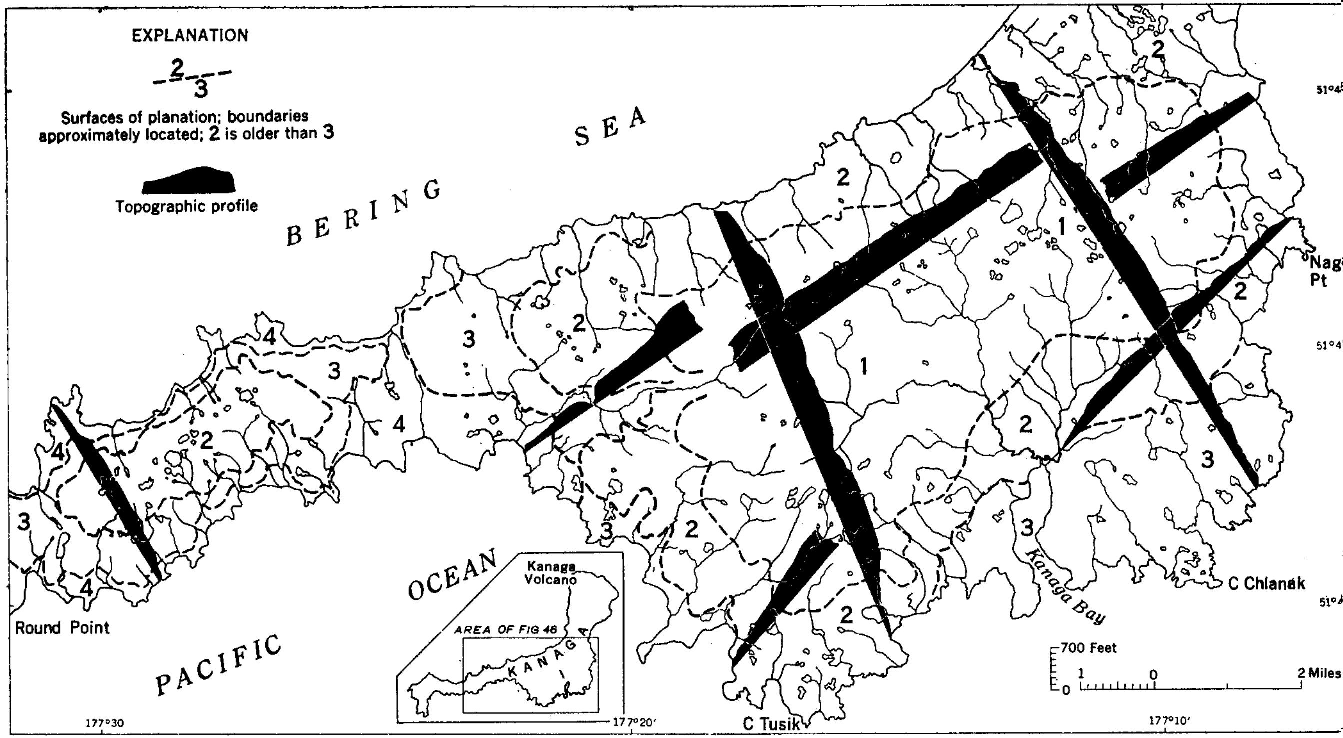


FIGURE 46.—Surfaces of planation and drainage map, central Kanaga Island, Andreanof group, Aleutian Islands, Alaska.

coast of the central part of the island on the northwest. Level 4 is at altitudes from 100 to 120 feet and is best preserved on the western elongation of the island; it is definable, however, near the west coast of the narrow neck area and as small remnants elsewhere. Level 5 (not shown in fig. 46) includes the narrow benches along the present shoreline. Sheer cliffs commonly separate level 5 from higher levels. Minor terraces which are suggested by the topographic map configurations and are locally apparent in the field, particularly in the levels below level 2, are not discussed here.

The planed surfaces are almost continuous in the broad central region and western elongation of Kanaga Island (fig. 46), but along the east coast north of Naga Point only levels 1 and 2 are present. Level 2 merges with the south slopes of Kanaton Ridge. The continuity of the surfaces inland from Cape Chlanak, southeastern Kanaga, is less apparent because of extensive stream erosion parallel with a broad northwest-trending dike swarm.

The drainage divide for most of Kanaga Island, excluding the volcanic highlands, is close to the north shore (fig. 46). Streams flowing northward into the Bering Sea from the central region drop as much as 600 feet per mile down a series of cliffs and scarps; those flowing southward into the Pacific Ocean are not so steep. The asymmetry is as marked farther west, but altitudes are lower. The tendency of the drainage to take southerly courses across most of the central region is commonly thwarted by structural controls, mostly bedding and diking.

Presumably, the greater age and higher altitudes of the central area are responsible for the close coincidence of drainage direction with four or five known structural trends. On level 1 the streams flow southwest or northeast, roughly parallel with the length of the island. Streams below level 1 commonly follow the other structural trends. Southeast drainage is dominant along the east coast. The two deeply incised valleys leading into Kanaga Bay from the north reflect a north-trending structural control visible in Kanaga Bay and extending north along the west margin of northern Kanaga Island (pl. 27). The parallel southward drainage along the island's western elongation may be simply downslope or may follow northerly strikes in the area.

Sea-level benches now forming on the south side of Kanaga are notably broader and more continuous than those on the north. This difference in width is consistent with the concept of a planation platform of marine origin tilted by up-faulting at the north. The fault scarp, subject to direct wave action, would recede with much of its steepness preserved; the newly inundated platform areas across the island, on the other hand, would favor water-level and subaerial weathering and the consequent development of a wider bench (Hills, 1949). Predominant southerly winds probably also contribute to the formation of broader benches along the south coast.

Physiographic evidence and geometric construction suggest southeastward tilting of the entire Kanaga Island block, excepting the volcanoes. A slope of at least 150 feet in 5.4 miles is indicated across central Kanaga. This slope is opposite to the prevalent dips.

Tanaga Island.—The physiography of Tanaga Island is similar to that of Kanaga. The northernmost part of the island is, like Kanaga, a mountainous area, that has been active volcanically during and since the Pleistocene. The volcanoes are alined east-west, and include relatively undissected, ash-covered cones and dissected shield volcanoes, some heavily glaciated. The glaciated peak nearest Gusty Bay has crevassed ice around the summit depression, and at least four recent cones to the east and south have poured lava and ash upon radial valleys and ridges. Tanaga Volcano and its twin to the west are located within an arcuate structure, possibly a caldera. The volcano at the northwest tip of the island appears also to have been built up within a similar structure.

Ponded areas and abandoned beach ridges resemble those on Kanaga, and imply a related emergence. Coats (1956c, p. 92) states that most of south Tanaga is a wave-cut platform mantled by marine gravel. Correlation with the planed surfaces of Kanaga Island has not been attempted.

The Delarof Islands.—The low, nearly flat Delarof Islands (pls. 31, 32) appear to be blocks planed smooth by waves and later faulted. Profiles drawn transverse to the trend of main topographic breaks on five islands (fig. 47) show the apparently unrelated orientations of subaerial planar surfaces.

Bedding traces are well exposed on wave-planed surfaces around most of these islands. On Ulak, where the ash cover is thin, a west-northwest bedding trend is reflected inland by alinement of ponds. This higher surface probably resulted from wave planation, possibly followed by glacial scouring.

Glacial erosion has etched a north-south backbone through the south half of Amatignak Island. The ridge crests trend north-northeast across the north half. A high area near the northwestern coast is underlain by more massive rocks. No continuous surfaces of planation are evident around the island. Either the emergence of Amatignak was later than the benching observed on nearby islands, or glaciation removed all trace of wave-cut planes.

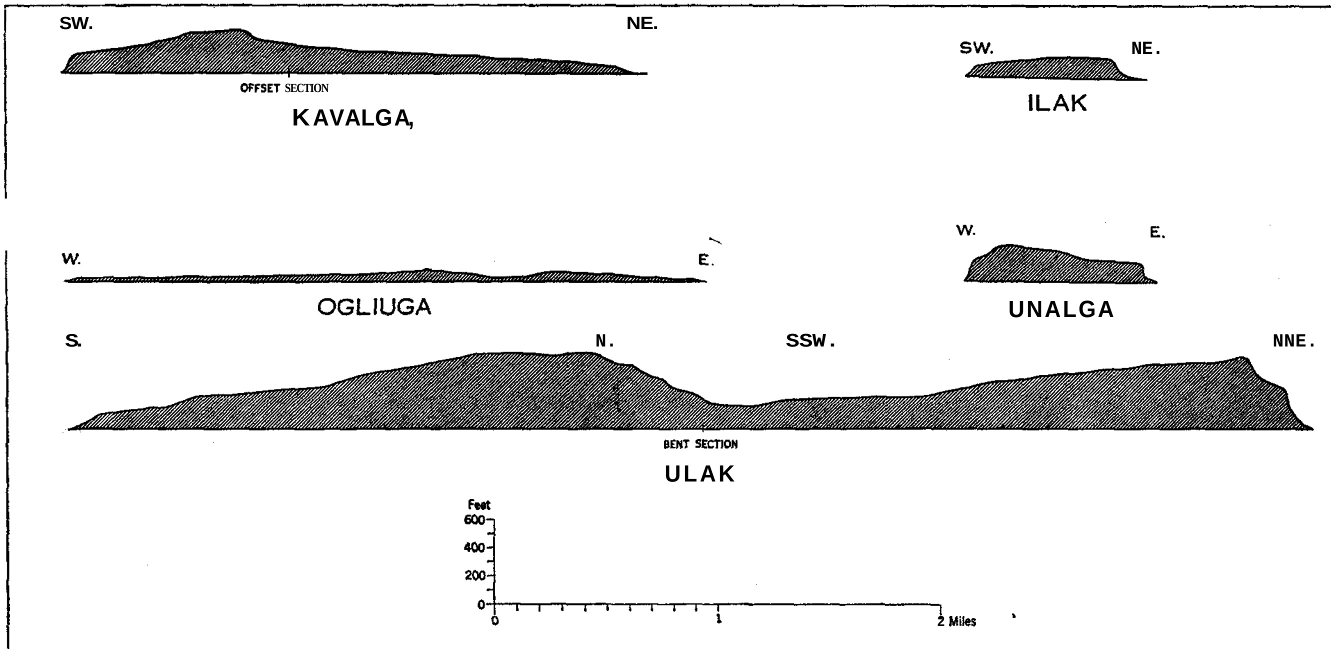


FIGURE 47.—Selected topographic profiles showing orientations of planar surfaces of five islands of the Delarof group.

GEOLOGIC HISTORY

The pre-Miocene history of this area is unknown, but two possible interpretations are suggested by available data: (1) Rocks in the Amatignak-Ulak area were deposited in early Tertiary in a fairly stable geosynclinal trough or on its flanks and were invaded and altered by granodiorite plutons. The area was uplifted and eroded during or after the time of intrusion. Later, in Miocene time, marine and subaerial volcanism began in the central Delarof-southern Kanaga area. These young Tertiary chaotic deposits contrast markedly with the well-bedded older rocks farther south. (2) Another possibility is that rocks in the Amatignak-Ulak area are actually the well-bedded, deeper water facies of Miocene deposits farther north (which are nearer their source) and the alteration of the southern facies is a result, not of greater age, but either of proximity to late Tertiary plutons or of different diagenetic conditions within the geosyncline.

The known geologic history, then, begins in Miocene time with the deposition of poorly bedded volcanic rocks. East-west normal faults probably localized a chain of volcanoes near the latitude of the central Delarofs, and this zone apparently moved northward to its present location. Depth contours of the present volcano belt on the north edge of the islands reveal many volcanic cones. These, and the volcanoes projecting above the sea, form a series of coalescing volcanic piles. Conditions in Tertiary time may have been similar to those of today; but shifting volcanic centers, concurrent and subsequent erosion of volcanic landforms, and deposition of Recent volcanic ash have all obscured the record. No centers have been found for the Tertiary deposits; and large areas of coarse pyroclastic rocks, not obviously related to volcanic centers, suggest episodes of generalized eruption (much of it submarine) during which mudflows and flood eruptions may have been important.

Many local unconformities record unstable conditions during late Tertiary time and no persistent lithologic units were deposited. Lava flows, pillow lavas, and poorly sorted tuff-breccia are the dominant rocks; many dikes and, locally, large shallow sills invaded this sequence. Some of the sills were uncovered by erosion and large columnar talus blocks from them were incorporated in later sedimentary and pyroclastic beds. Relief features produced by faulting, erosion, and deposition were masked by subsequent floods of lava and coarse pyroclastic rocks. Pockets of well-sorted tuff, some of which contain fossils, filled depressions on southwestern Kanaga.

During the entire period of volcanism recorded here, andesitic and basaltic rocks were dominant, with only sporadic and minor contributions of more acid rocks. Shallow-water marine life left a fragmentary record, and forested land areas existed where today there are no trees.

Near the beginning of Pleistocene time broad shield volcanoes formed near the sites of present volcanoes. These volcanoes were partly destroyed by caldera-forming processes, and Recent volcanoes of sharply conical form grew in the old, incomplete calderas. At almost the same time another volcano, Gareloi, formed on the ocean floor. This late volcanism was all confined to the northern ends of the islands.

Wave planation carved a series of platforms on the late Tertiary volcanic rocks during the Pleistocene; Amatignak Island, because it has not been planed, may have been uplifted in Pleistocene time. Glaciers modified Amatignak and the higher volcanic areas, and may have overridden the flat areas on other islands, particularly Ulak.

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