Stratigraphy and Depositional Environment of the Dutch Harbor Member of the Unalaska Formation, Unalaska Island, Alaska

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By STEPHEN M. LANKFORD *and* JAMES M. HILL

CONTRIBUTIONS TO STRATIGRAPHY

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STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT OF THE DUTCH HARBOR MEMBER OF THE UNALASKA FORMATION, UNALASKA ISLAND, ALASKA

By STEPHEN M. LANKFORD and JAMES M. HILL

ABSTRACT

A part of the Unalaska Formation of Drewes, Fraser, Snyder, and Barnett was reexamined in 1976 and a new suite of fossils collected. This Tertiary formation is exposed over about 70 percent of Unalaska Island and is 900–16,700 meters thick. It consists mainly of volcanic breccia, flows, tuff, and intercalated sedimentary rocks 1 cm to more than 100 m thick. A 126-m-thick sequence of early Miocene(?) sandstone and conglomerate, all thermally altered, was measured and examined in detail. This sequence, herein designated the Dutch Harbor Member, shows evidence of deposition by turbidity currents and debris flows.

The stratigraphic position of the Dutch Harbor Member within the Unalaska Formation is not well known, but it may be near the top of the formation. Fossils collected within the member include the bivalves *Chlamys* and *Pododesmus* of Miocene age.

INTRODUCTION

Unalaska Island, near the east end of the insular Aleutian arc, is perched atop the mostly submerged Aleutian ridge. This ridge separates the abyssal northern Pacific Ocean from the Bering Sea (fig. 1). About 70 percent of the island is covered by Tertiary volcanic and sedimentary rocks named the Unalaska Formation (Drewes and others, 1961). The thickness of the Unalaska Formation has not been determined, but on the basis of topographic data it is at least 900 m thick. From calculations on the regional dip, Drewes, Fraser, Snyder, and Barnett (1961) figure that it could be as thick as 16,000 m; they suspect that the actual thickness is of the order of 5,000–10,000 m.

During August 1976, we examined the Unalaska Formation and collected a new suite of fossils in the vicinity of the original collection site reported by Drewes, Fraser, Snyder, and Barnett (1961). The study area extends about 1–4 km southeast of the village of

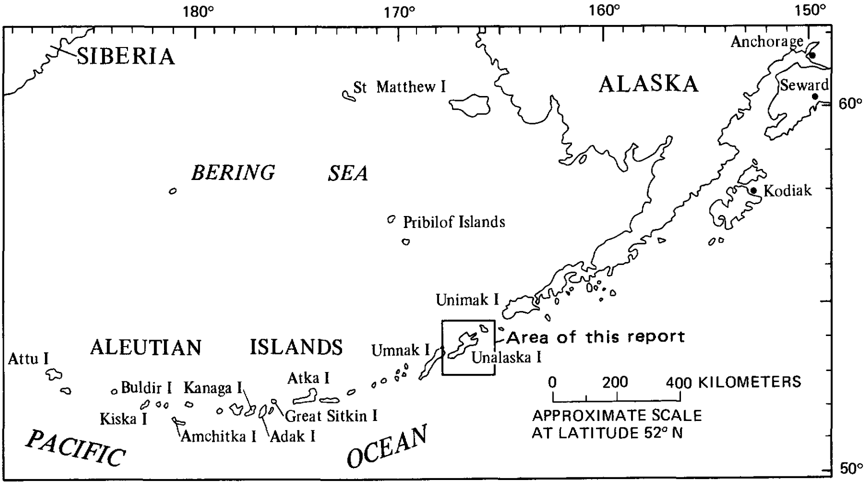


FIGURE 1.—Location of Unalaska Island near east end of Aleutian arc.

Unalaska on Unalaska Island (fig. 2), where a sequence of sedimentary rocks 126 m thick occurs. This distinctive sequence of sedimentary rock is here named the Dutch Harbor Member. A measured

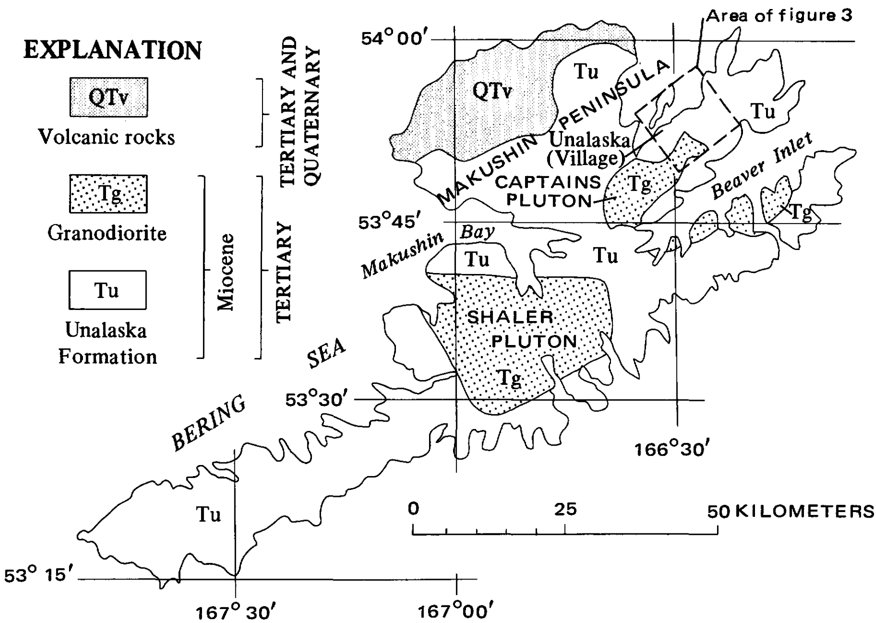


FIGURE 2.—Generalized geologic map of Unalaska Island. Modified from Drewes, Fraser, Snyder, and Barnett (1961).

FIGURE 3.—Aerial photograph showing location and partial extent of the Unalaska Formation and the Dutch Harbor Member, U.S. Navy photograph KAD–2 No. 13, June 20, 1951.

section (fig. 3) is herein designated the type section of the Dutch Harbor Member of the Unalaska Formation. The sequence is bounded by volcanic rocks that were not studied in detail.

The Dutch Harbor Member rests conformably upon, and is overlain by, undifferentiated aquagene volcanic rocks of the Unalaska Formation (fig. 3). Typically it strikes about N. 30° W. and dips 15°–25° NE. The member consists predominantly of sandstone interbedded with pebble and cobble conglomerate and scattered stringers of siltstone and shale as much as several centimeters thick. The section is discontinuously exposed along road cuts and small slides.

UNALASKA FORMATION

Drewes, Fraser, Snyder, and Barnett (1961, p. 590) described the Unalaska Formation as "a thick sequence of coarse and fine sedimentary and pyroclastic rocks intercalated with dacitic, andesitic, and basaltic flows and sills ***". They further state that greenish-gray argillite beds that are found predominantly along the south coast of the island are interrupted by abundant albitized andesite and basalt sills, domical masses, igneous pods, and pillow lava. Coarse sedimentary rocks in the Unalaska Formation include abundant graywacke, mudstone, and tuffaceous sandstone. Conglomerate beds that are found mainly on the northern part of the island occur in association with agglomerate and coarse volcanic breccia. The conglomerates are poorly bedded and are composed mostly of andesite and basalt clasts.

In the study area, the Unalaska Formation has been divided into a lower volcanic sequence, the Dutch Harbor Member, and an upper volcanic sequence. The volcanic sequences are here used as informal units.

DUTCH HARBOR MEMBER

EXPOSURE AND AREAL EXTENT

The Dutch Harbor Member is discontinuously exposed in a band about half a kilometer wide and 3½ km long. The easternmost part of the member is truncated by the Captains pluton, but it may be exposed on the other side of the pluton. To the northwest, the Dutch Harbor Member is concealed by the glacial alluvium that underlies the village of Unalaska and by Dutch Harbor. The member is probably present on Amaknak Island and possibly on the Makushin Peninsula, but logistical and time constraints precluded investigation of these areas.

Most of the Dutch Harbor Member is covered by low but dense vegetation and by a thick soil horizon, but enough rock is exposed to show that individual beds are lenticular and cannot be traced far laterally. No marker beds were found, and correlation with the sequence in other areas will be difficult. Where exposed, the member is characterized by typical well-indurated, light- to medium-greenish-gray, very fine or fine-grained sandstone.

LITHOLOGY

The volcanic rocks immediately below and above the Dutch Harbor Member consist predominantly of andesitic flows, tuff, and breccia; some basalt and dacite are present (Drewes and others, 1961). The volcanic beds in the area are typically only a few meters thick. The breccia contains angular to rounded andesite clasts that are poorly bedded or scattered in the matrix. At one locality, just above the top of the Dutch Harbor Member, graded bedding occurs within an exposed volcanic breccia. The volcanic rocks also contain thin, highly lenticular stringers of shale less than 1 cm thick and less than 2 m long.

Examination by microscope reveals that the dominant primary minerals in the andesite units are plagioclase and clinopyroxene occurring as microphenocrysts and in the groundmass. Plagioclase occurs in equant to elongate laths that are commonly pilotaxitic. The groundmass is slightly intersertal to holocrystalline; glass is rarely dominant (Drewes and others, 1961).

At the type section, the Dutch Harbor Member is 126 m thick. It is composed predominantly of light- to medium-greenish-gray, very hard, indurated sandstone (fig. 4). The sandstone is mostly very fine to fine grained and moderately to well sorted; individual grains, which are mostly subrounded, range from subangular to rounded. Bedding in the sandstone is commonly obscure. The beds are slightly wavy and average 10–30 cm thick but are as much as 1–2 m thick. Petrographic analysis of sandstone in units 2, 5, 7, 8, 10, 13 and 18 (fig. 4) indicates that grain-to-grain contacts are common; there is little matrix, and the sandstone is compacted. About 50 percent of the sandstone is andesite fragments that contain abundant pilotaxitic plagioclase laths. Individual laths of plagioclase, which commonly are compositionally zoned and display albite twinning, make up approximately 25 percent of the rock. Quartz is about 1–3 percent of the rock; other minor components are magnetite, pyrite, and pyroxene. Spherulites of chlorite and epidote as much as several millimeters in diameter are common. Chlorite and epidote are common interstitial minerals.

Rhythmically bedded sandstone and conglomerate, which are common in the Dutch Harbor Member, are most common in beds 7–11 and 17–19 (fig. 4). The lenticular conglomerate beds, generally 0.3–1 m thick and about 1–3 m apart, persist laterally for about 40 m or less (fig. 5). The conglomerate clasts are supported by a matrix composed of very fine to fine-grained sandstone. In some beds (beds 12, 15, 19, fig. 4) pebbles and cobbles occur as isolated clasts within the matrix (fig. 6*A*). Bed 19 contains a large angular clast 20 cm wide in a sandstone matrix (fig. 6*B*) along with scattered small well-rounded to angular pebbles. Texturally these deposits are diamictites. Clasts are generally subrounded, but they range from well rounded to angular and average about 2 cm in diameter. Clasts are composed of microporphyritic andesite; this andesite is very similar in composition to rocks in volcanic sequences that bound the Dutch Harbor Member.

Beds 2 and 18 (fig. 4) contain scattered siltstone and shale stringers that are medium gray, slightly sandy, and less than 4 cm thick. These stringers extend laterally for only a few meters.

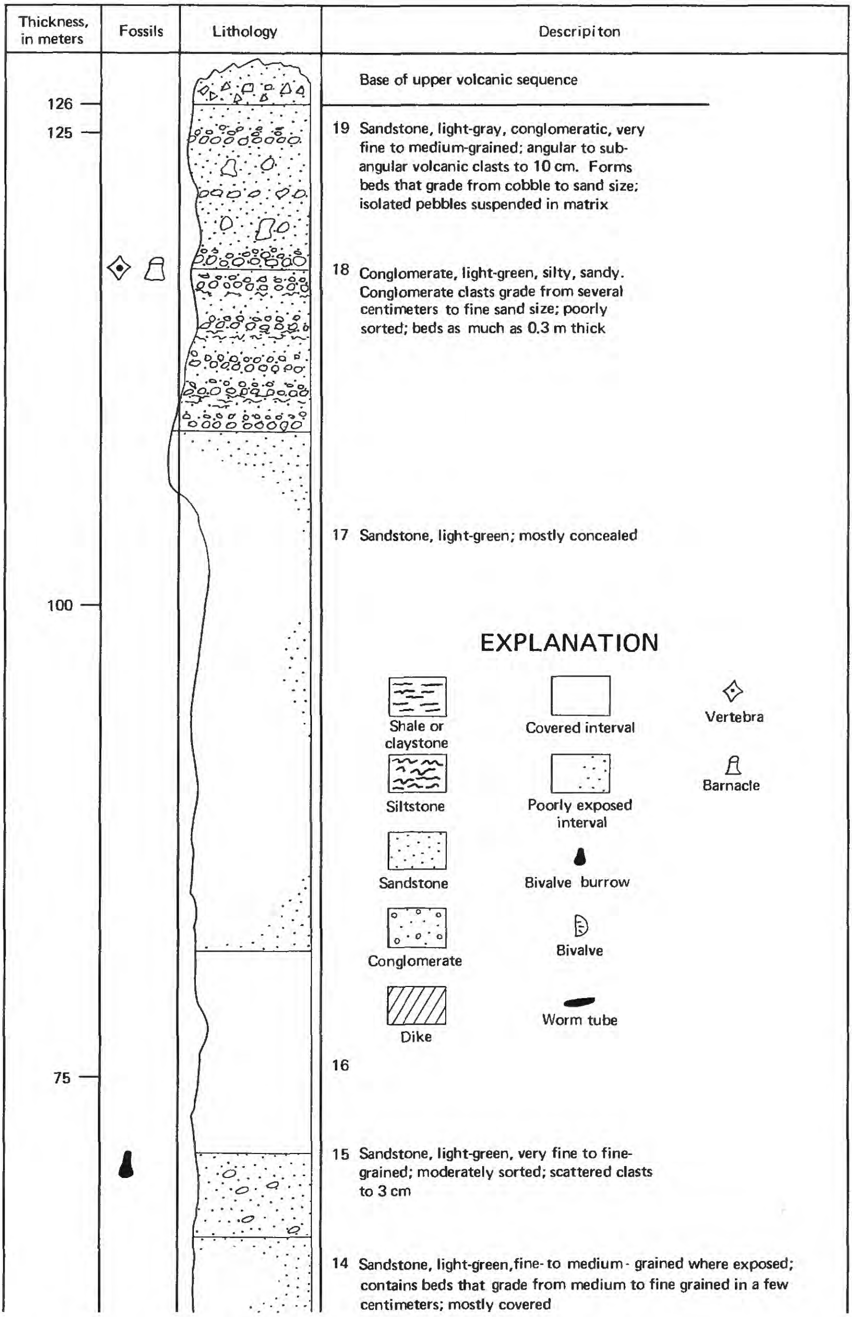


FIGURE 4.—Type section of the Dutch Harbor Member.

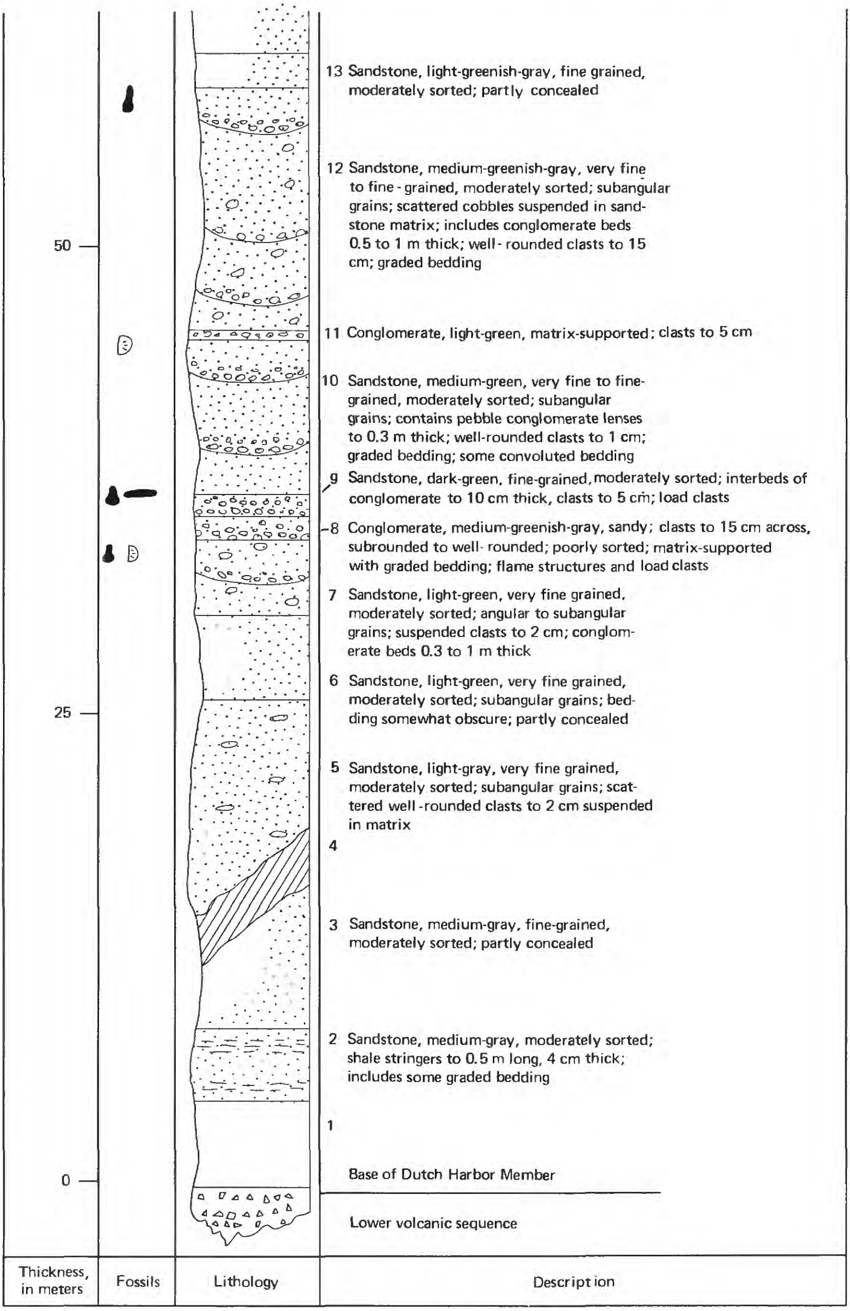


FIGURE 4.—Type section continued.

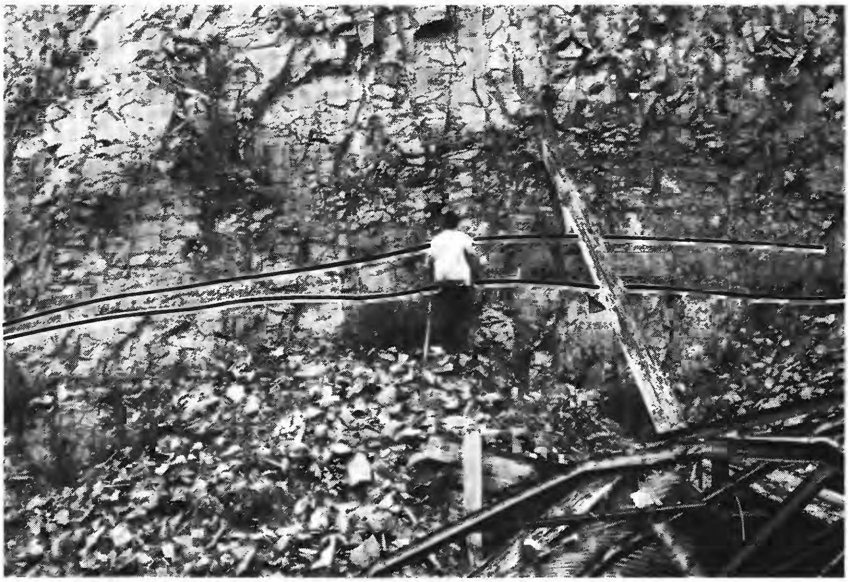


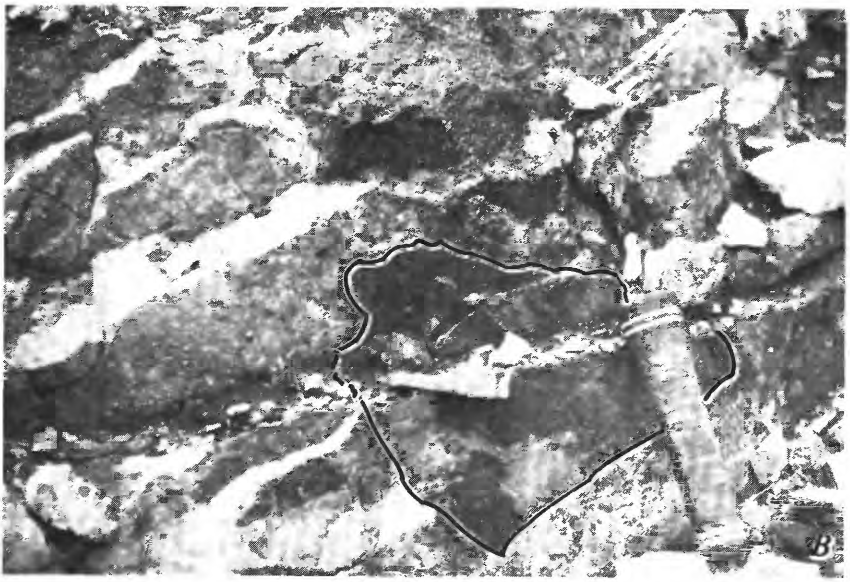
FIGURE 5.—Lenticular channel deposit that pinches out locally within about 40 m, Dutch Harbor Member.

Though beds 10 and 13 are poorly exposed, small outcrops suggest that these beds are lithologically more homogeneous than other parts. The exposures that are present are composed of light-green sandstone similar to that exposed in most of the section. The only observed sedimentary structure was exposed in bed 13, and it consists of sand grains that grade from coarse to fine within about 2 cm. There is in this part of the section a notable lack of siltstone and sandstone interbeds.

ALTERATION

All of the Dutch Harbor Member has been thermally altered. The member and its bounding volcanic rocks contain abundant (to 25 percent) authigenic, metamorphic, and secondary minerals. Euhedral pyrite cubes are sparse to abundant in the section. Chlorite and epidote occur both as spherules and as interstitial material that appear to be derived from an altered volcanic matrix. Plagioclase has been partially albitized. The mineral assemblage suggests greenschist-facies metamorphism (Williams and others, 1954). Drewes, Fraser, Snyder, and Barnett (1961) believe that the metamorphism of these rocks was caused by the intrusion of three plutons into the Unalaska Formation. One intrusive body, the Captains pluton (fig. 2), crops out near the type locality of the Dutch Harbor Member. Numerous dikes, some as much as several meters thick, intrude both the Dutch Harbor Member and the surrounding

A, Isolated cobble clasts.



B, Angular 20-cm wide clast in pebbly sandstone.

FIGURE 6.—Clasts in sandstone matrix exhibiting diamictite texture.

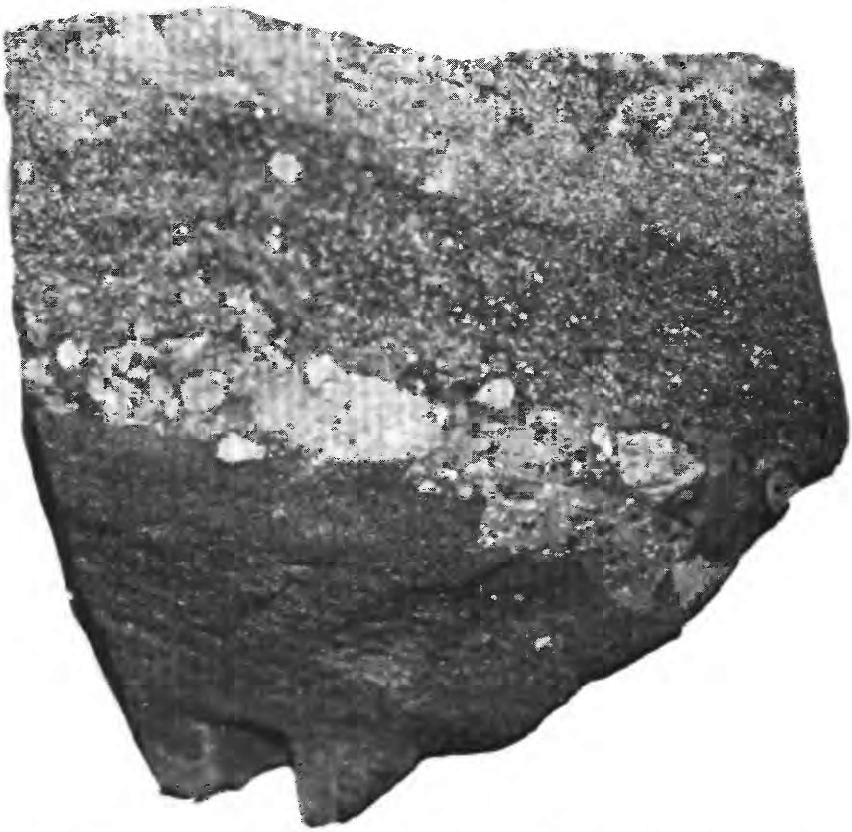


FIGURE 7.—Typical conglomerate that grades upward, Dutch Harbor Member. Horizontal scale approximately 16 cm.

volcanic rock and appear to radiate from the Captains pluton. The Dutch Harbor Member strikes into the Captains pluton, but poor exposures preclude exact determination of the contact. The Captains pluton is probably middle Miocene (13 m.y.) in age as determined by potassium-argon age dating (D. W. Scholl, oral commun., 1976). A potassium-argon date from the Shaler pluton, which also intrudes the Unalaska Formation, yielded an age of 11±3 m.y. (Marlow and others, 1973).

SEDIMENTARY STRUCTURES

The most common sedimentary structure in the Dutch Harbor Member is graded bedding. Subtle grading occurs within sandstone beds (beds 2, 8, 10, 12 and 13, fig. 4). Prominent grading is characteristic of beds forming lensoidal channel deposits (fig. 7); these deposits grade upward from cobble or pebble conglomerate to fine or very fine grained sandstone over an interval of 5–50 m (beds 7–11,

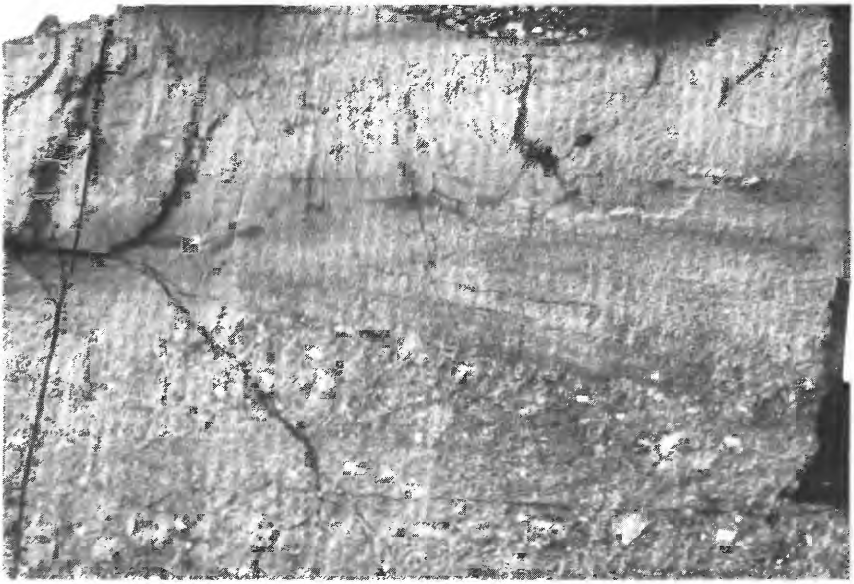


FIGURE 8.—Tabular planar cross-stratification in very fine grained sandstone near top of the Dutch Harbor Member. Horizontal scale approximately 0.5 m.

17–19). Cross-stratification, though rare (fig. 8), was found at one place in an outcrop near the top of the member just east of the type section. The tabular planar crossbedding has foreset beds about 15 cm long that dip N. 70° E. at 26°.

Conglomerate clasts on the bottom of the channel beds deform the underlying finer grained sediment to form load structures (fig. 7) and convolute bedding (fig. 9). The absence of lamination within many sandstone beds may be the result of bioturbation. Bed 9, for example, contains what appear to be worm tubes; the tubes are roughly circular in cross section and about half a centimeter in diameter. Beds 7, 9, 12, and 15 contain bivalve burrows fairly commonly; the burrows are as close as 5 cm apart, 15–20 cm long, and oriented perpendicular to bedding planes.

AGE

Fossils collected from the Dutch Harbor Member include bivalves, barnacle plates, burrow fillings, and a vertebra (W. O. Addicott, written commun., 1976). The bivalves, collected from beds 7 and 10 (fig. 4), are of the genera *Chlamys* and *Pododesmus* and are probably of Miocene age (W. O. Addicott, written commun., 1976). Earlier fossil collections from the lower part of the Dutch Harbor Member include bones and teeth of a marine mammal resembling a sea cow, probably of the genus *Cornwallius;* this genus generally indicates an

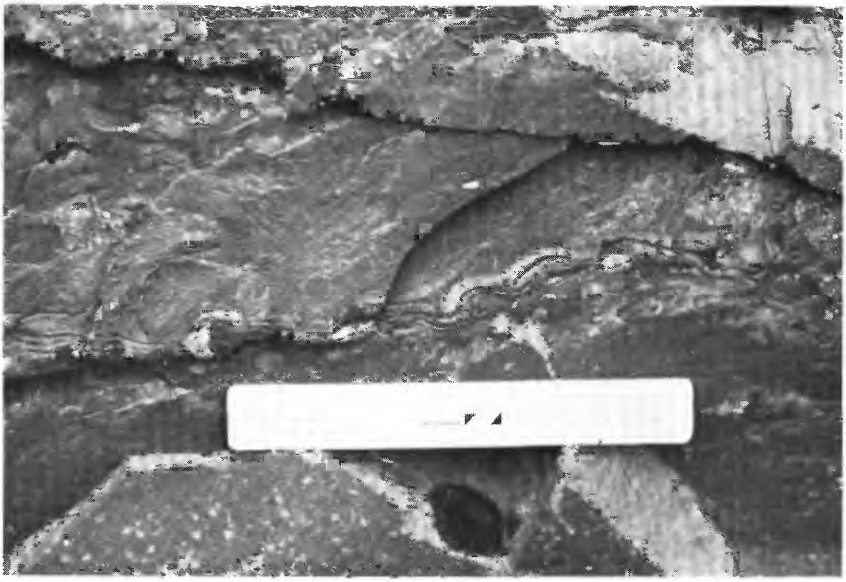


FIGURE 9.—Possible convolute bedding in sandstone, Dutch Harbor Member. Scale is 15 cm long.

early Miocene age (Drewes and others, 1961). W. O. Addicott (written commun., 1976) stated that the fossil evidence "seems to indicate an early or possibly middle Miocene age ***".

Most of the fossils have been transported and fragmented such that much of the original shell material is missing. Because they were transported rapidly by turbidity currents, however, the ages of the fossils and deposition of the Dutch Harbor Member are probably not significantly different. Therefore, on the basis of fossil evidence, we assign the Dutch Harbor Member a Miocene (probably early Miocene) age.

DEPOSITIONAL ENVIRONMENT

The presence of channel deposits, graded bedding, load structures, and cross-stratification all suggest proximal turbidite deposition of the Dutch Harbor Member. The diamictite texture of beds within the member and the occurrence of large angular clasts as much as 20 cm in diameter (bed 19) are perhaps more characteristic of debris flows. These structures indicate that the Dutch Harbor Member was laid down rapidly as deposits transitional between proximal turbidite flows and debris flows. Although the dominant mode of deposition was rapid, the preservation of bivalve burrows and the occurrence of lenticular silt and shale stringers suggest alternate periods of slow deposition. The textures and structures present in the volcanic rocks that bound the member suggest that the volcanic rocks

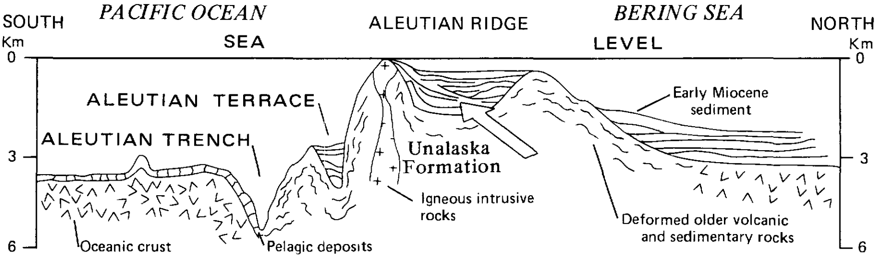


FIGURE 10.—Miocene cross section across Aleutian arc showing possible site of deposition and stratigraphic extent of the Unalaska Formation.

were deposited partly as submarine ash flows. Turbidite and debris flow deposition occurred on a slope, probably along the edge of a rapidly filling submarine basin (Crowell, 1957; Stanley, 1969).

SPECULATIONS ON THE REGIONAL SIGNIFICANCE OF THE UNALASKA FORMATION

Drewes, Fraser, Snyder, and Barnett (1961, p. 591) roughly divided the Unalaska Formation into three main parts that are lithologically distinct: "argillite south of Beaver Bay, graywacke and conglomerate in the northern bulge area and south of Makushin Bay, and coarse pyroclastic deposits in northeastern Unalaska Island, separated by wide transition zones." Interbedded coarse clastic rocks occur within the argillite zone, and fine-grained material occurs within the northern zone of sandstone and conglomerate beds. The regional dip suggests that the argillite is stratigraphically below the coarse-grained rock (Drewes and others, 1961). We speculate that the older part of the Unalaska Formation was deposited in relatively deep water. The complete absence of fossils in the argillite may be additional evidence of rapid and deep deposition (Drewes and others, 1961). The Dutch Harbor Member and other young parts of the Unalaska Formation contain fossils that are restricted to shallow water. These rocks and fossils suggest that the Unalaska Formation represents deposits in a rapidly filling basin that contained fine-grained distal turbidites near the bottom of the basin. As the basin filled, deposition became increasingly proximal. The Unalaska Formation may have been deposited in a summit or interarc basin (fig. 10) similar to present-day graben-controlled basins formed by rifting of the Aleutian ridge, (Scholl and others, 1975, fig. 2).

The basal argillaceous part of the Unalaska Formation contains most of the pillow structures on the island as well as numerous dikes and sills that appear to have been intruded into unconsolidated sediment (Drewes and others, 1961). Though the stratigraphically higher coarse sediments contain abundant volcanic flows and breccia, the dikes and sills seem to have been intruded later. This relation can possibly be accounted for by a rapidly changing vertical level of the volcanic source. Deep submarine fissures and vents may have supplied the volcanic material found in the argillaceous rocks. If the volcanic source was then building up faster than the basin was being filled, a steepening slope would provide a site of deposition for coarse-grained proximal turbidites and debris flows overlying older argillaceous deposits.

The Unalaska Formation appears to have been deposited in a basin adjacent to the submarine flanks of a middle Tertiary volcanic arc south of the study area. The proximal turbidite units and debris flows that make up the Dutch Harbor Member and other parts of the Unalaska Formation were probably deposited in an interarc basin perched on the summit of the Aleutian ridge.

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