Geographic Setting

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Amchitka Island lies at latitude 51.5°N and longitude 179°E. It is one of the Rat Island Group of the Aleutian Islands, Alaska, which comprise the emergent part of a long submarine ridge connecting North America and Asia and separating the Bering Sea from the North Pacific Ocean (Fig. 1). Amchitka is almost the southernmost Aleutian Island, only nearby Amatignak being farther south. It is thus almost the southernmost point in Alaska.

Amchitka is 2160 km (1340 statute miles) west-southwest of Anchorage, Alaska, and 4000 km (2500 miles) west-northwest of Seattle, Wash. It is almost half the way from North America to Asia, being 1400 km (870 miles) east of Petropavlovsk, Kamchatka, U.S.S.R., and 1230 km (765 miles) west of the tip of the Alaskan mainland at False Pass.

Amchitka and all the Aleutian Islands except a few of the esternmost ones are in the Aleutian Islands National Wildlife Refuge. All the investigations reported in this volume except for a few (e.g., sea otter and oceanographic studies) were carried out on Amchitka or in the nearby sea.

MAPS

The U. S. Army Map Service has prepared good topographic maps of the island in 1 : 25,000 scale as follows: Rat Islands sheets 2123 IV NW, 2023 I NE, 2023 I NW, 2024 II SW, 2024 III SE, 2024 III NE, 2024 III NW, 1924 II NE, in series Q801 [also designated, in the same order: Rat Islands (A-2) NW, (A-3) NE, (A-3) NW, (B-3) SW, (B-4) SE, (B-4) NE, (B-4) NW, and (B-5) NE]. These maps were prepared from aerial photographs taken in September 1948 and field surveys of 1949 and have a contour interval of 50 ft. As part of the Atomic Energy Commission (AEC) program on Amchitka, new aerial photographs were taken in 1968. From these photographs forty-one 1 : 6,000 scale maps covering the island with a contour interval of 10 ft were prepared. These maps are no longer available.

The region is shown in one generally available U. S. Geological Survey topographic quadrangle map, the 1 : 250,000 scale Rat Islands Sheet. This sheet is the result of a reconnaissance survey during the wartime years and is not satisfactory for more than the most general use. Another regional map generally available is the Sectional Aeronautical Chart of the Western Aleutian Islands issued by the National Oceanic and Atmospheric Administration National Ocean Survey in 1 : 500,000 scale.

The bathymetry of the surrounding seas is shown in the Environmental Science Services Administration (ESSA)/Coast and Geodetic Survey map sheet Kiska 1910N-1 of the 1 : 400,000 series "Bathymetry for the Aleutian Arc," reprinted from ESSA Monograph No. 3. This map sheet includes the whole of the Rat Islands from 175 to 180°E longitude. Inshore bathymetry is best shown in a set of four maps prepared by Doeringfeld, Amuedo, and Ivey of Denver, Colo. (now Amuedo and Ivey, Consulting Geologists). These maps are the East Cape, Makarius Bay, Chitka Cove, and Bird Cape sections, Amchitka. Copyright of these four maps remains with Amuedo and Ivey.

Two Coast and Geodetic Survey Navigational Charts cover Amchitka and vicinity. These are Chart No. 8864, Rat Islands (Semisopochnoi to Buldir Islands) at 1 : 300,000 scale; and Harbor Chart No. 9123, Constantine Harbor, Amchitka, at 1 : 10,000 scale.

Finally, the U. S. Geological Survey has prepared a new Amchitka Island Quadrangle at 1 : 100,000 scale for this volume. It has contour intervals on land of 100 ft and at sea of 25 ft to a depth of 300 ft and 100 ft below that. This map is based on the U. S. Army Map Service and the Amuedo and Ivey maps. A copy of this map is in the pocket at the back of this volume.

POPULATION

The region around Amchitka is sparsely populated. In the whole Aleutian Islands Census Division, which includes part of the Aleutian Peninsula, there were only 8057 people in 1970 (Bureau of the Census, 1971). All communities

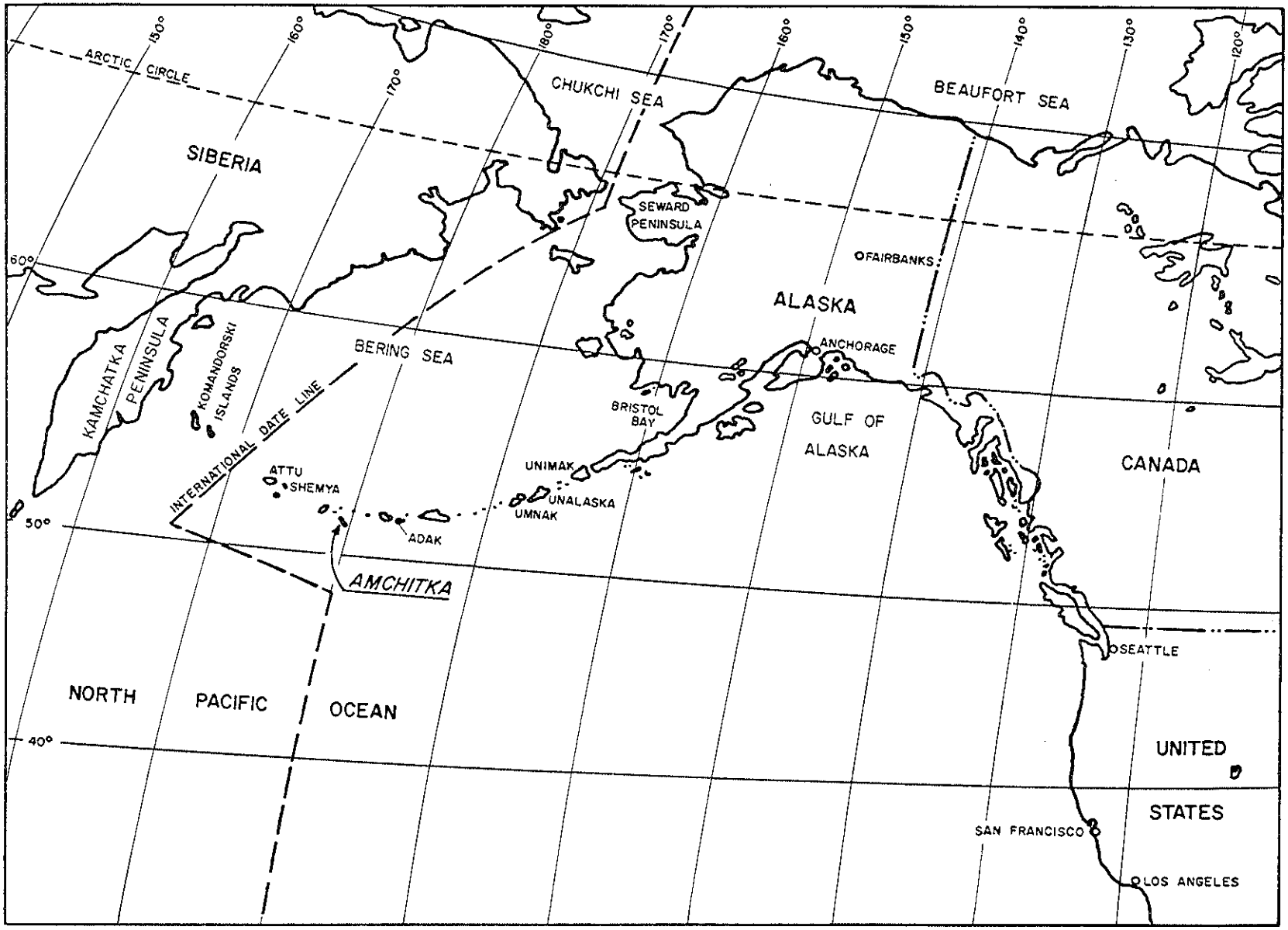

Fig. 1—Amchitka's position between Asia and North America.

listed by that census are shown in Fig. 2. The nearest populated places to Amchitka were then and still are the Adak Naval Station [300 km (190 miles) to the east] with a 1970 population of 2249 and the Shemya Air Force Base [370 km (230 miles) to the west] with a population of 1131. Not reported by the census is a small U. S. Coast Guard contingent on Attu just west of Shemya. The nearest nonmilitary point of habitation is the village of Atka [450 km (270 miles) east] with a population of 88, all Aleuts except the schoolteacher and his wife. Almost equally distant [about 800 km (500 miles)] to the east and west are the Aleut village of Nikolski on Umnak Island, population 57, and Mednyi (Copper) Island in the Russian Komandorskie Islands, which Hrdlička (1945, p. 397) reported had a population of about 150 in 1938. Amchitka itself has not had a permanent resident population since 1849 (Dall, 1877), although it has been intermittently occupied several times since then, most noticeably by the military in World War II and for a short while thereafter, during the Long Shot test, and from 1967 to 1973 by the AEC (Chap. 6, this volume).

The Aleutians lie nearly on a great circle from Anchorage, Seattle, or San Francisco, Calif., to Japan; so daily flights and frequent ship traffic pass by within a few hundred miles. In addition, the seas to both sides of the Aleutians are heavily fished at some seasons of the year (Chap. 15, this volume). Japanese or Russian trawlers can occasionally be seen from the island.

TOPOGRAPHY AND APPEARANCE

Amchitka lies entirely within the Alaska–Aleutian physiographic province (Wahrhaftig, 1965) and, biologically speaking, is an archetype of a maritime tundra regime.*

Amchitka is 65 km (40 miles) long and 2 to 7 km (1 to 4 miles) wide and has an area of about 30,000 ha (74,000 acres). As with other Aleutian Islands, Amchitka has a rugged coastline with sea cliffs and grassy slopes up to 30 m (100 ft) high nearly completely surrounding the island (Fig. 3). Sand beaches on the island are so few that their rarity occasions mention of the fact in some placenames. Only a few of the beaches, such as the one at the head of Constantine Harbor and the one at the northwest end of the island between Aleut Point and Bird Cape, give reasonably easy access inland. Much of the island is fringed by a wave-cut bench of rock as much as 100 m (330 ft) wide (Fig. 4). There is only one harbor on the island, Constantine Harbor on the Bering Sea side near the east end, and it is so exposed that, during storms from the northeast, ships must leave the dock. South Bight on the Pacific Ocean side and Chitka Cove on the Bering Sea side are sometimes used as shelters from storms (Coast Pilot, 1954).

The eastern third of the island is gently rolling country characterized by many shallow ponds with little or no drainage connections and streams half hidden by the seemingly ubiquitous cover of vegetation (Fig. 5). In the higher central portion of the island, this gives way to areas of more integrated drainage and greater wind erosion, with fewer lakes and with patches of bare bedrock rubble on ridges over 60 m (200 ft) high caused by diurnal freeze–thaw and high winds (Fig. 6). West of Chitka Point the island becomes quite mountainous, reaching a maximum elevation of 354 m (1160 ft) (Fig. 7). Here vegetation is quite sparse except in protected areas, such as stream valleys. Finally, the westernmost 5 km (3 miles) or so is a windswept rocky and barren plateau about 240 m (800 ft) high.

As a result of the military occupation in World War II and the more recent AEC occupation, there are numerous signs of the presence of man. About 2000 Pacific huts, which look like and are commonly called Quonset huts, remain from the military days. These are scattered seemingly at random in the area near Constantine Harbor, half buried by turf berms against the elements and many lying well away from the remaining dirt roads (Fig. 8, see also Chap. 6, Fig. 7, this volume). The military built a jeep trail that became known as Infantry Road along the crest of the island from South Bight on the east end to the beach near Bird Rock at the west end. The AEC improved this trail into an all-weather road easily driven by passenger sedan, although it must be plowed clear of snow at times during the winter.

The military built three airplane runways. The original one, Fox Runway at the head of Constantine Harbor, was trenched before they left and is unusable. Baker Runway, which is 10,000 ft long by 300 ft wide and which has numerous paved taxiways and hardstands, is the main runway. It has been resurfaced by the AEC. During the AEC program it was equipped with full Ground Controlled Approach (GCA) instrumentation for landing in poor weather; this has been removed, but the strip remains an excellent landing place if the weather permits a visual approach. The third

*A helicopter pilot on the program remarked how similar Amchitka looked to the Outer Hebrides of Scotland where he had spent his boyhood.

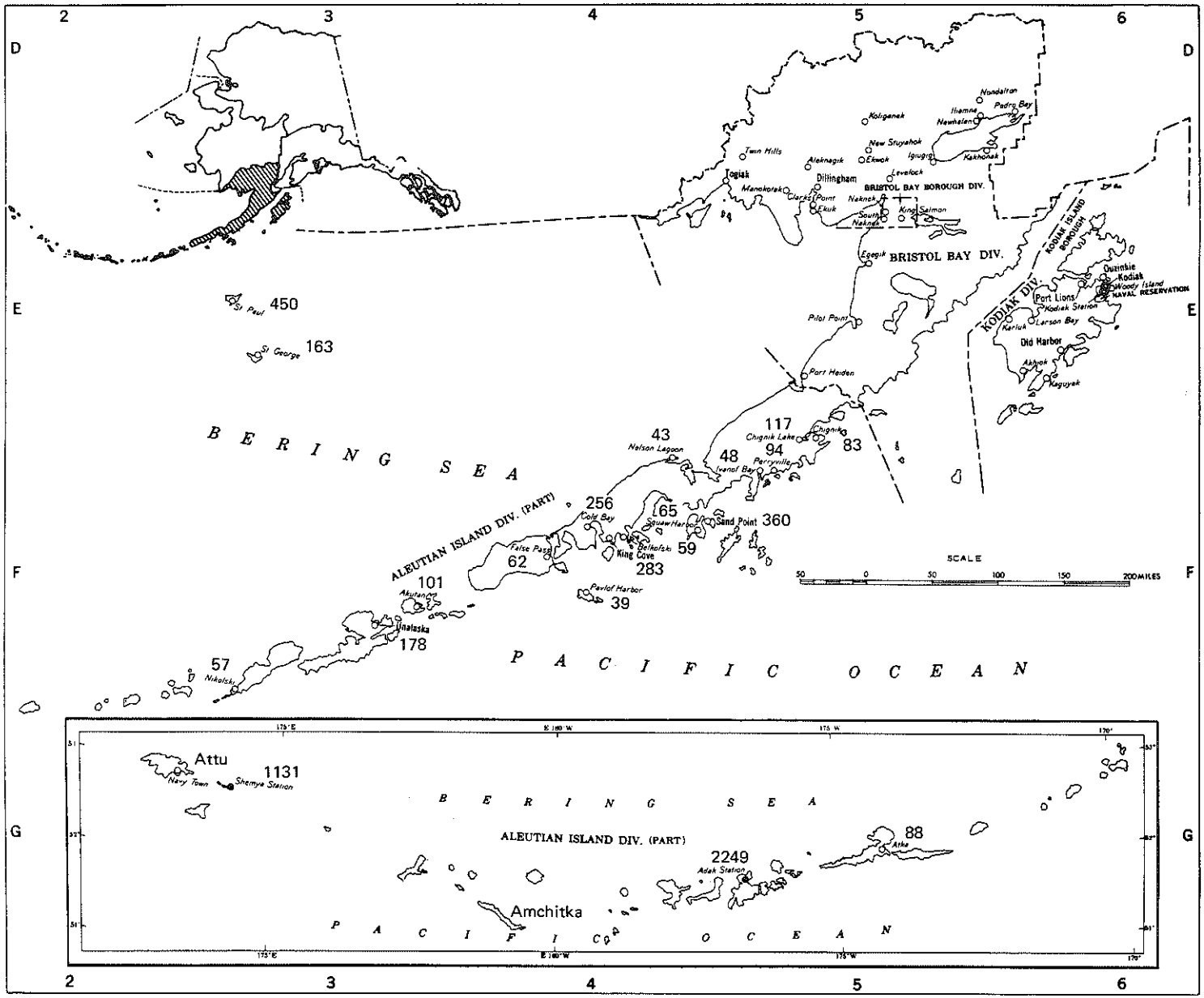

Fig. 2—Location and population of places in the Aleutian Islands Census Division with populations over 25.

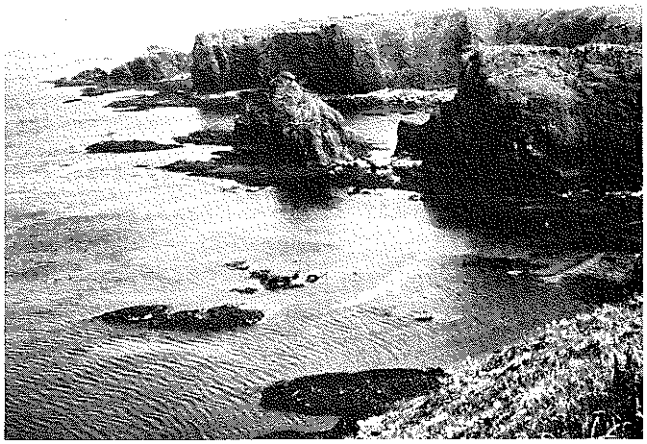

Fig. 3—Coastline near Square Bay.

Fig. 4—Intertidal bench in Square Bay.

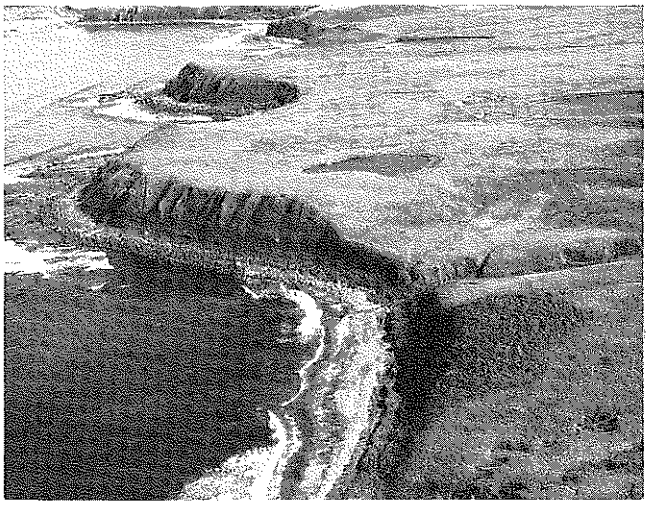

Fig. 5—Coastline between Banjo and Crown Reefer Points.

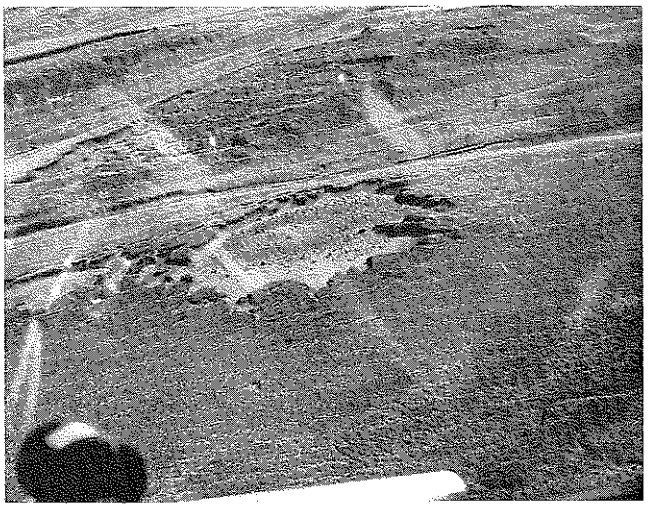

Fig. 6—Patches of rubble on ridges inland west of Sea Otter Point.

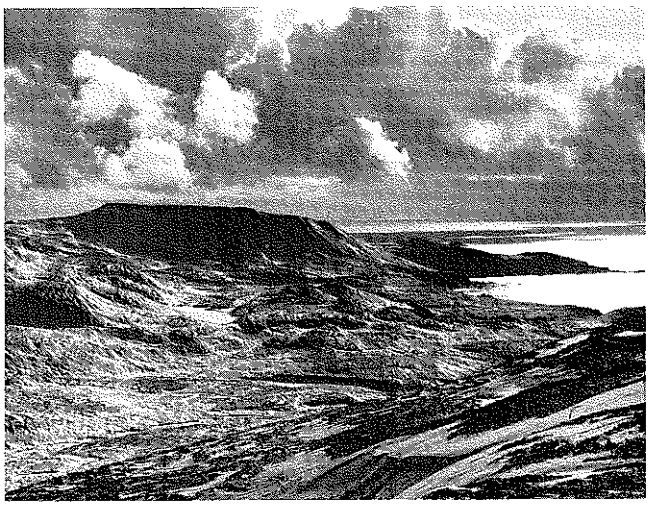

Fig. 7—Mountains near Topside Creek looking east.

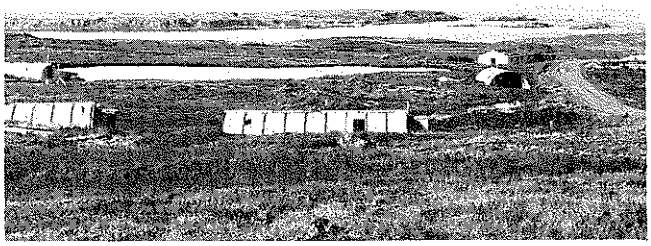

Fig. 8—Huts left from the military occupation south of Constantine Harbor.

runway, Charlie Runway, has not been maintained and was used only once during AEC occupation.

The port facilities in Constantine Harbor were originally of wood but have been completely rebuilt of steel piling and timber decking. They should remain in good condition for a long time (Fig. 9).

During the AEC occupation a main camp to house 750 people was built on a hardstand off the southwest end of Baker Runway (Fig. 10). At the end of 1975, only three barracks and the kitchen–mess hall building remained of this. For a short time there was a small camp at Topside, halfway through the mountains, and for a number of years there was a 200-man camp at the northwest end of the island; both of these have been closed down, and all buildings have been removed.

Fig. 9—Port facilities in Constantine Harbor.

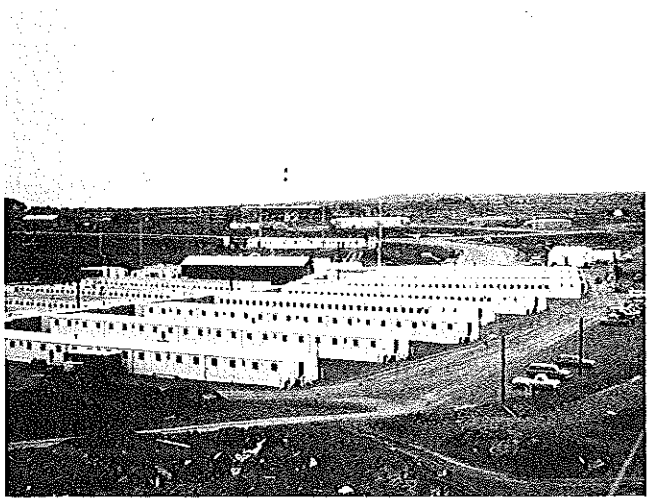

Fig. 10—Main AEC camp.

STUDY AREAS

The three underground nuclear explosions at Amchitka were Long Shot in 1965, Milrow in 1969, and Cannikin in 1971. Long Shot was sponsored by the military; its minimal biological program did not have a well-defined study area. Milrow and Cannikin were at the so-called B and C sites as shown in Fig. 11. Milrow was on the Pacific Ocean side of the island divide and Cannikin on the Bering Sea side. Both are in the eastern third of the island; Cannikin, at an elevation of 63 m (208 ft), was at the eastern edge of the region where bare rubble patches begin to appear.

The areas of most intensive study on Milrow and Cannikin were those within 5 km (3 miles) from the sites. The island is so long that more distant areas could be and were used as control areas not expected to be affected by the tests. Access to these areas was good where the roads existed. Access to offroad points was by foot, boat, helicopter, or Snow-Trac, a light-weight tracked vehicle.

TIME ZONES

Amchitka is nearly at the 180th meridian of longitude but keeps Bering Standard and Bering Daylight Times (165°W and 150°W meridian times). These times are related to Universal Time [Greenwich Mean Time (GMT)] as follows: BST = GMT – 11 hr; BDT = GMT – 10 hr; and local sun time = GMT – 12 hr 4 min, approximately.

PLACE-NAMES

Amchitka has been known by western man since the 1750s, but few of the early names survive. Bergsland (1959) has reported some of the native Aleut place-names for features on Amchitka as they were known in 1950 (Table 1). Certain of these appear to be of Russian or modern origin; for instance, the Russian word for harbor, gavan' (гавань), is used; and the name numbered 1023 in Table 1, which I have been unable to correlate with any known feature, appears to be anecdotal. The word Amchitka itself, however, is a genuine native name reported from early in Russian times (Orth, 1967).

Place-names used by project people were to a large extent new names, invented ad hoc for the many features that had to be kept track of and for which no previous names appeared to exist. Names given on the U. S. Army Map Service maps were used, but, in the process, few other names used earlier by the military or by the refuge manage-

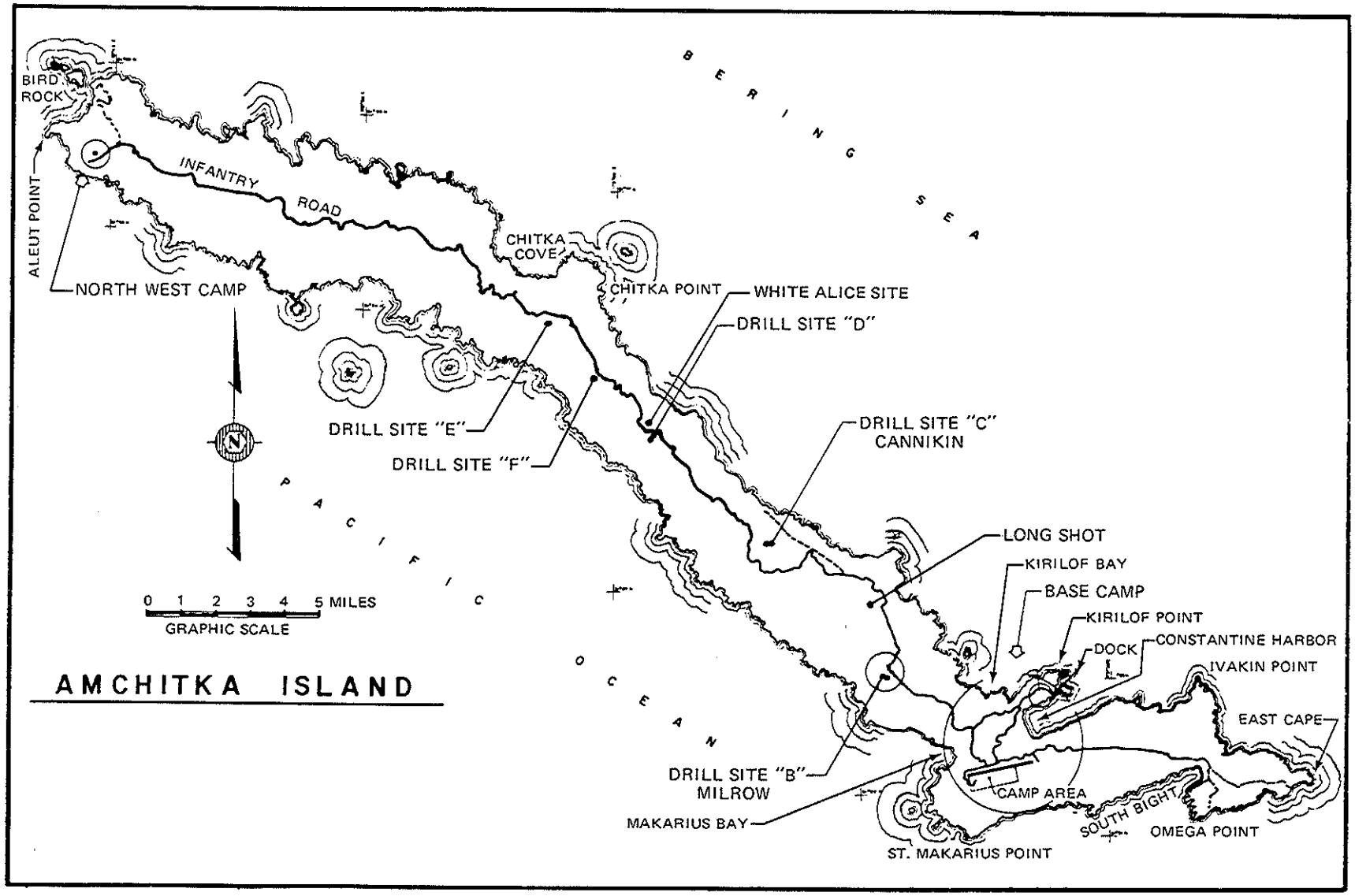

Fig. 11—Locations of major exploratory holes.

Table 1—Aleut Place-Names on Amchitka*

Aleut name	Description or translation	Modern name	Bergsland's listing number
amciglar	Amchitka	Amchitka Island	1008
amcigla-qakaŋa·	The east side of Amchitka		1009
amciglam qakaŋan tanriŋis	The islets at the east side of Amchitka	Sea Otter Rocks	1010
tumgas uda·	Ivory bay	South Bight	1011
sadali-magis		Sea lion rocks off Ivakin Point	1012
agu·lur	A stay	Whale Cove	1013
amciglam ga·vana·	Amchitka harbor	Constantine Harbor	1014
ga·vana-ya·ra	The point at the harbor	Kirilof Point	1015
kiji·lam uda·	Kirilof bay	Kirilof Bay	1016
tanasulrur	The big inshore island	Bat Island	1017
ga·vana-sitaca	The other side of the harbor	Makarius Bay	1018
tanasur	The inshore island	Rocks off St. Makarius Point	1019
tijinti-ya·ra	Terenty's Point	Rifle Range Point	1020
tanam ala	The middle of the island	Duck Cove (?)	1021
yam aduŋis	The long reefs	Not identified	1022
si·duj hasa·	Cedor's skerry		
afana·sim hasa·	Afanasy's skerry	Not identified	1023
ju·f hasa·	Rolf's skerry		
hanilgur	A village and a stay	Site 49-RAT-66 in Cyril Cove	1024
isuris ya·ra	Hear seals point	Crown Reefer Point	1025
anaʍgir			1026
ciranarsga·	There is a creek	Falls Creek	1027
cirsaglar	Partly shallow	Limpet Creek	1028
wala·g	A group of sea lion rocks	Column Rocks	1029
cimig	The two tracks	Column Ridge	1030
alag halar	Has wind from two directions	Chitka Cove	1031
alag hala-tanasu·	The inshore island at alag hatar		1032
unanas talu·	Cookers' lagoon	Chapel Cove	1033
amciglam na·rir ayla·	The western end of Amchitka		1034
ta·ŋular	Thirsty	Aleut Point	1035
sa·lanas	Bird's place or lying towards the front	Bird Rocks	1036

*Data taken from K. Bergsland, Aleut Dialects of Atka and Attu, *Trans. Amer. Phil. Soc.*, 49(3): 40-41 (1959). Phonological symbols used are explained by Bergsland on p. 8 of the journal, whence this table of "segmental phonemes":

Vowels		a			i		u		
long		a·			i·		u·		
Glides		—			y		w		
aspirated		h			Y		F		
Nasals		ŋ			n		m		
aspirated		ŋ̊			N		M		
Liquids				j	l				
aspirated					L				
Spirants	r	g	z		d	v		b	
aspirated	R	G	s			f			
Stops and affricates	q	k	c	T	t			p	

ment survived. Table 2 lists those place-names for features other than lakes or streams commonly used during the program and hence elsewhere in this volume. The Geological Survey map in the pocket at the back of this volume shows the location of most of these. Table 2 also indicates which of these place-names predate the AEC occupation and which ones have been submitted to and have received acceptance by the U. S. Board on Geographic Names and hence are fully acceptable and official. Not all names used were submitted, and not all that were submitted were accepted. Nevertheless, these unofficial names served an essential purpose.

Table 3 gives place-names of lakes and streams. Almost all of these are unofficial names. The two biological projects most concerned with lakes and streams, the project on limnology of the Battelle Columbus Laboratories and the project on freshwater ecology of the Utah State University (reported in Chaps. 13 and 14, respectively, this volume), each created an accounting system to designate lakes and streams. Their designations are cross-referenced in Table 3.

Table 2—Place-Names on Amchitka Other Than Lakes and Streams

Name	Status	First use*		Bergsland's listing	Comment
Aleut Point	†	1935	USN	1035	
Amchitka	†	<1741	Aleut	1008	
Andesite Point	‡				
Baker Runway	†	1955	AMS		
Banjo Point	‡	1960	USGS		
Bat Island	‡			1017	Fault Block Island
Bird Cape	†	1836	IRN		Мыс Птичий
Bird Rock	†	1935	USN	1036	
Buoy Point	‡				
Burr House Cove	†	1957	AMS		
Chapel Cove	†	1957	AMS	1033	
Chapel Cove Island			RM		
Charlie Runway	†	1955	AMS		
Chitka Cove	†	1951	USGS	1031	From "Amchitka"
Chitka Point	†	1935	USN		
Chitka Ridge	‡				
Clevenger Lake	†	1955	AMS		
Clevenger Road	†	1957	AMS		
Column Ridge	‡			1030	
Column Rocks	‡			1029	Trident Rocks
Constantine Harbor	†	1849	IRN	1014	Гавань Константина
Constantine Point	†	1944	ACP		
C P Bluff	‡				
Crown Reefer Point	‡			1025	
Cyril Cove	†,‡	1944	ACP		Variant: Kirilof Cove
Duck Cove				1021 (?)	
East Cape	†	1855	USN		
Engineer Road	†	1955	AMS		
Fault Block Island			RM		Bat Island
Fox Cove			RM		Signal Cove
Fox Runway	†	1955	AMS		
Fumarole Cove	‡				
Galion Pit					At coordinates 536975
Grampus Point	‡				
Infantry Road	†	1957	AMS		
Ivakin Point	†	1852	IRN		Мыс Ивакин
Jones Lake	†	1955	AMS		
Kirilof Bay	†	1836	IRN	1016	
Kirilof Islets					Islands at harbor mouth
Kirilof Point	†	1935	USN	1015	
Landslide Cove	‡				
Loran Island			RM		St. Makarius Islands
Low Bluff	†	1855	USN		
Makarius Bay	†	1951	USGS	1018	St. Makarius Bay
Mex Island	‡				
Midden Cove	‡				
Midden Point	‡				
North Bight	‡				
Omega Point	†	1955	AMS		
Peregrine Point	‡				
Petrel Point	‡				
Pillow Point	‡				
Pluton Cove	‡				
Rifle Range Point	‡			1020	
Rifle Range Road					Clevenger Road

(Table continues on page 10.)

Table 2—(Continued)

Name	Status	First use*		Bergsland's listing	Comment
Rim Point	‡				
St. Makarius Bay					Makarius Bay
St. Makarius Islands				1019	Loran Island, off St. Makarius Point
St. Makarius Point	†	1935	USN		
Sand Beach Cove	‡				
Sandy Cove	‡				
Sea Otter Point	‡				
Sea Otter Rock	†	1955	AMS	1010	
Signal Cove	‡				Fox Cove
South Bight	†	1946	ACP	1011	
Square Bay	‡				Variant: Cyril Cove
Square Bluff	†	1855	USN		
Stone Beach Cove	‡				
Topside Camp	†	1957	AMS		
Trident Rocks			RM		Column Rocks
Vista Island			RM		
WE Site			RM		
Whale Cove	‡			1013	
White House Cove	†	1957	AMS		
Windy Island	‡	1960	USGS		

*USN, place-names given by a navy expedition; AMS, place-names that first appear on an Army Map Service map; IRN, place-names given by the Imperial Russian Navy; RM, place-names appearing first in Refuge Manager's reports; and ACP, place-names appearing first in the Alaskan Coast Pilot. (Data taken from D. J. Orth, *Dictionary of Alaska Place Names*, U. S. Geological Survey, Professional Paper 567, 1967.)

†Place-names that appear on Army Map Service maps.

‡Place-names newly accepted by the Board on Geographic Names.

Table 3—Amchitka Place-Names of Lakes and Streams

	USU*	BCL†	Coordinates‡	
Big Lake	AG		667961	
Bridge Creek	AA	§	518018	
Burr House Creek			206218	
Cannikin Lake			467040	
Chapel Cove Creek			281200	
Clam Lake	BI	22	522985	
Clear Pond		36	494034	
Clevenger Creek	AF		512968	
Clevenger Lake	AC	¶	555946	
Clevenger Lake Outlet	AB		552947	
Clover Lake			629942	
Deep Lake			417069	
Duck Cove Creek			504979	
Duck Pond		10	515962	
Emerald Lake	AU	51§	430066	
Falls Creek		§	400073	
Fault Lake	AN	58a	392111	
Fumarole Creek			316137	
Fox Runway Creek			586957	
GE Lake			625972	
Grauman Lake				Quonset Lake
Heart Lake	AK		516981	
Island Pond				Pumphouse Lake
Jones Lake	DA	5¶	576965	
Limpet Creek		§	367099	

Table 3—(Continued)

	USU*	BCL†	Coordinates‡	
Little Lake			527987	
Long Lake		§	565932	
Long Shot Lake		29	512002	
Long Shot Pond		30	514006	
Lower Twin Lake	BU	24	518984	
Mason Lake			561955	
Midden Creek			234208	
Mud Pond		35	493034	
Pratfall Lake	AP		529979	
Pumphouse Lake	AJ	1	585932	Island Pond
Quonset Lake	AQ	28§	519999	
Range Pond		7	515965	
Rifle Pond		9	516963	
Rifle Range Creek				Clevenger Creek
Rifle Range Ponds		7-12		Range, Rifle, and nearby ponds
Roller Coaster Creek	AD		636972	
Round Lake	DD	31b	521016	
Sewer Pond				Long Lake
Signal Cove Creek (N&S)			224165, 222168	Two streams
Silver Salmon Creek (outlet)			546993	
Silver Salmon Lake	AL	19b§	541990	Pistol Lake (military name)
Sixty Four Lake			641963	
Strange Pond		33	493030	
Teal Creek		§	427037	
Tent Lake		15	522976	
Tern Lake			515026	
Tin Lake			571972	
Topside Creek			273159	
Twin Lakes				Upper and Lower Twin Lakes
Ultra Creek		§	465001	
Upper Twin Lake	BL	23	518986	
Weed Lake	BT	26	527994	
White Alice Creek		§	477050	
White House Cove Creek			303148	
Wild Lake				Quonset Lake

*Notation for this lake or stream used by freshwater ecologists from Utah State University.

†Notation for this lake used by limnologists from Battelle Columbus Laboratories.

‡Coordinates are based on the 1000 meter Universal Transverse Mercator Grid, zone 60. First three digits are the east coordinate and the second three the north coordinate to the nearest 100 meters. Thus 303148 means E630300, N 5714800.

§Name newly accepted by the Board on Geographic Names.

¶Name appearing on Army Map Service maps

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2

Geologic History

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Amchitka Island is one of the most southerly islands in the Aleutian Island arc. In general terms its geologic history is probably representative of most of the Aleutian Islands. Three distinct volcanic episodes have been recognized and dated by fossil evidence and by radiometric dating. The oldest of these is early Tertiary, probably Eocene, and is represented by altered basic to intermediate submarine lavas and volcanic debris. Next, coarse turbidites and other sediments of basaltic debris shed from nearby volcanoes were deposited on the sea floor during late Eocene or early Oligocene time. After a period of uplift, tilting, faulting, erosion, and invasion by small dioritic plutons in mid-Tertiary time, a subaerial volcanic complex of andesitic composition was constructed during the Miocene. At that time the island probably stood higher above sea level than at present and trees were common. This volcanic complex is probably genetically related to one of the Miocene plutons. During Pliocene time minor shallow basaltic and hornblende andesitic intrusions occurred. In early Pleistocene time the island was still above sea level, the climate was somewhat warmer than now, and trees were present. During glacial and interglacial episodes, sea level fluctuated. During glacial periods terraces were carved as much as 91 m below sea level, and deposits of two episodes of glaciation are preserved. During interglacial times flights of marine terraces were cut above present sea level, and marine deposits on the island are correlated with two of them. Tensional faulting continued into Wisconsinan time; however, the island appears to have been tectonically stable during the past 2000 to 4000 years.

Multidisciplinary studies by the U. S. Geological Survey (USGS) conducted on and near Amchitka Island from 1964 to 1972 have contributed to a better understanding of the geologic, hydrologic, and tectonic environment of the island. These investigations are the only comprehensive earth-science studies made in the Aleutians and constitute the first intensive geologic study of the area since reconnaissance mapping by the USGS during the 1940s and 1950s (e.g., Powers, Coats, and Nelson, 1960). A geologic map of Amchitka Island is being compiled at a scale of 1 : 48,000.

This chapter summarizes the geologic history of Amchitka Island as determined from these studies and provides a brief description of the Aleutian Island arc.

GEOLOGIC SETTING

The Aleutian Arc

Amchitka Island lies in the western part of the Aleutian Island arc—one of the most striking physiographic features on the face of the earth. The arc consists of a curving submarine trench as deep as 7600 m, which extends 3200 km from the Gulf of Alaska across the north Pacific to Kamchatka, and a parallel ridge rising to the north, 3660 m above the Pacific Ocean floor. The eastern third of the ridge consists of the mountainous Alaska Peninsula. The western two-thirds of the ridge is an almost completely submerged mountain range; the Aleutian Islands are the exposed peaks of this range. The Aleutian arc is one of many island arc systems that border the Pacific Ocean basin.

Formation of the Aleutian trench began during the Tertiary Period. The central and western parts of the trench are believed to have developed in the earlier half of the Tertiary (Hamilton, 1967), while the eastern end may not have been formed until Pliocene time (von Huene and Shor, 1969).

Unpublished marine geophysical data supplied by the Lamont–Doherty Geological Observatory suggest that the arcuate Bowers Ridge lying north of Amchitka Island may be part of an older inactive structural arc. Accordingly, Amchitka lies near the intersection of the Aleutian Ridge and the Bowers Ridge arcs (Anderson, 1971) (Fig. 1).

The Aleutian Ridge can be divided into a series of physiographically similar blocks (Fig. 1) separated by transverse canyons of probable structural origin (Anderson, 1971). Each block has a similar cross section: north and south slopes with a wide flattened crest topped by peaks, some of which rise above the ocean surface as islands. The south slope in many, but not all, places flattens to a broad terrace that commonly has closed depressions on it. Each of these physiographic blocks appears to be a seismic entity in that aftershocks of any major earthquake that may occur in a specific block are generally confined to that block and may continue for as much as a year after the quake (Jordan, Lander, and Black, 1965; Engdahl, 1971).

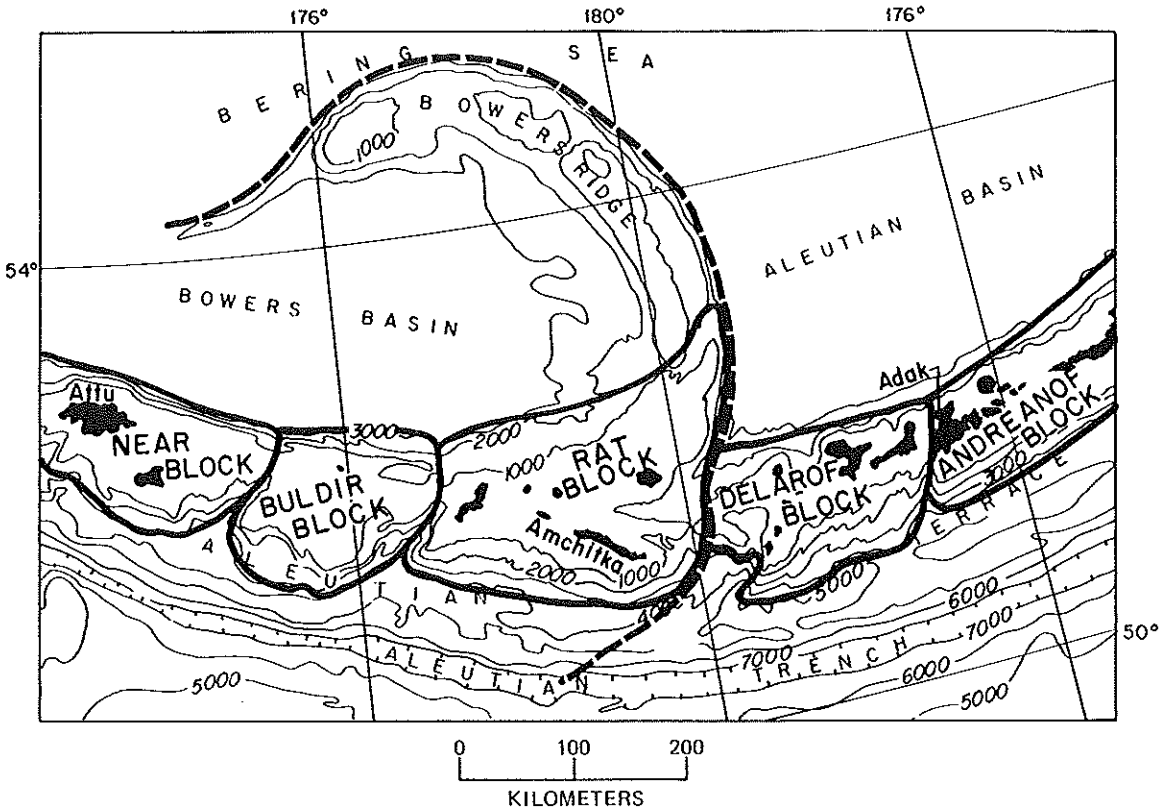

Fig. 1—Index map of central Aleutian arc showing major physiographic blocks and trace of east margin of uplift for the Bowers arc (heavy dashed line). Bathymetric contour interval, 100 m [From R. E. Anderson, USAEC Report USGS-474-75 (Rev. 1), U. S. Geological Survey, 1971.]

Amchitka lies on the Rat block, which is separated on the west from the Buldir block by the transverse Murray Canyon just west of Kiska Island and on the east from the Delarof block by a complex of submarine canyons in Amchitka Pass (Anderson, 1971, Plates 1A and 1B).

One of the most prominent features of the arc is the alignment of active and quiescent volcanoes along the northern edge of the ridge crest. Thirty-six of the seventy-six volcanoes have been active since 1760 (Coats, 1950); Kiska volcano extruded a small lava flow at sea level on its northern flank in 1965 or 1966.

The Aleutian arc lies along a zone of convergence between the Pacific Ocean floor and the Bering Sea floor. The leading edge of the Pacific plate is forced downward beneath the Bering Sea plate at the Aleutian trench, from which a well-defined zone of seismic activity at the plate juncture dips northward beneath the ridge. Engdahl (1971, Fig. 2) showed that hypocenters of earthquakes of magnitude 3.0 or greater near Amchitka Island, which were recorded during a 3-year period from 1969 through 1971, delineate a well-defined zone that plunges northward beneath the ridge from a depth of about 20 to 30 km beneath the Aleutian slope to a depth of about 250 km beneath the northern edge of the ridge—a horizontal distance of about 170 km.

During the 386-day period from Jan. 11, 1971, to Jan. 30, 1972, earthquakes having epicenters within a 60-km radius of the Cannikin underground nuclear explosion were plotted by Willis et al. (1972). During that period, 1559 events with body-wave magnitudes that ranged from 0.0 to 4.5+ were detected in this area. Of these, 1265 were shallow events (0 to 70 km deep) and 294 were intermediate events (>70 km deep). The readily apparent clustering of shallow events in the southern half and of intermediate events in the northern half of the circle supports the concept of a northward-dipping subduction zone. A similar pattern of seismic activity before and after the Cannikin event "suggests that the detonation of Cannikin did not alter the nature of the underthrusting process beneath Amchitka Island" (Willis et al., 1972, p. 55).

Despite the abundant evidence that the arc is located along a zone of convergence, most of the tectonic features visible on the islands or inferred from sea-bottom topography are of probable tensional origin. Abundant dikes, normal faults, grabens, and other submarine depressions, as well as the narrow zone of active volcanism, all suggest

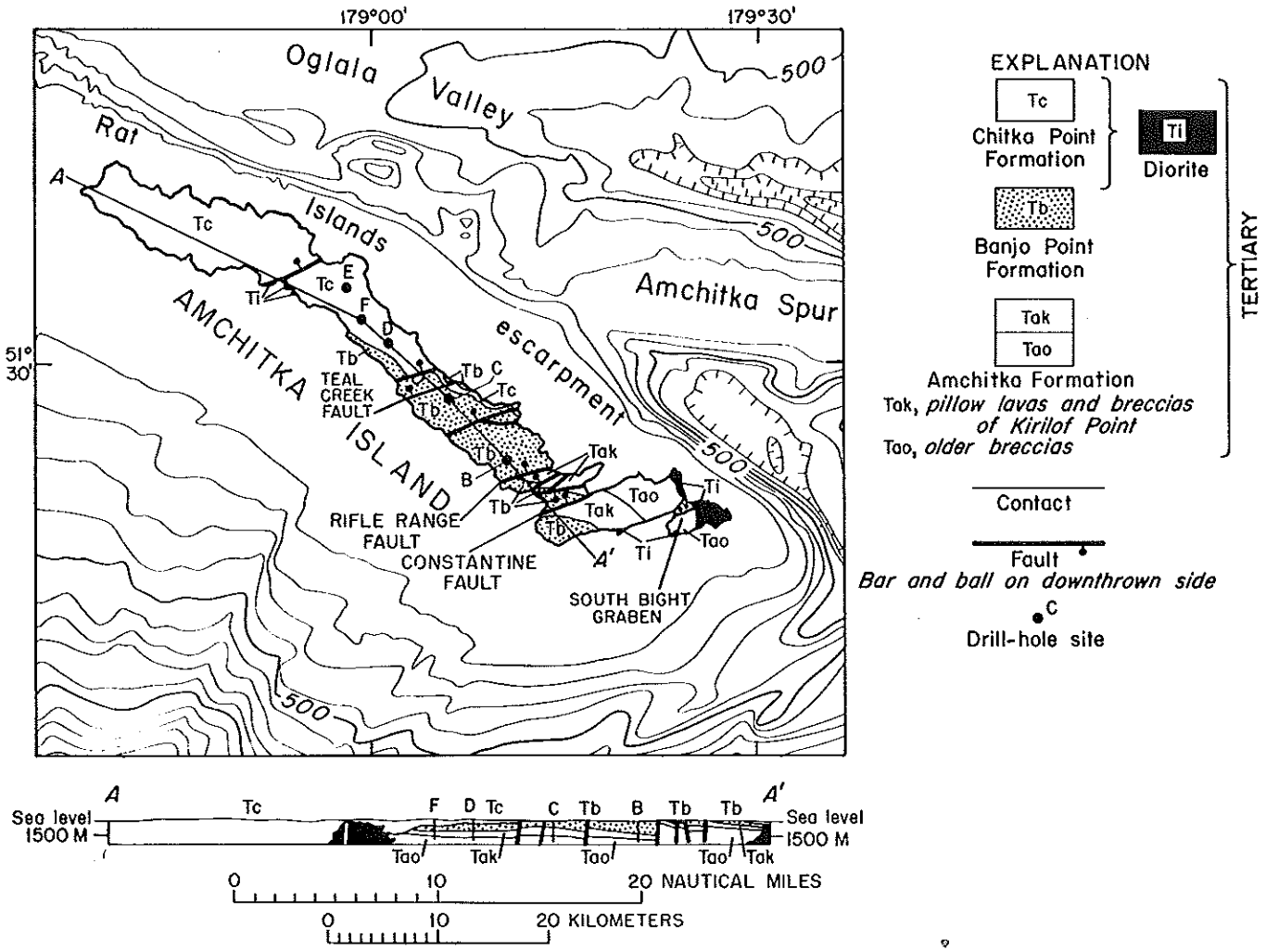

Fig. 2—Geologic sketch map and cross section of Amchitka Island.

tensional stress. According to Anderson (1971, p. 1), these tensional features must reflect "... igneous-related tectonism including distension of the surficial skin over rising and spreading epizonal plutons, volcano-tectonic subsidence, and rifting . . . ." Most of the faults crossing Amchitka trend east-northeast and probably first moved in late Oligocene or Miocene time before eruption of the Miocene Chitka Point lavas. Movement has continued on some faults into late Pleistocene time; however, there has been no significant fault movement on Amchitka in Holocene time.

Geologic mapping in the Aleutians indicates that the oldest rocks lie on the southern part of the ridge and the youngest occur in a narrow zone of active volcanoes along the northern edge. Melting and mixing of hyperfusible materials along the subduction zone beneath the arc provided the volcanic material that forms the ridge (Coats, 1962; Anderson, 1971). The north-to-south progression from younger to older rocks along the ridge suggests that the ridge may be migrating slowly southward from a relatively fixed source of volcanism and is being rolled under itself along the zone of subduction (Anderson, 1971, p. 17). Recent geologic mapping on Amchitka (Fig. 2) has supplemented and modified the original study by Powers, Coats, and Nelson (1960). The new work included geologic mapping, isotopic dating, deep drilling, geophysical surveys, and hydrologic investigations.

This current work (Carr, Quinlivan, and Gard, 1970; Carr et al., 1971) has defined and dated rocks of three general episodes of volcanism: the Amchitka Formation, consisting of breccias of principally intermediate composition, monolithologic glassy breccias and pillow lavas, and local tuffaceous beds mostly of submarine origin, which is overlain by the Banjo Point Formation, consisting of breccias and minor pillow lavas that are mostly of basaltic composition, which, in turn, is overlain nonconformably by the Chitka Point Formation, consisting of subaerial lava flows, flow breccias, pyroclastic rocks, and minor tuffaceous

sediments and conglomerates, all of andesitic composition.

Faulting began in mid-Tertiary time and continued intermittently along certain faults into late Pleistocene time. Most faults exposed or interpreted on Amchitka strike generally northeastward, dip steeply northwest, and tend to repeat the stratigraphic section. Although they are normal faults, slickenside directions indicate that there has been some component of horizontal movement along many of the faults.

Physiography of Amchitka Island

Amchitka Island, in the west central part of the Aleutian arc, lies just west of the 180° meridian and just north of 51°N latitude. With the exception of Amatignak Island, about 100 km to the east, it is the most southerly of the Aleutian Islands.

Amchitka is about 65 km long and 5 to 8 km wide. It is roughly boot shaped and probably owes its shape, in part, to faulting. Except for the southeastern foot, it trends northwest, paralleling the trend of the Aleutian Ridge in the Rat block. The island is paralleled on the north by the steep slope of the Rat Islands escarpment and on the south by the Aleutian Slope, which descends to the trench. The Rat Islands escarpment descends steeply from a submerged Pleistocene terrace at −91 to −100 m to a maximum depth of −1500 m about 5 km northeast of the island. The escarpment bounds the south side of an area of graben-like closed basins on the sea bottom north of Amchitka.

The southeastern foot end of the island parallels and is delineated by east-northeast-trending normal faults that form grabens at Constantine Harbor and at South Bight.

The island can be divided into various landforms: a mountain segment, a high plateau, the Chitka Point segment, lower plateaus, and an intertidal bench (Powers, Coats, and Nelson, 1960).

The mountain segment, an erosional remnant of the Chitka Point volcano, lies between Chitka Point and Windy Island. It is composed of a sinuous ridge that rises as high as 366 m above sea level and roughly parallels the island axis. Extending north and south from this ridge are several steep U-shaped valleys separated by prominent ridges. Some of these ridges represent reversal of topography; they are formed of valley-filling lava flows that resisted erosion better than the underlying pyroclastic rocks of the Chitka Point Formation. To the southeast an outlier of the mountain segment, 300 m high, is separated from the main part by a low saddle, Fumarole Valley, little more than 100 m above sea level. Intense hydrothermal activity in this area altered the rocks, allowing them to be easily eroded. Solifluction is exceptionally active there today.

Northwest of the mountain segment, a high partly dissected plateau, ranging in altitude from 214 to 275 m, extends to Square Bluff. Except for this bluff, which is underlain by andesitic lava flows, the surface of the plateau is composed of deeply weathered hydrothermally altered pyroclastic rocks. Scattered well-rounded cobbles on Square Bluff (Powers, Coats, and Nelson, 1960, p. 525) are probably either remnants of conglomerate of the Chitka Point Formation or, more likely, remnants of outwash from glaciers covering the plateau. Andesite erratics as large as 1.5 m in diameter scattered on the plateau surface indicate that ice moved northwestward from the mountain segment.

There is no reason to believe that the high plateau was formed by marine planation. Except for the rounded cobbles on Square Bluff, evidence is lacking which would suggest that relative sea level during either the Pliocene or the Pleistocene Epochs was ever 214 to 275 m higher than at present. Indeed, a subaerial basalt flow at Cyril Cove, presumed to be of Pliocene age, suggests that relative Pliocene sea level was at or below present sea level. Altiplanation offers a simpler explanation for the origin of the surface in attributing it to solifluction and related mass movement, which tend to produce flat surfaces at high elevations and latitudes.

A smoothly rounded surface south of Chitka Point lies at the same altitude, 152 to 214 m, as Chitka Point Bluff and a small flattish area north of Windy Island (Fig. 3). The origin of this surface is probably also altiplanation. Weakly cemented iron-stained unfossiliferous gravel and sand, which crop out on the surface south of Chitka Point, I believe to be part of the Chitka Point Formation rather than a littoral-zone deposit as suggested by Powers, Coats, and Nelson (1960, p. 541). The mountain segment stands above the high plateau and Chitka Point segments because, in the mountain segment, the Chitka Point Formation is composed mainly of lava flows containing only subordinate pyroclastic rocks, whereas the areas that have been beveled by altiplanation are mainly pyroclastic rocks with subordinate lava flows.

The lower plateaus, especially prominent on the eastern half of the island (Figs. 3 and 4), are a flight of Pleistocene interglacial terraces discussed later in this chapter. Several landslides interrupt these interglacial marine terraces along the Bering coast. The largest of these lies just east of Chitka

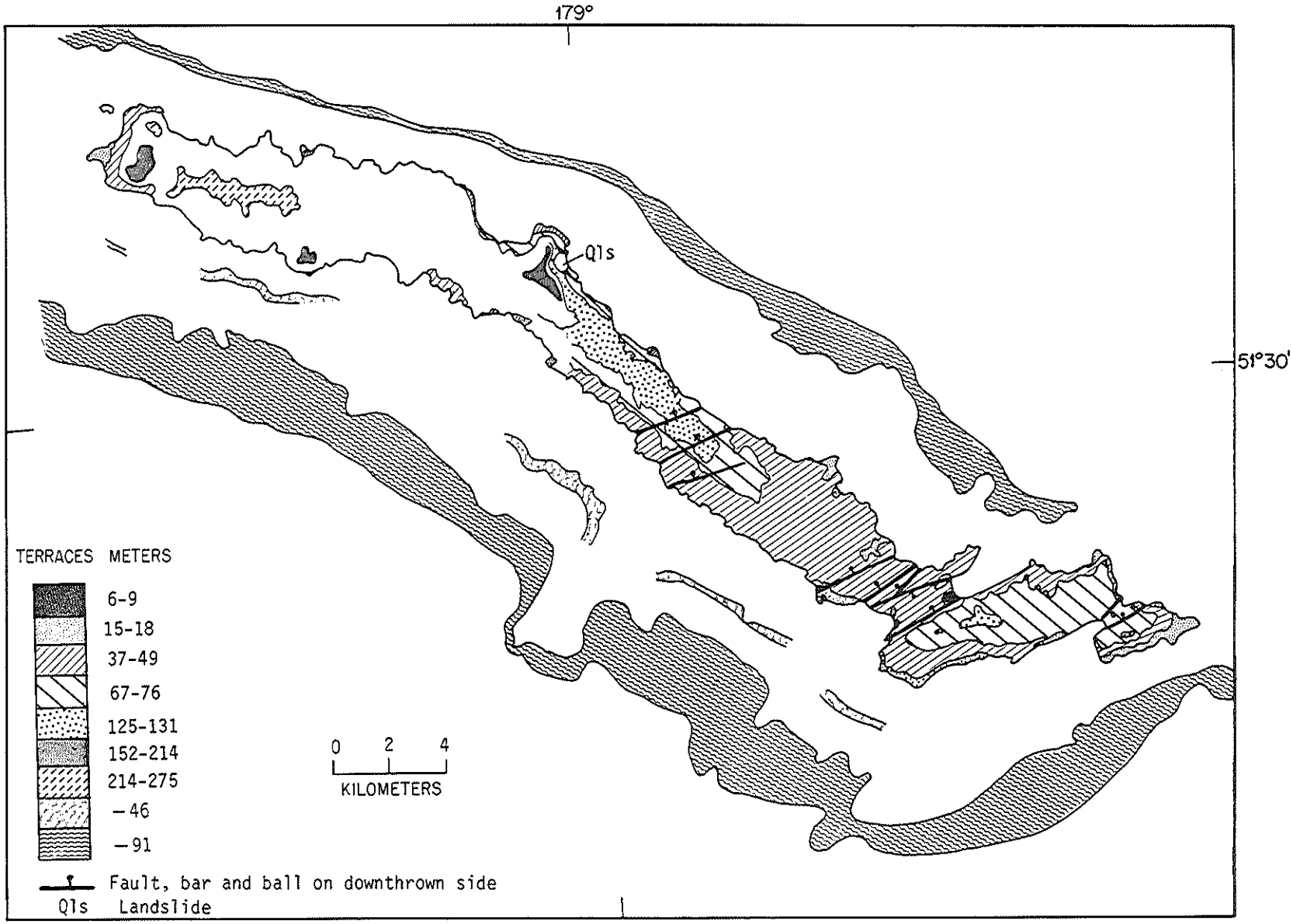

Fig. 3—Map showing surfaces of planation, Amchitka Island. Altitudes determined at bases of abandoned sea cliffs except for surfaces between 152 and 214 m. Altitudes from Holmes and Narver, Inc., topographic map, 1 : 6000.

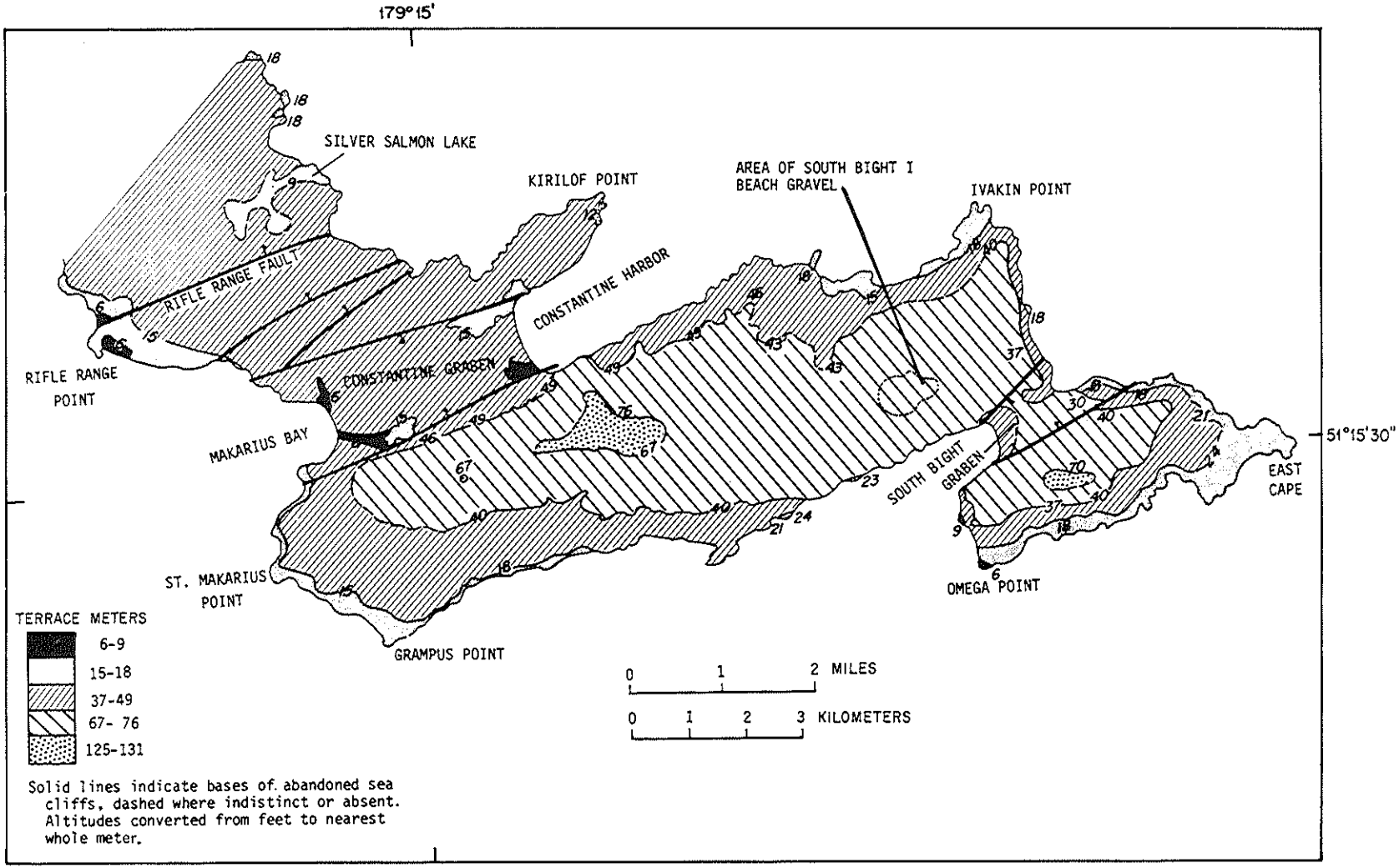

Fig. 4—Map showing distribution of marine terraces, eastern end of Amchitka Island. Altitudes from Holmes and Narver, Inc., topographic map, 1 : 6000, contour interval, 10 ft.

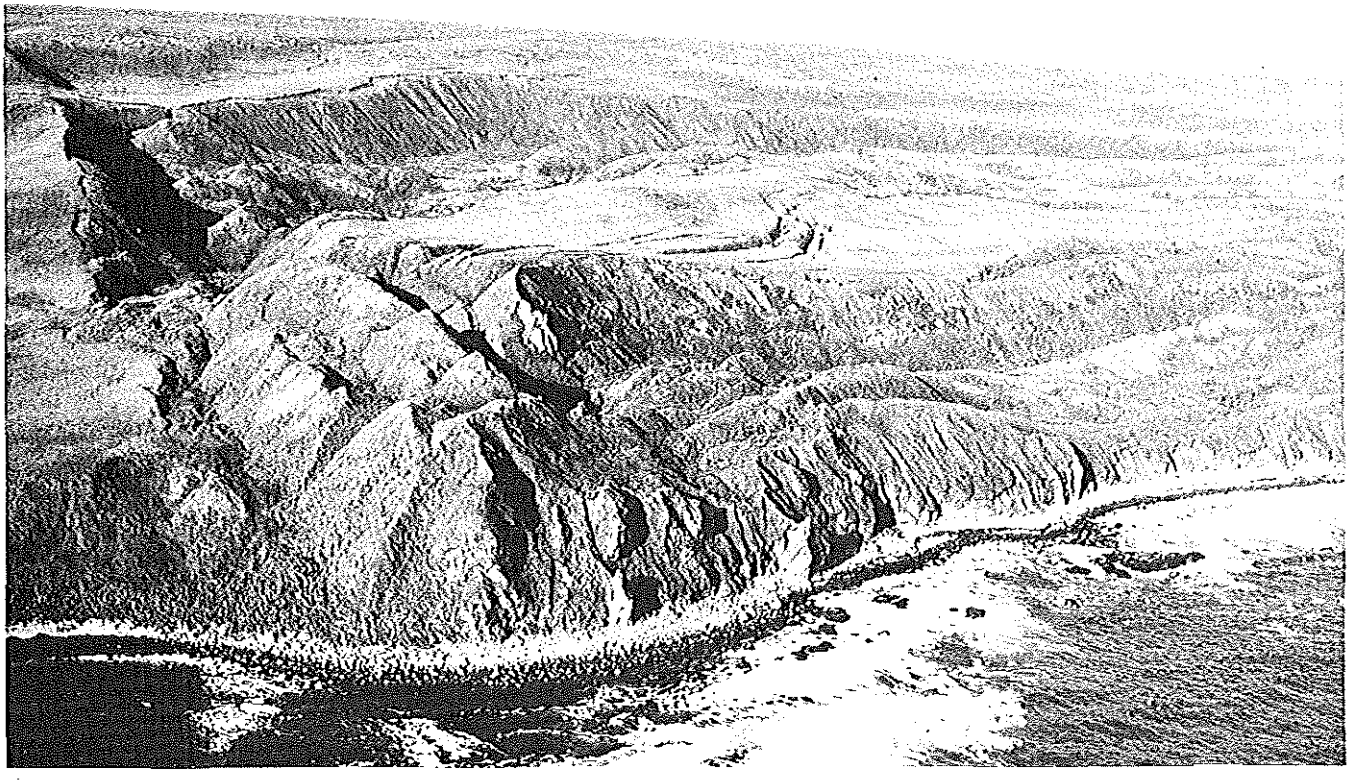

Fig. 5—Landslide near Chitka Point on Bering coast. The slide, about 1 km^2 in area, is in conglomerate, tuffs, and breccias of the Chitka Point Formation. Note disruption of interglacial marine terrace on the left side of the picture.

Point and is about 1 km^2 in area (Fig. 5). Its unmodified appearance suggests that it may be quite young. All have developed in poorly consolidated conglomerates and laharic breccias of the Chitka Point Formation and could have been lubricated by sea-level fluctuations during the Pleistocene or merely by seismic shaking of saturated rocks.

A terrace is currently being developed at about mean sea level around most of the island perimeter. This intertidal bench is well developed on fine-grained sedimentary rocks but poorly developed on coarse-grained sedimentary rocks and igneous rocks. Development of the intertidal bench on moderately coarse-grained turbidites* of the Banjo Point Formation is shown in Figs. 6, 7, and 8. The bench is inferred to be the result of frost action on the sea cliffs (Powers, Coats, and Nelson, 1960) and of abrasion by stones on the ramp between the actively retreating cliff and the bench rather than of direct wave action. The frost-riven rubble is removed by storm waves. Streams cascading over the sea cliff locally have prevented freezing and delayed the cliff retreat (Fig. 9).

*A turbidite is a rock or sediment layer deposited from a gravity-influenced bottom-flowing current laden with suspended sediment, which moves swiftly down a subaqueous slope and spreads horizontally on the ocean floor. At Amchitka these turbid currents were probably initiated by earthquake-induced sliding. The resulting deposit is characterized by graded bedding; i.e., beds which are coarse-grained at the base, grading upward to fine-grained at the top.

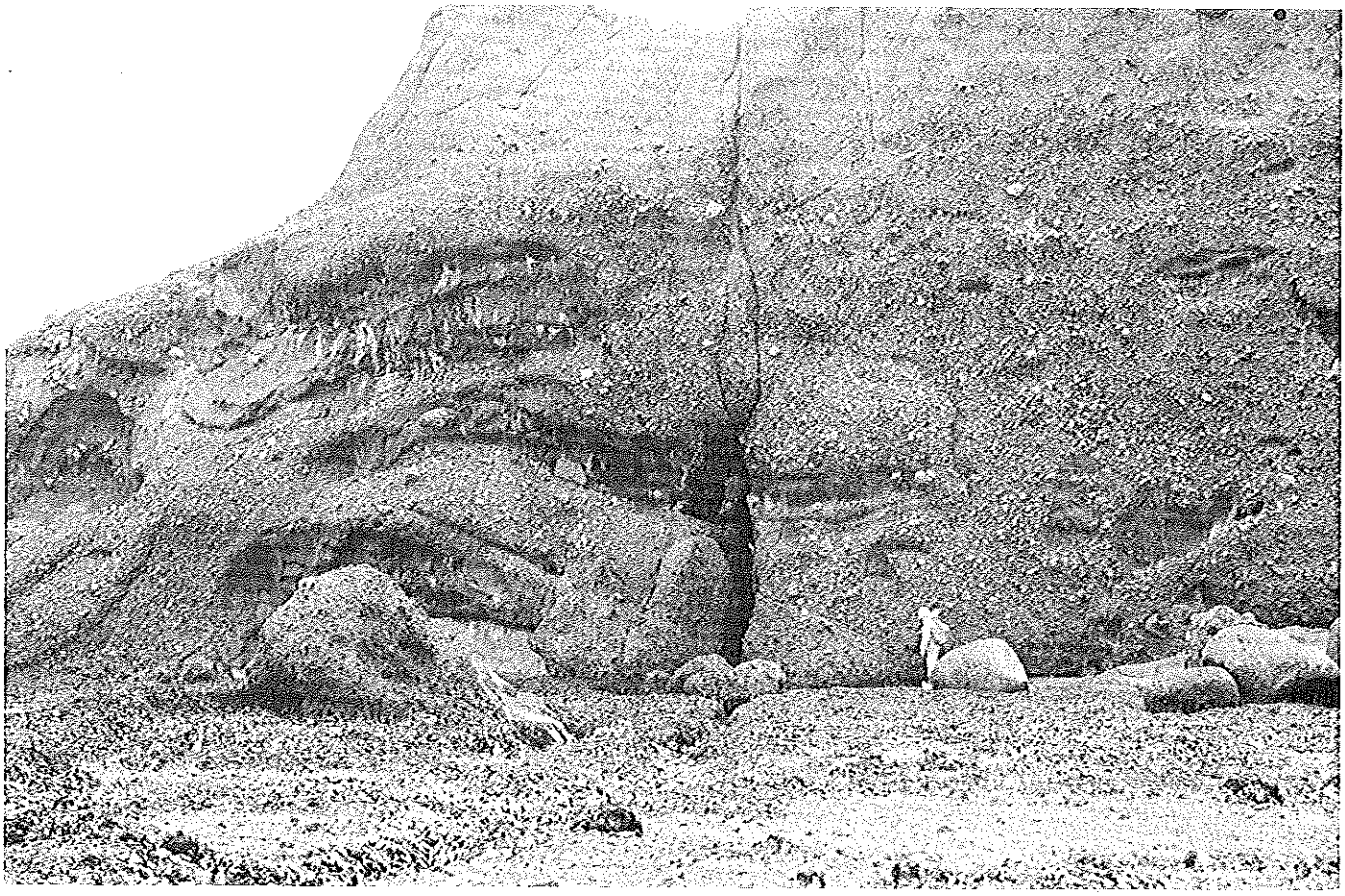

Fig. 6—Discontinuous sandstone blocks in turbidite bed of the Banjo Point Formation. Note the upward decrease in grain size of turbidite. Kelp-covered intertidal bench is shown in foreground.

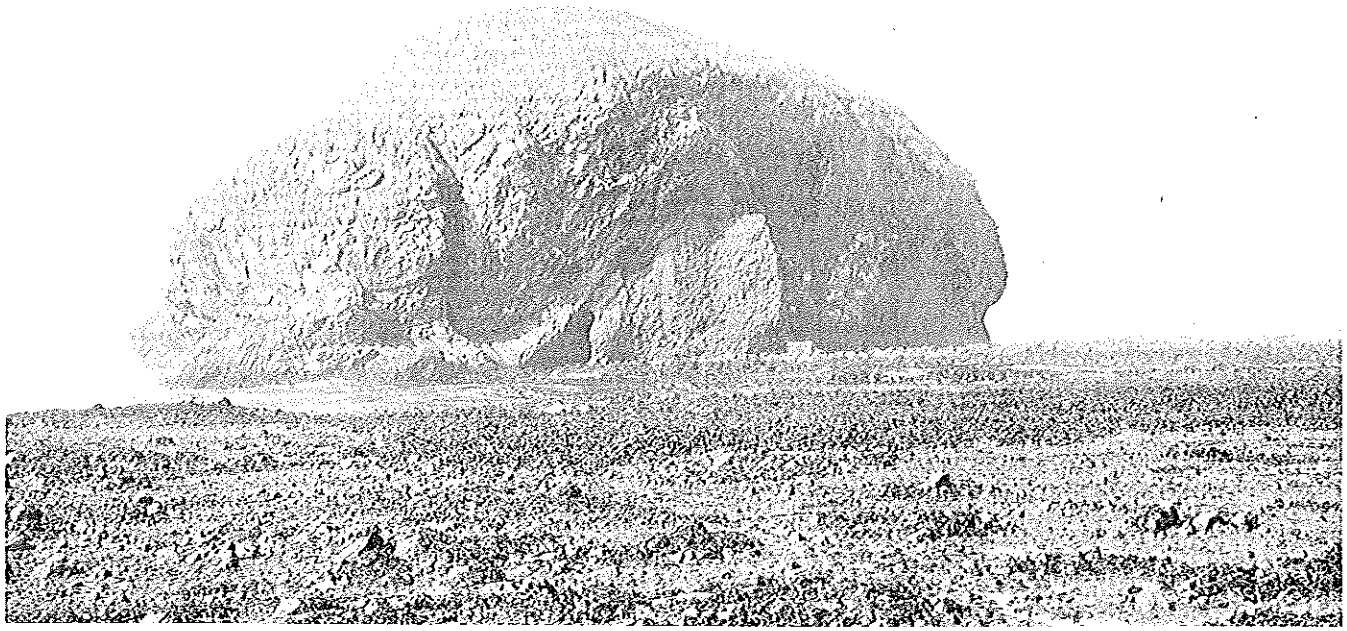

Fig. 7—Mex Island, an erosional remnant of resistant Miocene Chitka Point lava that filled a valley cut in breccia of Eocene or Oligocene Banjo Point Formation. Note fanned columns lying normal to the steep valley wall at center of island. The intertidal bench at low tide shows in foreground.

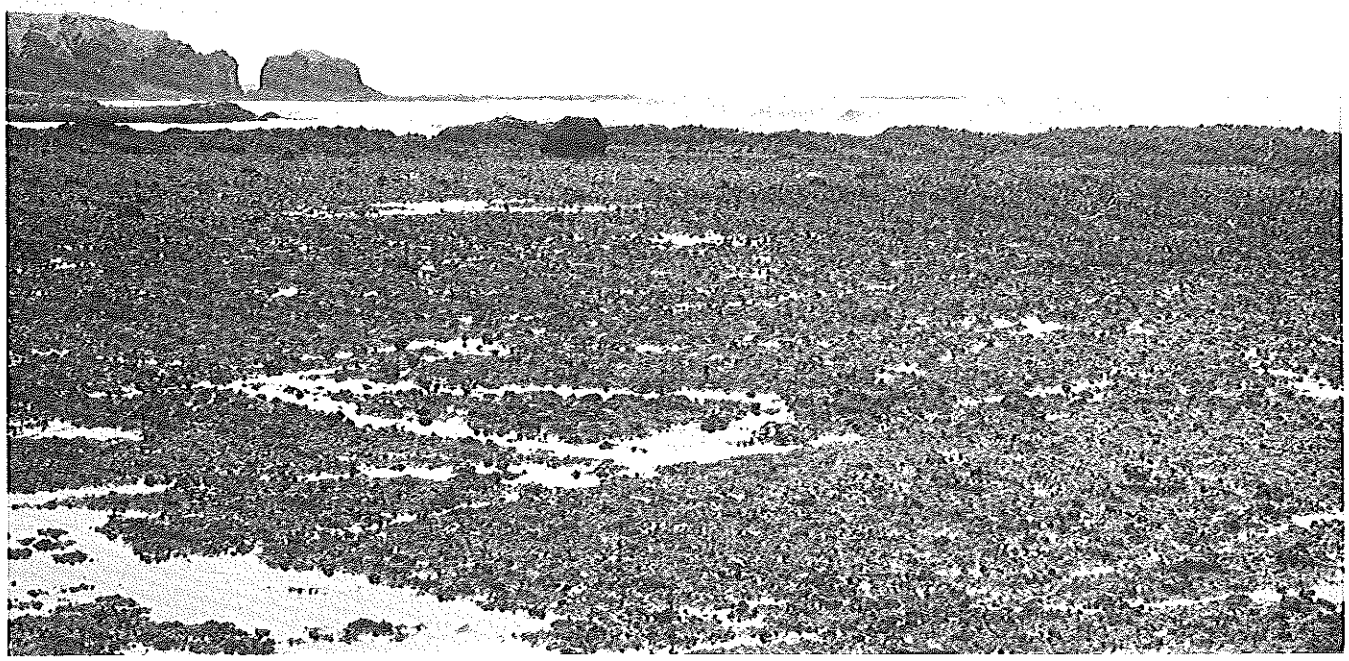

Fig. 8—Intertidal bench cut on breccia of Banjo Point Formation exposed at low tide. Firmly cemented erosion-resistant boulders project above bench surface. The berm at outer edge of bench is probably preserved from freeze and thaw mechanical weathering by constant wave splash. Note the water-filled eroded joints.

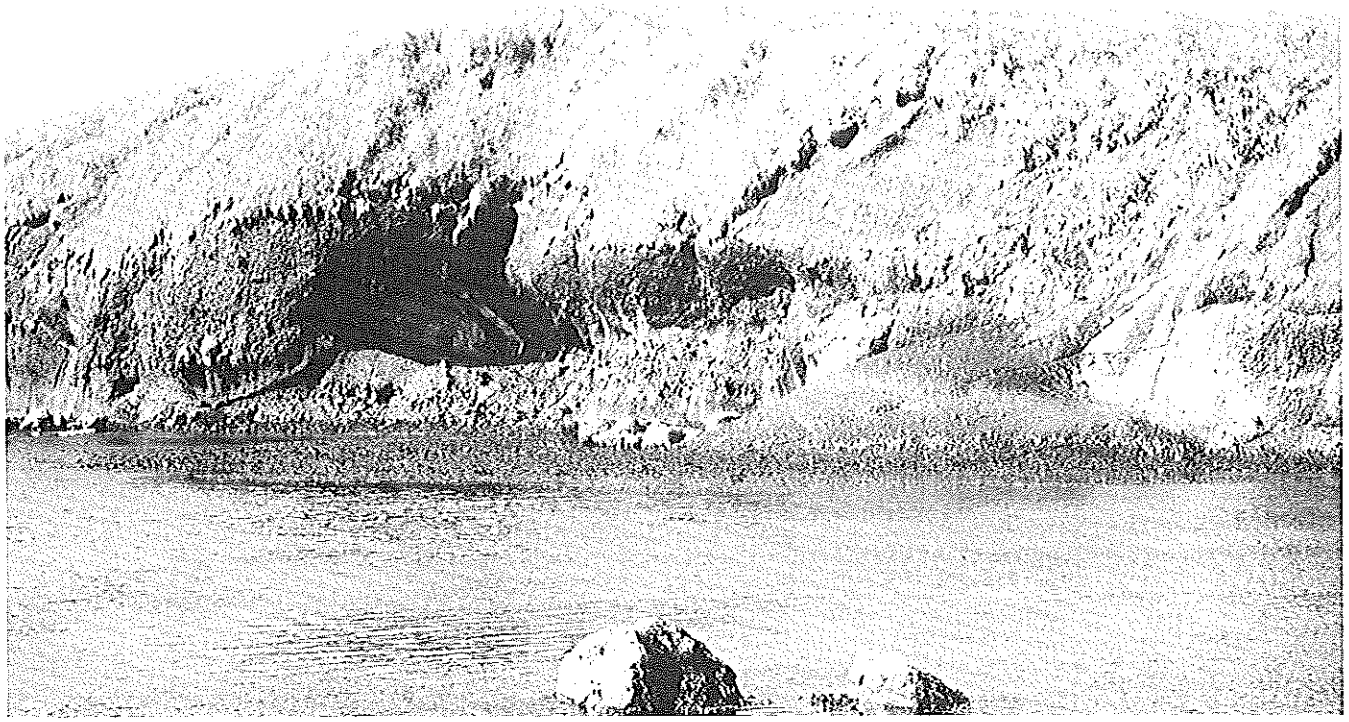

Fig. 9—Sea-cliff retreat caused by freeze and thaw. Bedrock cone is protected from freezing by a stream cascading over its surface. Bedrock is breccia of Banjo Point Formation. Note low-angle joint that extends from cliff at right across bedrock cone. Near high tide covers the intertidal bench.

Fig. 10—Pillow lava in upper part of Amchitka Formation 1100 m west of Constantine Harbor. Devitrification of glassy rinds allows differential weathering. The hammer in the center of the photograph is 30 cm long.

GEOLOGIC HISTORY

Eocene and Oligocene Epochs

The geologic history of the Aleutian Ridge is, in a general way, reflected by the history of Amchitka Island. The rocks of Amchitka (Fig. 2) record a long history of Tertiary volcanic activity. The oldest rocks on Amchitka Island, the Amchitka Formation of early Tertiary age (Carr, Quinlivan, and Gard, 1970), provide a local record of deposition and alteration of more than 2300 m of submarine pillow lavas, breccias, and turbidites of basic to intermediate composition. Toward the end of deposition of the Amchitka Formation, a thick pile of monolithologic glassy breccias and at least two pillow lavas (Fig. 10) were extruded on the sea bottom.

Following this episode of local volcanic activity, after only a short interval of time, the Banjo Point Formation was laid down during late Eocene or early Oligocene time. Although locally there are submarine lavas at the base of the formation, the Banjo Point Formation consists almost entirely of fossiliferous marine volcaniclastic rocks. These rocks are mainly turbidites that range from coarse breccias to mudstones composed of basaltic rock fragments (Fig. 11).

There is considerable evidence to indicate that the turbidites were derived from material shed

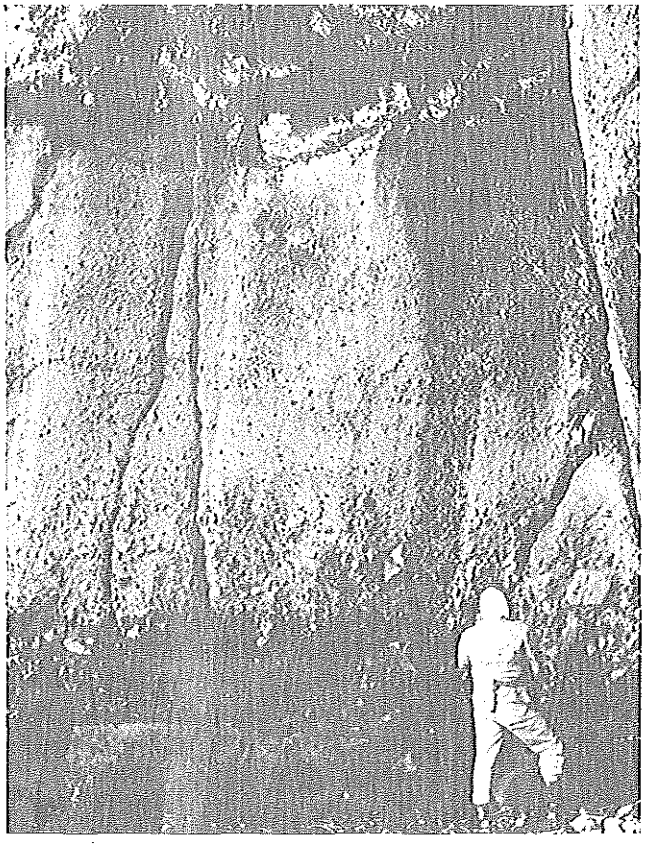

Fig. 11—Coarse-grained turbidite bed in Banjo Point Formation. The bed grades from angular boulder-sized clasts at base to angular pebbles and sand at top.

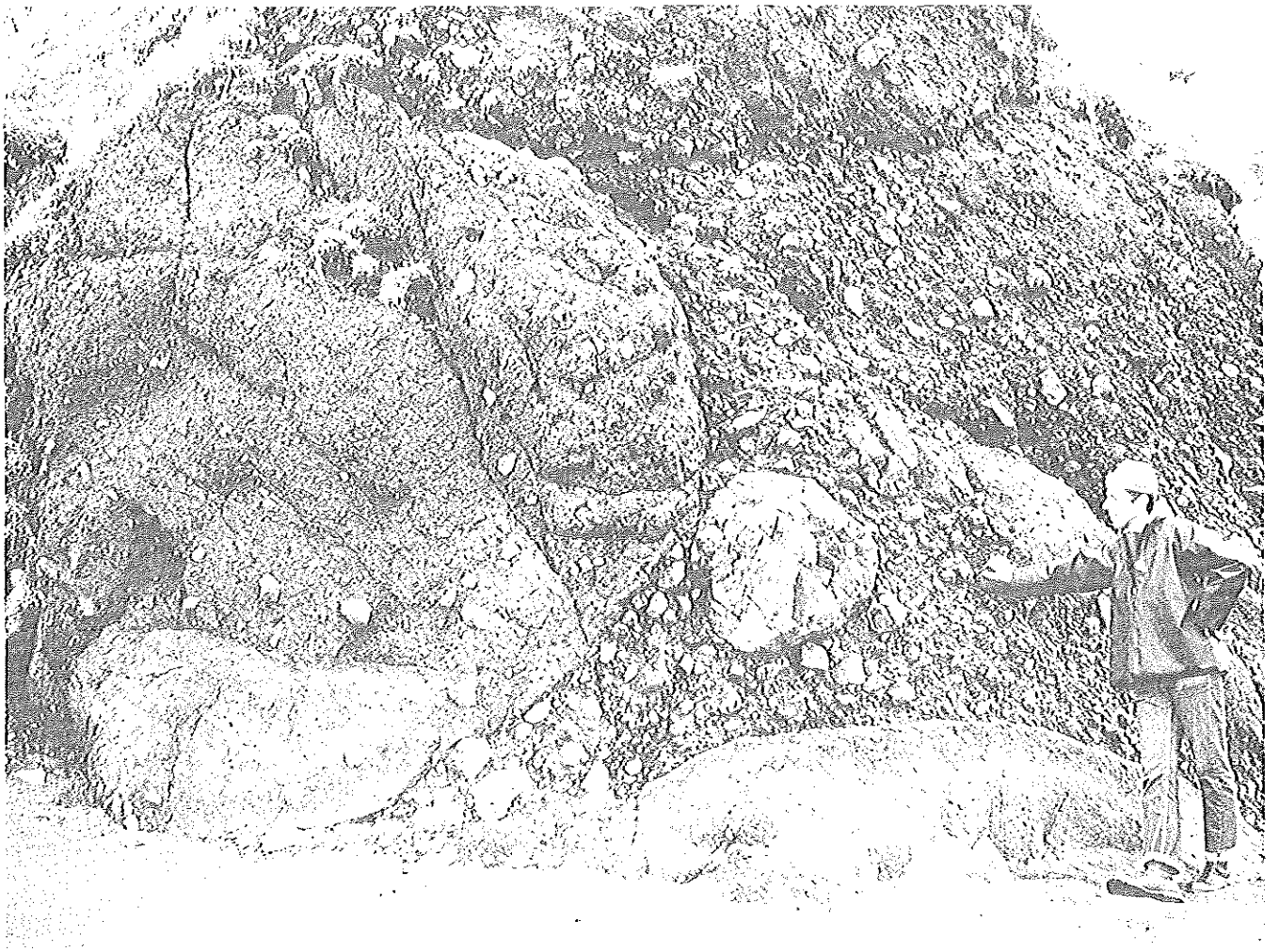

Fig. 12—Rounded boulders of previously deposited breccia in a coarse-grained turbidite bed of the Banjo Point Formation.

from the sides of nearby ancient subaerial volcanoes. This debris slid down the submarine flanks of the volcanoes as turbidity currents and was deposited on the sea floor. Because of their density these submarine slides had the ability to transport huge blocks of eroded material; yet, curiously, they occasionally were remarkably gentle in their handling of these large blocks. Rounded blocks of displaced breccia (Fig. 12) as large as 5 m in diameter and sheets of sandstone 1 m thick and 100 m long have been observed. Many of the discontinuous sandstone sheets conform to the attitude of the enclosing turbidite beds but pinch out abruptly or degenerate laterally into discontinuous blocks of sandstone (Fig. 6).

Foraminiferal and molluscan assemblages found in the finer grained turbidites indicate a late Eocene or Oligocene age for the Banjo Point Formation (Carr, Quinlivan, and Gard, 1970). Because of a major erosional unconformity at the top of the formation, no complete section of the Banjo Point Formation is exposed. Although it crops out over much of the eastern half of the island, the section has been repeated by normal faulting. The maximum known thickness of Banjo Point Formation is 967 m, penetrated in an exploratory drill hole at site B (Fig. 2).

Miocene Epoch

In mid-Tertiary time, uplift, erosion, and initiation of normal faulting along mainly northeast-trending faults occurred on Amchitka. Uplift appears to have occurred throughout the central and western Aleutian Ridge (Gates, Fraser, and Snyder, 1954) and was accompanied by intrusion of widespread epizonal plutons. A concordance of potassium–argon isotopic dates of plutonic rocks from Shemya to Unalaska (Scholl, 1972) tends to confirm a widespread period of plutonism and, hence, uplift during middle and late Miocene time.

On Amchitka this intrusive episode is represented by two separate small plutons, one cropping

Fig. 13—Typical outcrop of East Cape pluton showing wide-spaced blocky jointing.

out at East Cape and the other at White House Cove. The East Cape pluton (Fig. 13), which varies in composition from gabbro to biotite granite, invaded rocks of the Amchitka Formation. Contact metamorphism has locally changed wall rock and roof pendants to hornfels and amphibolite gneiss. A potassium–argon date of 15.8 ± 0.7 million years was obtained from a biotite-bearing phase of the pluton (Carr, Quinlivan, and Gard, 1970).

The White House Cove pluton (Fig. 14), a diorite porphyry that is exposed in only a few places, probably underlies much of the western third of the island and is believed to be genetically related to the Chitka Point Formation. The undated White House Cove pluton has the same negative remnant magnetization as the Chitka Point Formation but is different from the weakly positive magnetization of the East Cape pluton.

The mountainous western third of Amchitka Island consists of remnants of a subaerial volcano. These rocks, the Chitka Point Formation, clearly indicate that in late Miocene time, after the earlier Tertiary marine rocks of the Banjo Point Formation had been uplifted, faulted, and eroded, stratovolcanoes were built on the remnants of the ridge. The volcanic complex, which probably was a linear series of cones, is believed to have stretched from the middle of Amchitka northwestward to the eastern part of Rat Island (Carr et al., 1971) and may have been 17 km wide.

Cauldron subsidence associated with the Chitka Point volcanic rocks is suggested by a prominent arcuate negative magnetic anomaly, the White House Cove anomaly (Bath et al., 1972, p. 22). Subsidence is further suggested by drill-hole information at sites E and F (Fig. 2), by anomalous seismic velocities within the postulated cauldron (Engdahl, 1973), and by an arcuate fracture pattern (not shown in Fig. 2) north of Windy Island. Three potassium–argon dates of 12.4 ± 1.1, 13.2 ± 1.2, and 14.1 ± 1.1 million years on Chitka Point lava flows confirm a middle to late Miocene age for the Chitka Point Formation, as indicated by a fossil-pollen assemblage (Carr, Quinlivan, and Gard, 1970), and thus the same age for the White House Cove pluton.

At that time sea level was relatively lower—or the ridge was relatively higher—than it is today. Stumps of trees in growth position found in a laharic breccia 23 m below sea level (Barr, Ellis, and Helle, 1973; Humphrey and Branstetter, 1973) provide evidence that relative sea level may have

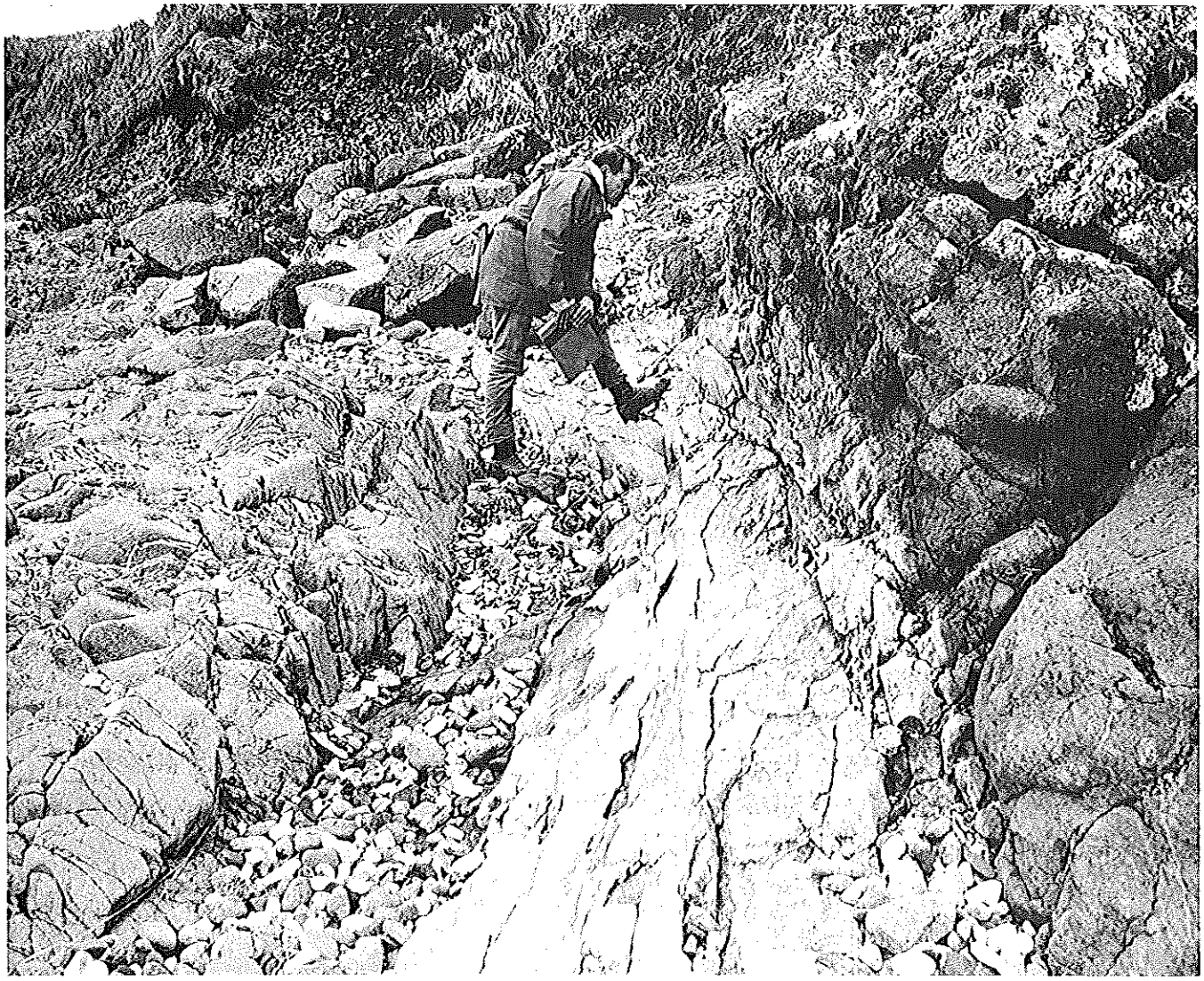

Fig. 14—Intrusive contact of light-colored White House Cove pluton with darker pyroclastics of the Chitka Point Formation. A geologist is standing on the fine-grained chill border. Note porphyritic texture of diorite in pluton on left.

been at least 23 m lower. The site of these stumps, however, lies near the offshore extension of the Teal Creek fault, which has dropped the Chitka Point Formation down on the north side. It is not certain on which side of the fault this site lies, but submarine topography suggests it is on the upthrown side. Irregular knobby sea-bottom topography and small offshore islands composed of subaerial Chitka Point columnar lavas around the western half of the island suggest that sea level may have been relatively as much as 80 or 90 m lower than at present.

The climate during Chitka Point time must have been considerably less severe than the present climate. Laharic breccias, conglomerates, and bedded tuffs contain remnants of large trees and wood fragments in various stages of silicification. Pollen from a thin coaly seam identified by E. B. Leopold (Carr, Quinlivan, and Gard, 1970) indicates that such trees as cypress, yew, pine, alder, spruce, birch, poplar, hickory, and walnut were present. She reported that "the sample count contains 6.5 percent of deciduous broadleaved trees now exotic to Alaska, and about a fifth of the generic list includes forms foreign to the region . . . ."

Many of the Chitka Point lava outcrops are long, narrow, thick remnants of valley-filling flows which now form ridges such as Column Ridge (Fig. 15) and Andesite Point, suggesting that considerable erosion was concomitant with construction of the volcanic complex. Resistant narrow submarine ridges extending offshore as deep as 90 m below sea level are probably extensions of

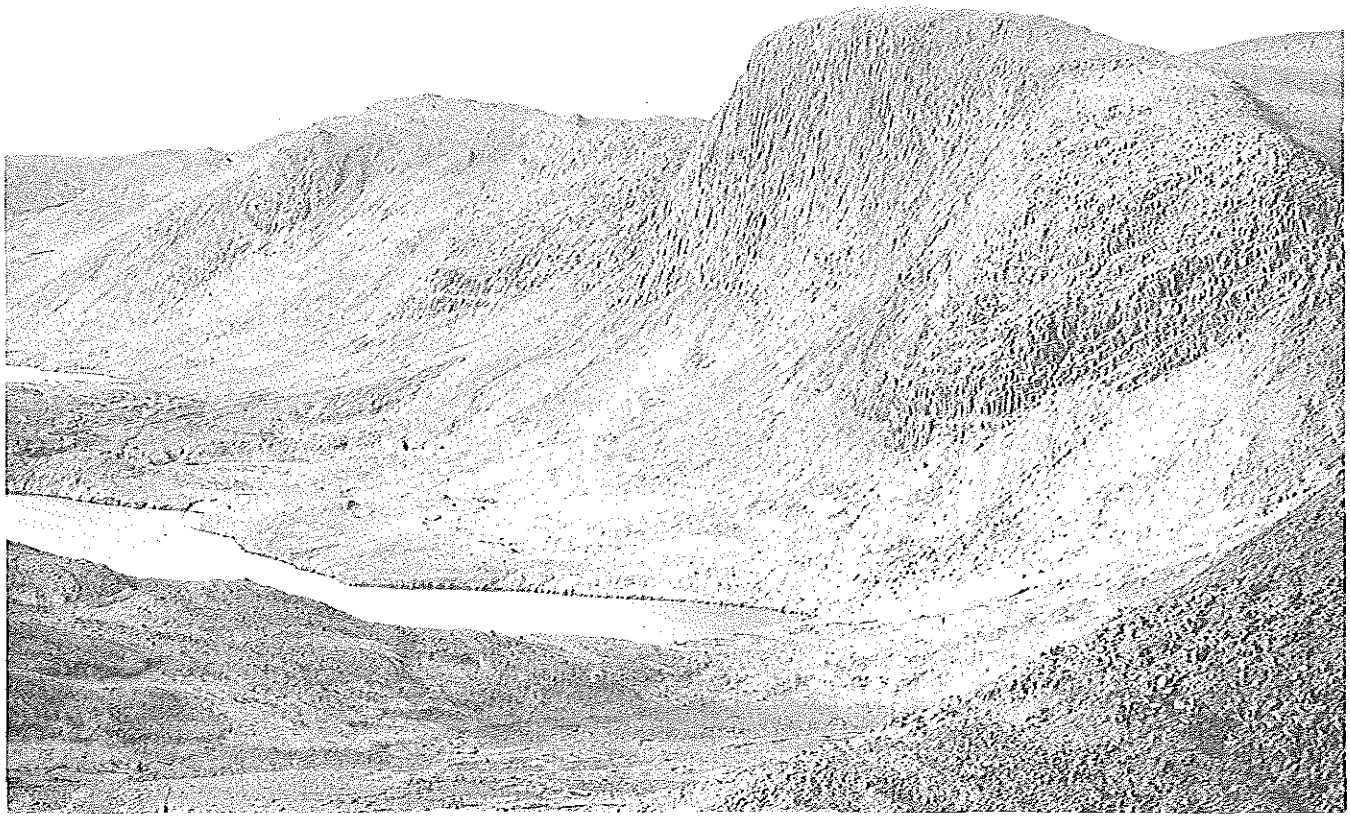

Fig. 15—Column Ridge formed by lava flow that filled a valley cut in pyroclastics of the Chitka Point volcanic complex. Differential erosion has removed pyroclastics and left lava flow as a ridge. Cliff is about 100 m high.

these flow remnants. Mex Island (Fig. 7) is a Chitka Point andesite flow remnant that fills a small valley cut in basaltic breccia of the Banjo Point Formation, and a submarine ridge extends offshore from it for a distance of 11 km.

Pliocene Epoch

During and after Chitka Point volcanism, the area of Amchitka Island appears to have remained above sea level. Two periods of minor intrusive activity occurred during the Pliocene Epoch. Small basaltic dikes and sills crop out on the eastern half of the island and were also found mainly intruding the Banjo Point Formation in the exploratory drill holes. Potassium—argon dates on two basalt dikes are 8.9 ± 0.6 and 10.2 ± 1.1 million years (Carr, Quinlivan, and Gard, 1970). If these intrusives had broken through to the surface, nearly all evidence is now gone; however, one small outcrop of what appears to be a basalt flow remnant and an accompanying flow breccia is located at Cyril Cove. A swarm of hornblende andesite dikes intrudes rocks near the eastern end of the island. Crosscutting relationships between a hornblende andesite dike and a basalt sill at St. Makarius Point indicate that the hornblende andesite intrusives are younger than the basalt.

Pleistocene Epoch

Graben faulting has preserved a rather remarkable series of Pleistocene deposits on Amchitka Island. Sediments are preserved at and near South Bight, at Constantine Harbor, and along the Rifle Range fault. Although the Pleistocene history is far from completely known, these strata reveal more than has been reported so far from any other Aleutian Island. Evidence is found for at least two glaciations separated by a fossiliferous marine deposit.

Marine transgressions during interglacial times have carved at least four well-developed marine terraces (6 to 9, 15 to 18, 37 to 49, and 67 to 76 m) on Amchitka Island (Fig. 3), the latter two of which are warped, tilted, and faulted and are

correlated with fossiliferous marine and beach deposits. Marine regressions during glacial advances have cut one broad extensive terrace (–91 m) and at least two smaller discontinuous terraces (–46 and –77 m) which are now below sea level. Only the –46- and –91-m terraces are extensive enough to be shown on Fig. 3.

Marine terraces are much better developed on the eastern half of Amchitka Island because pre-Chitka Point erosion and beveling had already reduced the rocks of earlier Tertiary age to a low surface. On the steep flanks of most of the western part of the island, Pleistocene terraces are restricted to narrow discontinuous ledges.

Fossil sea cliffs and terraces generally are better developed on the south side of Amchitka than on the north. This same phenomenon holds true for the Holocene tide-level bench (Fig. 8), which is better developed along the Pacific coast than it is along the Bering coast of the island. I believe this is mainly because the southern exposure to the low winter sun allows more thawing and freezing to take place on the south-facing Pacific cliffs during the winter months when the sea cliffs are commonly ice coated than on the north-facing Bering cliffs, which are continually in the shade. Possibly, too, Pacific storms are stronger and generate larger, more powerful waves which would aid in more rapid removal of frost-riven rubble. Fraser and Barnett (1959, p. 240) also noted the better development of the modern tide-level bench on the south side of Kanaga Island, but they attributed it mainly to the southward tilting of that island, which would favor water-level and subaerial weathering.

Early Pleistocene Lake. The South Bight graben was once a closed depression which, in early Pleistocene time, formed a quiet tree-flanked lake along what is now the south shore of the island. Since then, coastal erosion has destroyed the south- and west-bounding bedrock shores of the lake, leaving a cross section of the sediments deposited in the subsiding graben exposed in the sea cliff at the head of the bight (Fig. 16).

The earliest Pleistocene record to be found consists of more than 80 m of tilted and faulted lake sediments exposed in the lower part of the sea cliff (Fig. 17). The beds, mainly of carbonaceous clayey silt and sand, record graben subsidence and, mainly, quiet water conditions.

Thin beds of angular boulders and logs extend into the lake sediments from the north shore, recording times of graben subsidence and sloughing of debris from the north-bounding fault scarp. The boulder beds extend laterally into the lake beds for about 30 m from the fault, and this subsidence event is marked farther out from shore by a stratum of logs. Four such beds have been noted in the exposed section of lake beds. The graben block must have been subsiding evenly during this time since no angular unconformities have been observed in the fine-grained lake beds. Evenness of the bedding suggests that the lake was deep enough that the bottom sediments were not disturbed by wave action. In the upper half of the section, however, a slight erosional unconformity overlain by 35 m of cross-stratified sand and strongly iron-stained weathered pebble gravel records changed conditions. Whether this deposition records uplift nearby or whether it is outwash from an early glaciation is not known. Subsequently, the graben again reverted to quiet lacustrine conditions for a short time, and 3 m more of carbonaceous sand and silt were deposited.

The lacustrine strata in the lower part of the sea cliff contain freshwater diatoms, pollen, carbonized logs, and wood fragments. Thin ash layers tell of intermittent eruptions of nearby volcanoes. Spruce, pine, and, perhaps, alder grew on Amchitka at this time, and ferns dominated the local vegetation. The pollen assemblage "suggests that the average July temperatures were 2 or more degrees C warmer than now in July. These samples could be either Pliocene or early Quaternary age, and of these an early Quaternary age seems more likely" (Leopold, 1970). The presence of trees suggests that this lake may have existed during the early Pleistocene before the advent of glaciation.

These lower Pleistocene beds may correlate with carbonaceous conglomerate and tuff layers on Tanaga Island which contain a similar pollen assemblage (Fraser and Barnett, 1959, Table 1, locality 14).

South Bight I Marine Transgression. Overlying the lacustrine deposits with apparent conformity, as much as 18 m of even-bedded marine sand and gravel (Fig. 17) provides the first record of a Pleistocene interglacial rise of sea level at Amchitka. This event is referred to as the South Bight I marine transgression.

The lack of evidence of current or wave action in the sands at South Bight and the general fine-grained aspect of the deposit suggest that the sea-level rise was swift and the lake in the graben was overwhelmed and transformed into a closed sea-bottom depression lying offshore. Initially, gravel and then sand were trapped in the depression. The sand contains unworn delicate dichotriaene spicules of a siliceous tetraxial marine sponge (Finks, 1972). Although these sponge spicules are not diagnostic of age, water depth, or temperature, according to Finks they do indicate the sediment is marine.

Fig. 16—Sea cliff at South Bight. Lake beds of early Pleistocene age (1) form lower part of cliff at left (north) and are conformably overlain by South Bight I interglacial marine deposits (2). Both are tilted and faulted (3) and beveled (4). Unconformity (4) has been tilted down to south (right) and is overlain by South Bight II interglacial beach deposits. Sea cow localities are at (5). White sand bed above unconformity at right of picture is composed of cross-stratified shell fragments.

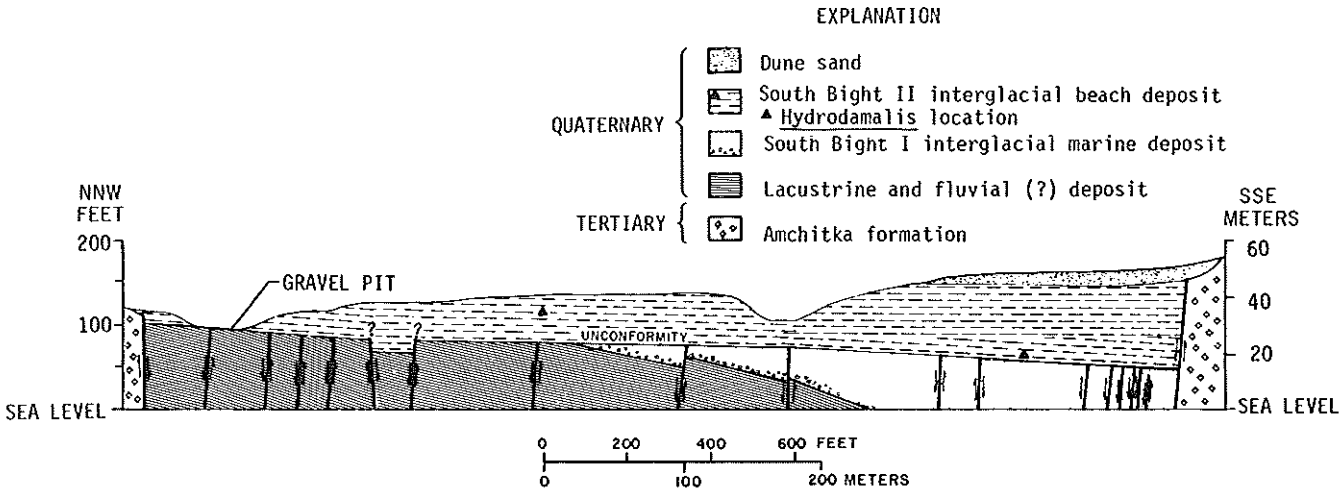

Fig. 17—Diagrammatic geologic cross section of South Bight graben, Amchitka Island. Faults are generalized in part. Vertical exaggeration, 2 X.

A thin deposit of very coarse gravel lies at an altitude of 65 m on a prominent marine terrace about 1.5 km northwest of South Bight (Fig. 4); sand in this deposit contains worn and broken sponge spicules. The base of the abandoned sea cliff of the terrace lies between 67 and 76 m above present sea level (Figs. 3 and 4). I consider this terrace to be related to the South Bight I marine transgression and the gravel to be the remnant of a bouldery beach deposit of the same age. A thin fossiliferous marine deposit cropping out in the cliff at the northwest corner of Constantine Harbor is tentatively correlated with the South Bight I marine transgression and is discussed in more detail later in this chapter.

The South Bight I marine transgression is clearly older than the overlying South Bight II transgression, but at present I am unable to correlate it with marine transgressions recorded on the coast of mainland Alaska.

The South Bight I marine deposit and the underlying lacustrine deposit in the South Bight graben have been tilted southward and broken by a myriad of small faults generally of less than 3-m displacement.

South Bight II Marine Transgression. After tilting and faulting, both earlier deposits were beveled by a new eustatic high-level stand of the sea—the South Bight II marine transgression. This high-level stand of the sea must have persisted for a considerable length of time, for it cut a widespread terrace whose sea-cliff base now lies between 37 and 49 m above present sea level (Figs. 3 and 4). Continued uneven subsidence of the South Bight graben lowered and tilted the unconformity southward and preserved a 6- to 30-m-thick wedge of highly fossiliferous coarse sand to boulder beach gravel that was deposited on the unconformity (Fig. 17).

Activity of nearby volcanoes is recorded by beds of pumice pebbles. Pumice fragments apparently floated to this area, were rounded by wave action and were stranded on the interglacial beach.

This beach deposit contains both vertebrate and invertebrate fossils as well as fossil coralline algae. Uranium-series dating of bone and shell material yielded a preliminary age of about 135,000 ± 12,000 years for this deposit (Gard and Szabo, 1971). Further refinement of this date indicates an age of 127,000 ± 8,000 years (Szabo and Gard, 1975). A recent study of the rich invertebrate fauna provides evidence for paleotemperatures and paleoecology. Allison (1973) reports that the mean February water temperature probably was about 3.9°C and the mean August sea temperature was between 10.0 and 11.7°C; these are similar to present-day temperatures of 3.9°C for February and 10.0°C for August.

Remains of four marine mammal taxa have been found in this deposit. These are Steller's sea lion (*Eumetopias* cf. *E. jubata* Schreber), walrus (*Odobenus rosmarus* Linnaeus), whale, and Steller's sea cow (*Hydrodamalis gigas* Zimmermann) identified by G. E. Lewis and F. C. Whitmore, Jr. (Gard and Szabo, 1971).

The Amchitka fossil is the first recorded discovery of Steller's sea cow remains in place in Pleistocene deposits (Gard, Lewis, and Whitmore, 1972). The giant beast, now extinct, was discovered in 1741 by the German naturalist G. W. Steller along the coast of Bering Island, one of the Komandorskie Islands, the most westerly islands in the Aleutian chain. The sea cow, whose closest living relatives are the manatee and dugong, probably had survived the onslaughts of hunting man only because the islands were unknown to man until the Bering expedition was shipwrecked there in 1741. After that it was only a matter of time—27 years—until these huge sluggish beasts were slaughtered to extinction. They were easy to catch and good to eat, and Russian ships regularly stopped there for victualing.

Parts of the skeleton of a young but apparently nearly full-grown individual, as well as parts of two others, were found in the deposits of the South Bight II marine transgression (F. C. Whitmore, Jr., and L. M. Gard, Jr., 1974). The Pleistocene animal was toothless, as was his eighteenth-century counterpart, and undoubtedly also subsisted on kelp. The South Bight specimen is indistinguishable from the modern species although it was probably somewhat larger. A female specimen found at Bering Island was measured by Steller and found to be 7.5 m (25 ft) long and was estimated to have weighed as much as 10 metric tons (22,000 lb) (Scheffer, 1972).

Powers, Coats, and Nelson (1960) were first to recognize the South Bight II deposit as Pleistocene. They speculated that it was "probably interglacial, and perhaps the youngest interglacial age, inasmuch as the deposit has not been removed by erosion."

Although others have suggested various pre-Illinoian ages for this deposit (Hopkins, 1967; Allison, 1973), mainly on the basis of faunal assemblages, my conclusion is that these beds and the 37- to 49-m terrace were constructed during the last major interglaciation, the Sangamon. This conclusion is based on the extensiveness of the terrace, the freshness of the deposit, and the radiometric age date of 127,000 ± 8,000 years, which is roughly equivalent to dates accepted elsewhere for the age of the Sangamon Interglacia-

tion (Richmond and Obradovich, 1972; Mesolella et al., 1969; Szabo and Rosholt, 1969; Birkeland, Crandell, and Richmond, 1971).

The widespread nature of the terrace suggests that the high-level stand of the sea persisted longer than would have been likely during substages of the Wisconsinan Stage. It is even less likely that the deposit is as old as pre-Illinoian age. A recent fission-track date of 600,000 years for ash beds in late Kansan or early Yarmouth deposits in the western United States seems much too old for the age of the South Bight II deposit as determined by the uranium-series method. Age-dating methods, as a whole, are susceptible to continuing refinements, however, and many of the "absolute" dates now existing doubtless will be modified in the future.

Other Subaerial and Submarine Terraces. Two brief high-level stands of the sea cut small subaerial terraces at 15 to 18 m and 6 to 9 m above sea level on Amchitka. The terraces are discontinuous but at places have well-developed sea cliffs that are best manifested at Rifle Range and Omega Points (Fig. 4). No deposits or fossil records have been found associated with either terrace; their undissected surfaces and sea cliffs suggest that they are quite young. They may represent brief high sea stands during two of the substages of the Wisconsinan Stage. Carbon-14 dates of 9810 ± 160 years on a soil lying at 5 m above sea level near Silver Salmon Lake (Black, 1972) and 8500 ± 350 years (measurement made by Meyer Rubin, U. S. Geological Survey laboratory sample W-2660) for a peat sample 2.6 m above sea level at Rifle Range Point provide a minimum age for the lower terrace.

Powers (1961) has suggested that a small marine terrace is present at 3 to 5 m above sea level on islands in the Aleutians and elsewhere around the Pacific Ocean. Although scattered remnants of flat surfaces at about this altitude are found at the mouths of some streams on Amchitka, it is debatable whether these were surfaces formed by a high-level stand of the sea or whether they are merely related to storm berms.

Pleistocene southward tilting of the island segment lying between Constantine and South Bight grabens is indicated by variations in altitude of abandoned sea cliffs (Fig. 4). The South Bight I terrace is tilted southward more than 6°, but the South Bight II terrace is tilted less than 0.5° to the south. Tilting of this segment started before cutting of South Bight II terrace and continued after it was formed. The lack of tilting of the lake sediments trapped in the South Bight graben before deposition of the conformable overlying South Bight I beds suggests that tilting of the island block probably did not start until after South Bight I time.

Sea level is believed to have been relatively stable for the past 2000 to 4000 years, on the basis of the presence of a broad intertidal bench (Fig. 8) found at many places around Amchitka and other Aleutian Islands (Morris and Bucknam, 1972). Such geomorphic evidence indicates that, despite the high seismicity of the Aleutian arc, most of the islands have remained isostatically stable during this time, although abandoned sea cliffs on some of the Delarof Islands lying east of Amchitka Pass suggest that several meters of uplift may have occurred there during the past several thousand years (Morris and Bucknam, 1972).

During the glacial advances sea level was considerably lower than at present because large volumes of water were stored in massive continental glaciers. Detailed bathymetric charts indicate several submerged marine terraces around Amchitka Island. The two that are best developed are shown in Fig. 3. The largest of these is quite extensive and is found on both the Bering and Pacific sides of the island. It consists of a smooth, almost featureless platform lying between −91 and −100 m and is as much as 4.8 km wide on the Pacific side of the island. Other less well developed submarine terraces lie at about −46 and −77 m (not shown in Fig. 3). Other smaller submarine terraces doubtless are present, but the lack of density of soundings, especially near shore, prevents adequate delineation of such features.

The width and continuity of the −91-m submarine terrace suggest that it may have been formed by more than one marine regression. Although minor tilting and faulting of abandoned subaerial sea cliffs are recognized, no large variations in the altitude of the −91-m terrace is apparent. Perhaps this is due to a lack of density of bathymetric soundings, but it does suggest that tectonic warping of this segment of the Aleutian Ridge was minimal during the Pleistocene epoch. In the Delarof Islands group, south to southwestward tilting of marine terraces and minor Holocene uplift have been recognized (Morris and Bucknam, 1972). When sea level was at −91 m, Amchitka, Rat, and Kiska islands were part of one large island, which was 165 km long and varied from 5 to 50 km in width.

Other Pleistocene Deposits. Glacial till and outwash are rare on Amchitka and, like the interglacial deposits, are generally restricted to topographically low, protected areas. Hummocky sea-bottom topography associated with closed depressions suggests that glacial deposits lie offshore in greater quantity. The most extensive subaerial deposits are found in Constantine graben and north of the Rifle Range fault. Till less than 0.5 m thick

and scattered faceted and striated boulders overlie the South Bight II beach deposit at South Bight.

On the north side of the Rifle Range fault, a deposit of probable outwash sand and gravel of unknown age, which is broken by several small faults, is overlain by scattered faceted and striated glacial erratics.

Two till-like sheets (or diamictites*) of distinctly different ages crop out in the cliff at the northwest corner of Constantine Harbor. Little can be said concerning the age of the older deposit except that it is probably pre-Wisconsin. This is the only evidence found on Amchitka of an older episode of glaciation. The deposit is extremely well indurated, displays rude stratification, contains discontinuous chaotic sandy beds, some weathered cobbles, and many faceted and striated cobbles and boulders. It is overlain by a shallow-water fossiliferous marine deposit, which, in turn, is overlain by Wisconsin till or diamicton. The older diamictite and the marine deposit have been offset as much as 20 m by a fault.

The marine deposit, presumably interglacial, cannot be correlated with certainty with either of the interglacial deposits at South Bight. It contains a small poorly preserved assemblage of shallow-water pelecypods (Addicott, 1972) and sponge spicules. One of the pelecypods, *Macoma nasuta,* has never been found in Pleistocene marine transgressive deposits on mainland Alaska (Hopkins, 1967), nor has it been found in the deposits of the South Bight II marine transgression on Amchitka (Allison, 1973). Induration, iron staining, pebble weathering, and leaching of carbonate in the fossil shells suggest, however, that this deposit is quite old. Its position beneath a diamicton thought to be of Wisconsinan age indicates that it predates that deposit. The presence of sponge spicules, which, so far, are found only in deposits of the South Bight I marine transgression, suggests that these marine beds might be correlative with the South Bight I deposit. Admittedly, this is a very tenuous correlation since the sponge spicules have a wide-ranging age. If these shallow-water deposits are of South Bight I age, however, they either have been downfaulted at least 50 m, or, more likely, they were deposited sometime during advance or retreat of the South Bight I transgression. If the *Macoma*-bearing beds are of South Bight I age, then the subjacent diamictite must be very old—at least Kansan in age.

A widespread but probably thin ice cap deposited a sandy, stony diamicton less than 2 m thick upon the marine deposit and older diamictite and throughout much of Constantine graben where ice has striated bedrock and deposited extensive sandy and silty outwash and ice-front pond deposits under the diamicton (Fig. 18). In Constantine graben these outwash deposits are tilted southeast and, in places, are broken by many small faults. A thin clayey till interbedded in the outwash on the north side of the graben, and in fault contact with Constantine fault on the south side of the graben, probably represents direct deposition from the ice. In most places this glacier left only randomly scattered faceted and striated erratics.

This younger glaciation is not directly dated, but we may speculate on a minimum age based on carbon-14 dates. The oldest dates on peat or organic soil on Amchitka are on the order of 9000 to 10,000 years B. P. (Everett, 1971; Black, 1972). A carbon-14 date of 8090 ± 300 years (measurement made by Meyer Rubin, U. S. Geological Survey, laboratory sample W-2849) was obtained from a 15-cm-thick undulating soil overlying about 1 m of dune(?) sand which, in turn, overlies the younger diamicton. The sample site lies about 550 m inland from Constantine Harbor at an altitude of 17 m. These ages suggest that the island either was not deglaciated or had too harsh a climate to support vegetation again until about 10,000 years ago.

The Quaternary geology of the central and western parts of Amchitka has been studied in less detail, but it must be assumed that a thin ice cap also covered those parts of the island since they are topographically higher than the eastern end. Depositional evidence of glaciation northwest of the Rifle Range fault is rare; erosional evidence in the form of rock-defended lakes lying west of site C (Fig. 2) suggests that that part of the island also was ice covered. In the mountainous western third of the island, glacially eroded U-shaped valleys and cirques indicate that glaciers filled the valleys, but glacial deposits are rare on land. Scattered erratic boulders lie on the high plateau west of the mountain segment. Hummocky sea-bottom topography suggests that these glaciers may have deposited debris as much as 90 m below present sea level although no distinctive terminal moraine shapes are seen.

Correlation of Amchitka Pleistocene deposits with other Pleistocene deposits and marine transgressions on mainland Alaska or with classical Pleistocene sections of the Midwestern United States or Europe is for the most part tenuous at

*A nongeneric term for nonsorted or poorly sorted, noncalcareous, terrigenous sedimentary rock that contains a wide range of particle sizes in a muddy matrix. Diamicton is the nonlithified equivalent. The terms are used here because the rude stratification in these deposits suggests the influence of moving water during their deposition and that they may not have been deposited directly by ice. Lack of disturbance of the lake deposits underlying the diamicton shown in Fig. 18 tends to strengthen this argument.

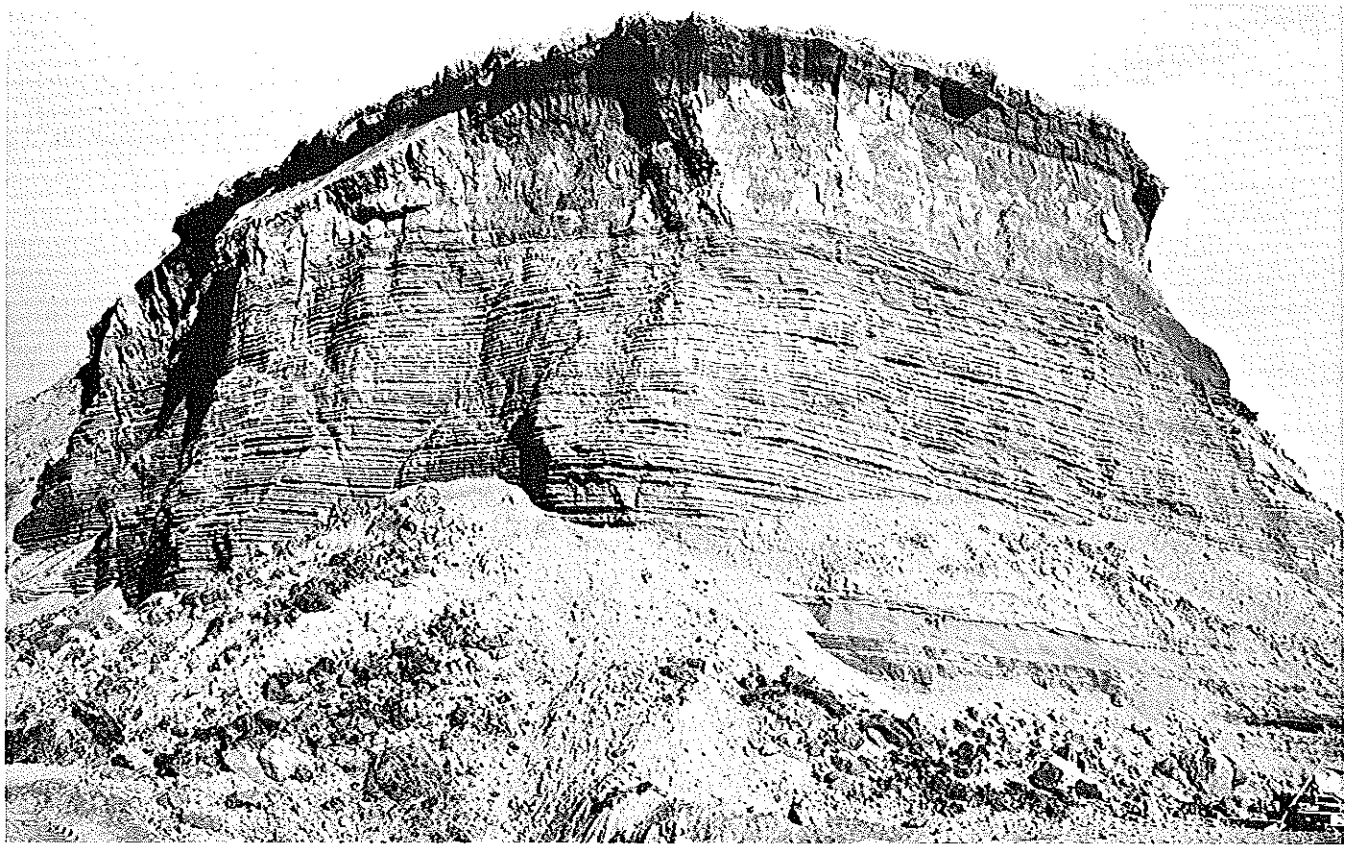

Fig. 18—Rhythmically bedded glacial-pond deposit of alternating sand and silt overlain by 2-m-thick diamicton of unsorted stony clayey sand. Weathered surface of diamicton at right shows faint trace of layering, which suggests that it may not have been directly deposited from melting ice. The dark band at top of face is peat containing thin ash layers. The shovel at lower right is about 1.3 m long.

best. On mainland Alaska pre-Wisconsin (Illinoian ?) glaciation was far more extensive than that of the Wisconsin (see, for example, Alaska Glacial Map Committee of the U. S. Geological Survey, 1965). It appears, however, that, although this same relationship may have also occurred on the western Alaska Peninsula and in the Aleutian Islands, Wisconsin glaciers were extensive enough to have covered most of what is now land surface and to have removed most evidence of the pre-Wisconsin glaciation. For example, on the western Alaska Peninsula, the Cold Bay area is reported to have been covered by an asymmetrical ice sheet that centered on the continental platform south of the Aleutian Range (Alaska Glacial Map Committee of the U. S. Geological Survey, 1965; Funk, 1973). On Umnak Island in the eastern Aleutians, early studies by Byers (1959, p. 349) suggested that extensive glaciation of the Nikolski plain "was late Pleistocene, possibly Wisconsin in age". Extensive Wisconsin glaciation on Umnak is further substantiated by Black (1972), who states that "no glacial deposits have been recognized earlier than late Wisconsinan when an extensive ice sheet covered all but the highest peaks until 10,000 or 11,000 years ago." In the western Aleutians, Schafer (1971, p. 788) recognized that extensive ice sheets, which he suggests were "no older than Wisconsinan," covered the Near Islands (Attu, Agattu) and the Semichi Islands.

The lack of peats or soils yielding carbon-14 dates older than about 10,000 years not only on Amchitka Island but also on 13 other islands from Kiska in the west to Tanaga in the central Aleutians strongly suggests that ice caps or permanent snowfields must have covered these islands during late Wisconsinan time. According to Black (1972), "the lack of soils older than 10 or 11 thousand years seems universal from the Alaska Peninsula westward at all points I have seen. If the islands were not covered by ice, then I dare say a periglacial climate brought extremely rapid mass movements [of colluvium]. This does not seem defensible, however, because I at least have not found any massive accumulations [of colluvium] in low areas."

Thus, evidence from other islands at the extremities of the Aleutian chain supports the

findings on Amchitka that an ice sheet of Wisconsinan and probably late Wisconsinan age covered Amchitka Island.

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3

Hydrology

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Amchitka Island is composed of stratified volcanic rocks that vary widely in hydraulic properties. Because of the low interstitial permeability in most of the rocks, groundwater moves most actively in the upper few hundred meters where fractures in the rocks are numerous and more open. Together with the thick surficial mantle of vegetation and peat, the shallow aquifers comprise a groundwater reservoir that responds strongly to infiltration of precipitation. Flows of most streams and levels of many of the lakes are sustained during dry periods by discharge from the shallow groundwater system. Direct surface runoff of precipitation occurs frequently, however, and the quality of the surface water during these periods is influenced by salt spray from the oceans.

Hydraulic tests and temperature measurements in deep drill holes show that the hydraulic head decreases with depth beneath the island. The rocks have sufficient permeability to permit slow downward flow of small amounts of fresh groundwater in response to this gradient to estimated depths of more than 1000 m where it then moves laterally and upward along an interface with saltwater to discharge at the ocean floor.

The collapse of the cavity produced by the Cannikin nuclear explosion created an unsaturated rubble chimney and an area of surface subsidence now filled with water and known as Cannikin Lake. Both surface runoff and flow from the shallow groundwater system were captured for more than a year to fill the chimney voids and the lake basin. The lake and rubble chimney may have almost doubled the depth of fresh groundwater flow, allowing circulation into the rubble-filled explosion cavity. If the hydraulic properties determined by testing in the exploratory hole at this site are similar to those along a hypothetical flow path, it is estimated that water presently in the cavity could discharge to the Bering Sea within 100 years. The rate of the discharge to the Bering Sea would be extremely small, about 20 m^3/day.

Amchitka Island has an area of about 300 km^2 (Coats, 1956, p. 86). Altitudes on the island range from sea level to 350 m (1160 ft), and the estimated average altitude is 85 m (280 ft). The topography consists of varied landforms, including mountains, a high plateau, lower plateaus, and an intertidal bench (Gard, Chap. 2, and Everett, Chap. 8, this volume). Except for the steep-sided rugged mountains on the northwest end of the island, most of the land surface has a rich growth of alpine-zone mosses and grasses. The island is transected by many faults (Gard, Fig. 2, Chap. 2).

The U. S. Geological Survey has performed hydrologic studies on Amchitka Island since 1964. A long-term hydrologic monitoring network was established in 1967 to document the effect of nuclear testing on the island. Prior to these investigations, little was known about the hydrology of the island.

Hydrologic studies on Amchitka have been concentrated in the central part of the island bounded by Sites B and F (Fig. 1). The data acquired from surface-water studies and from groundwater studies in a few deep exploratory holes and in several shallow holes are used here to describe the hydrology of the island.

SURFACE WATER

There are many streams and lakes on Amchitka Island. The drainage basins for the streams are relatively small, usually less than 2.6 km^2 (1 $mile^2$). Gaging stations were established to measure discharge on five of the larger streams near potential explosion sites. Records of monthly precipitation at the airport [67.0 m (220 ft) above mean sea level] (Fig. 1) were collected from October 1967 through June 1972.

Stream Runoff and Precipitation

Greater discharge is associated with streams having basins at higher altitudes than with those in the lowlands of southeastern Amchitka Island. This relationship was tested by comparing average drainage-basin altitudes with distributed annual runoff, expressed as the depth of water (in millimeters) that would occur if the total volume of annual runoff were distributed over the area of

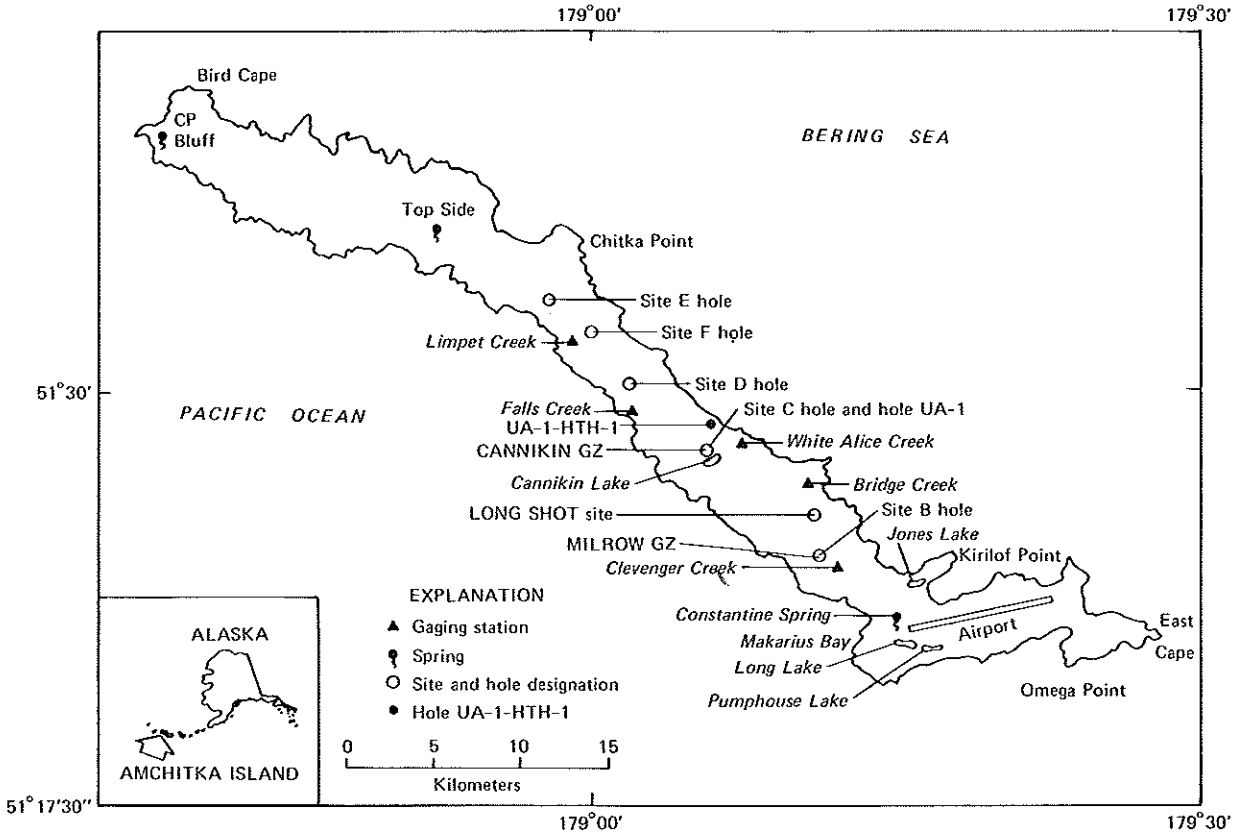

Fig. 1—Hydrologic monitoring points and site locations, Amchitka Island.

the drainage basin. Average basin altitudes and drainage areas were determined from topographic maps. Results of the comparison, using discharge records for calendar years 1969 and 1970 (U.S. Geological Survey, 1970, 1971, and 1972) at Bridge Creek, Falls Creek, and Limpet Creek (Fig. 1), are as follows:

Drainage basin	Average altitude, m	Distributed annual runoff, mm
Bridge Creek	38.4	598
Falls Creek	74.4	949
Limpet Creek	88.7	1198

Figure 2 shows these results. The average annual precipitation at the airport of 953 mm (37.5 in.) for almost 5 years of record (Armstrong, Chap. 4, this volume) is also plotted against the altitude of the gage. These data indicate that distributed runoff, and thus precipitation, does increase with altitude. Furthermore, the comparison of precipitation at the airport with the runoff–altitude relationship in Fig. 2 indicates that most of the precipitation results in surface-water runoff.

Stream-discharge records collected during dry periods and between storm periods show a base streamflow sustained by groundwater discharge (Figs. 3 and 4). Figure 3 shows the base flow of Falls Creek gradually declining during May and June 1968, a period of little precipitation, as water in the surficial materials and underlying bedrock was depleted. The increases in discharge in July and August are small in relation to the corresponding increases in total volume of precipitation, which is estimated by multiplying the daily precipitation at the airport (the only point at which

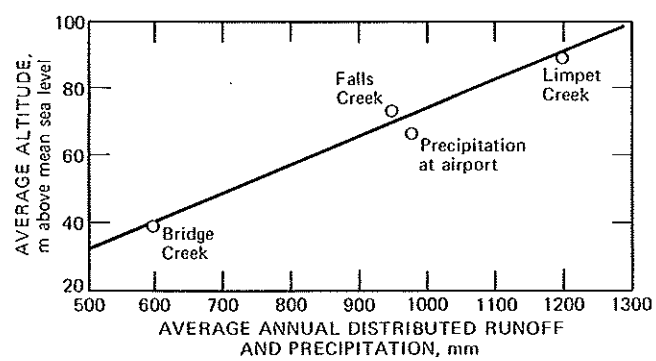

Fig. 2—Distributed annual stream runoff (January 1969–December 1970) and average annual precipitation at the airport (October 1967–June 1972) versus altitude. Airport precipitation from Armstrong, Chap. 2, this volume.

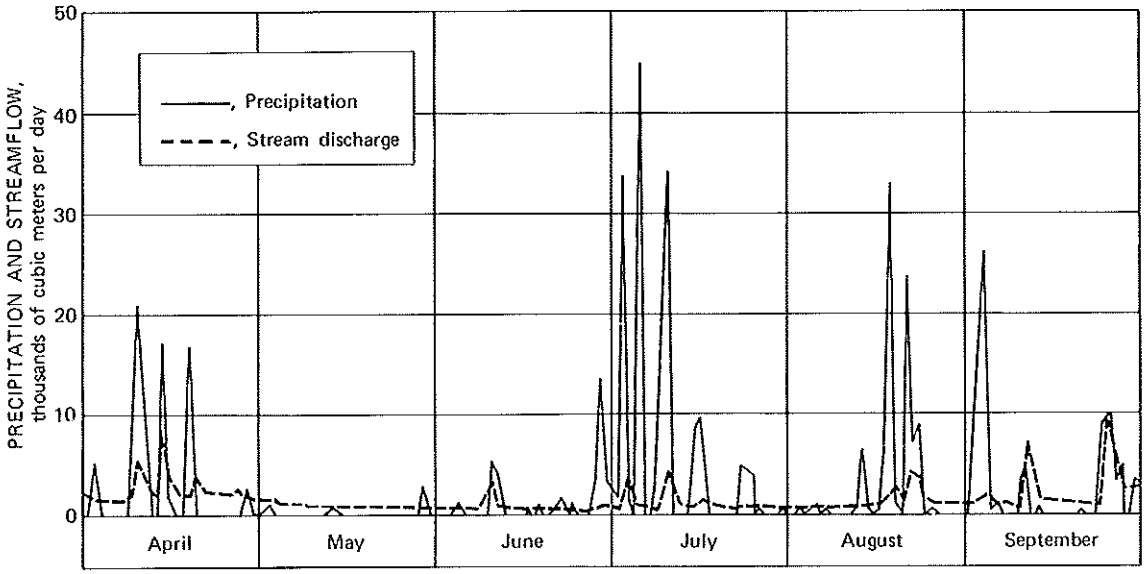

Fig. 3—Discharge and estimated precipitation in Falls Creek drainage basin, April through September 1968.

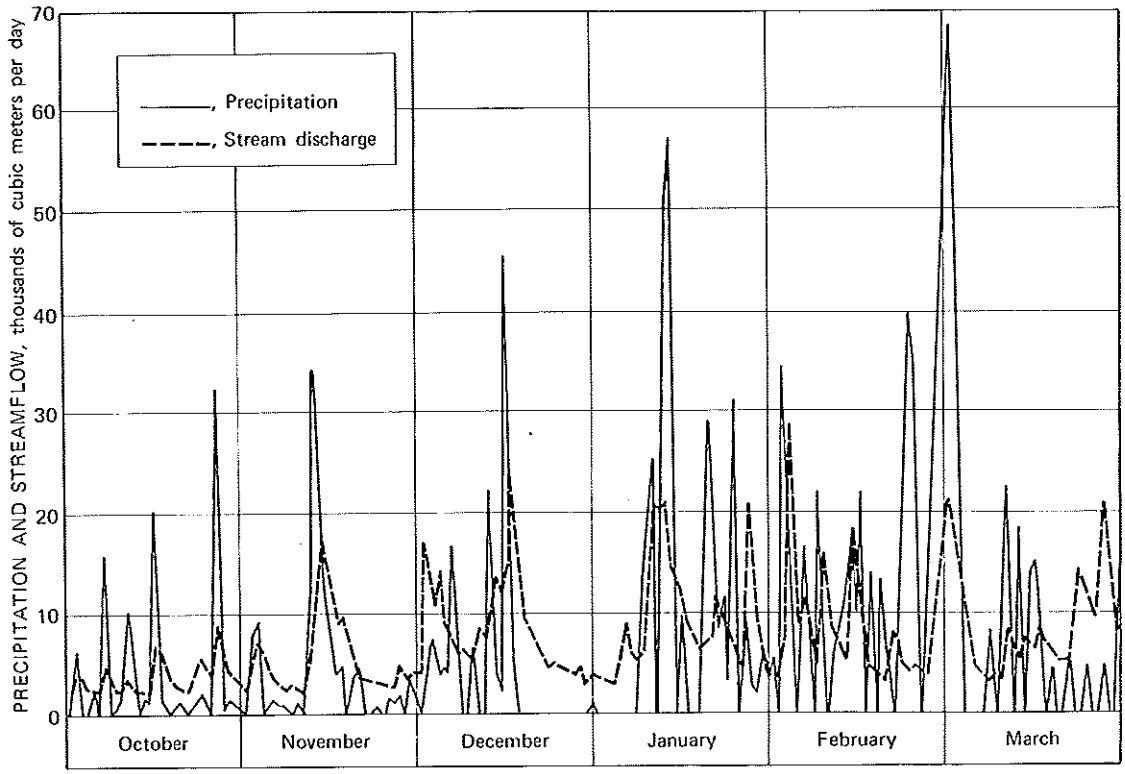

Fig. 4—Discharge and estimated precipitation in Falls Creek drainage basin, October 1968 through March 1969.

long-term data were collected) by the area of the Falls Creek drainage basin. The difference indicates that the surficial materials and underlying bedrock had to be resaturated by recharge from precipitation before discharge increased in September. Precipitation and discharge (shown in Figs. 3 and 4) may not always coincide because of the 22-km distance between the precipitation and streamflow gages.

lost all their water through evaporation and infiltration. Through this period some deeper lakes, such as Pumphouse Lake, Long Lake, and Jones Lake (Fig. 1), which occupy bedrock depressions and are apparently fed by perennial springs, continued to discharge water to streams.

Cannikin Lake. Cannikin Lake (Fig. 5) is unique among the many lakes on the island

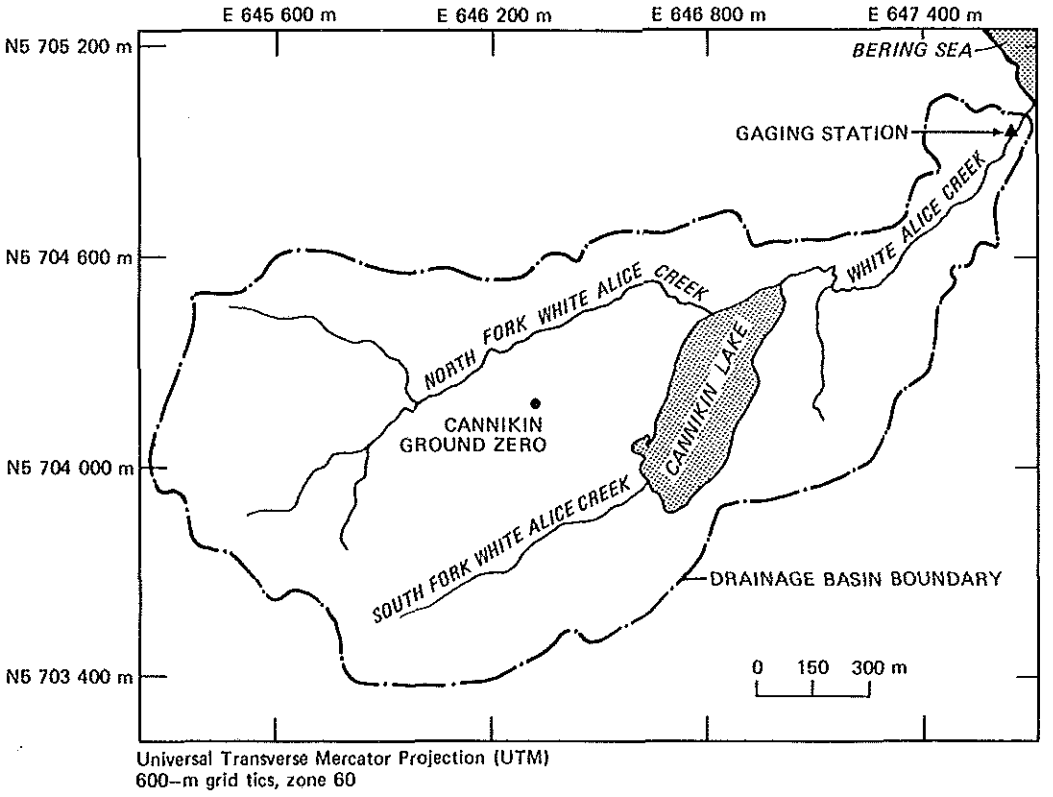

Fig. 5—Cannikin Lake and White Alice Creek drainage basin. Modified from Gonzalez et al. (1974).

Lakes

Hundreds of small shallow lakes dot the landscape on Amchitka, especially on the marine terraces on the eastern two-thirds of the island. These lakes range in width from less than 30 m to more than 100 m and in depth from less than 1 m to more than 3 m. Lakes in the mountainous areas occupy bedrock depressions; lakes in the southeast part of the island are more numerous, however, and most are confined entirely by the thick vegetation and peat. These lakes occupy depressions in the peat and have bottoms composed of organic material, silt, and clay of low permeability. During rainy seasons water flows from the lakes and intermittent springs, but during dry seasons many lakes and springs become dry. May and June 1968 was a dry period during which many lakes

because it fills the surface depression that resulted from the collapse of the cavity formed by the Cannikin nuclear explosion. Figure 6 is a photograph of the lake taken in May 1974. This lake is one of the largest and the deepest on Amchitka. It has a surface area of 12 ha (30 acres), a depth of about 10 m (33 ft) at its deepest point, and a volume of 4×10^5 m^3 (1.4×10^7 ft^3) (Gonzalez, Wollitz, and Brethauer, 1974).

The Cannikin nuclear device was detonated at a depth of 1791 m below land surface on Nov. 6, 1971. The explosion cavity, which collapsed 38 hr after detonation, formed a near-vertical rubble chimney extending to the land surface. The collapse at the surface formed a closed depression with associated fractures and faults centered about 360 m southeast of ground zero. (For a discussion of the asymmetry of the collapse, see Morris, Gard,

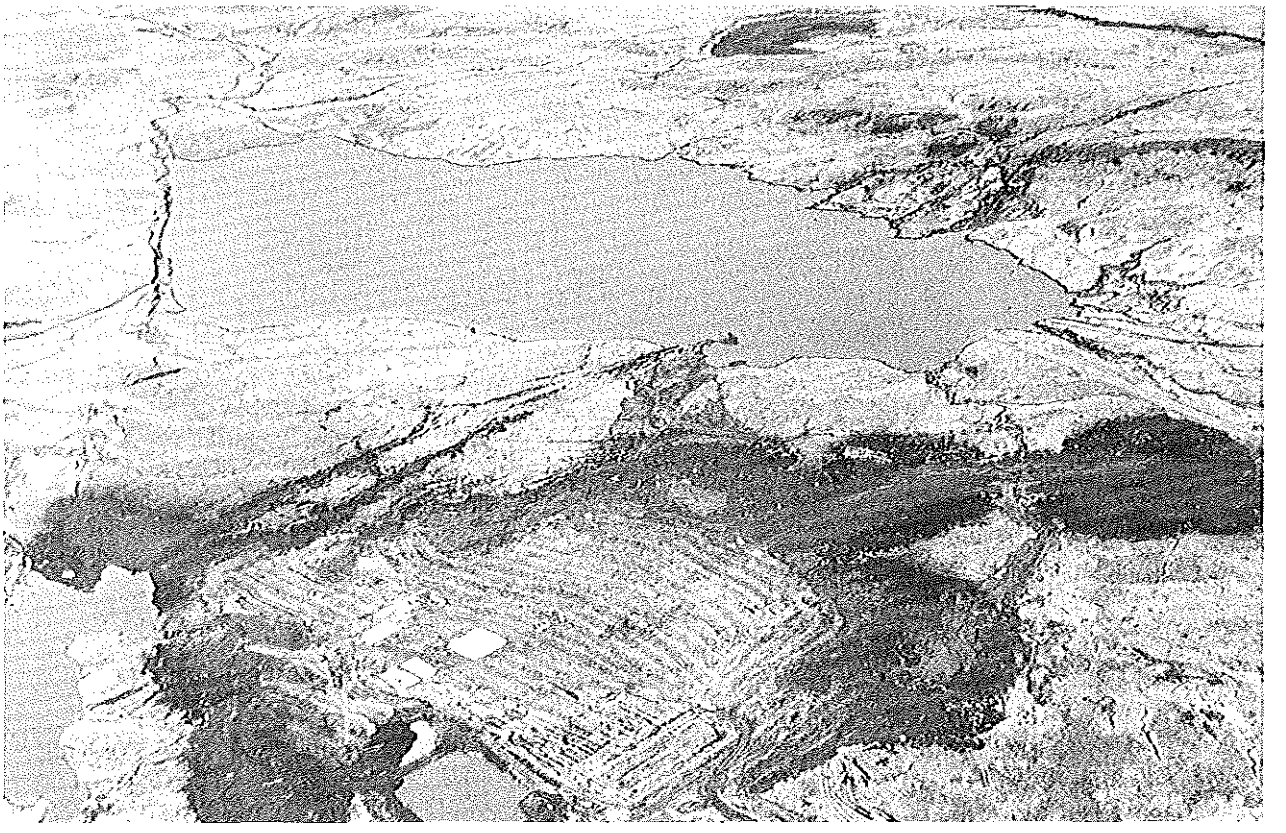

Fig. 6—Aerial view of Cannikin Lake.

and Snyder, 1972.) This closed depression captured surface-water discharge from 84% of the surrounding (White Alice Creek) drainage area (Gonzalez et al., 1974).

The rubble chimney created a hydraulic sink, and groundwater flowed toward and infiltrated the chimney. The decline in groundwater level around the site also induced infiltration of surface water. Except for small ponds, no visible filling of the surface depression occurred for more than 10 months after the chimney collapsed.

The closed subsidence depression began to fill in September 1972, which indicates that the infiltration rate changed significantly that month. Gonzalez et al. (1974) deduced that the rate change was caused by the saturation of the rubble chimney. By December 1972 the surface depression had filled and had begun to overflow into the lower reach of White Alice Creek and thence to the Bering Sea. After Cannikin Lake had filled, discharge records (Fig. 7) show that White Alice Creek again responded normally to precipitation, which also indicates that the rubble chimney was saturated.

Chemical Quality of Surface Water

The water in streams, lakes, and springs on Amchitka Island is of excellent quality, generally containing less than 200 mg of dissolved solids per liter. Sodium (Na^+) and chloride (Cl^-) are the dominant cation and anion, respectively. In terms of reacting-value percent (100 times milliequivalents of ion per liter divided by total milliequivalents of cations or anions per liter), Na^+ constitutes about 70% of the cations and Cl^- about 52% of the anions. The relative concentrations of both of these ions are greater than those generally found in continental surface water or precipitation, which indicates that the quality of precipitation on Amchitka Island is strongly influenced by salt spray from the nearby Pacific Ocean and Bering Sea.

Chemical characteristics of water from sources on Amchitka Island and various other sources of interest are given in Table 1 for comparison. Examples of the chemical character of precipitation in continental areas are given for rainfall in North Carolina and Virginia (A in Table 1) and for low-conductance water from European Alpine lake (B in Table 1). The data for A and B contrast markedly with those for oceanic water (C in Table 1) and, in terms of the ratio Na^+/Cl^-, with those for precipitation in the Pacific Ocean (D in Table 1). The Pacific Ocean samples were collected during September 1961 on the flying bridge of the U.S. Coast and Geodetic Survey ship *Pioneer*

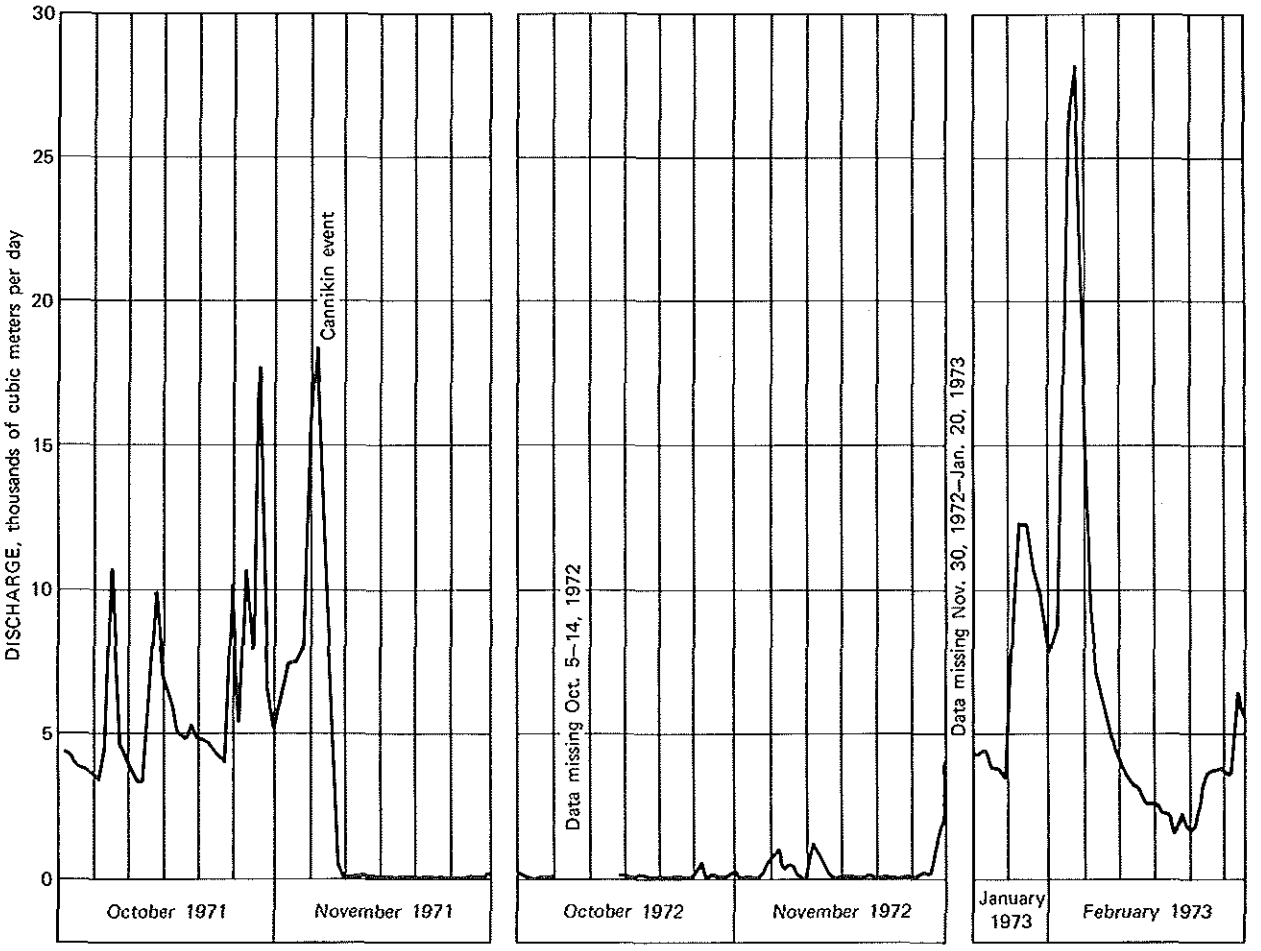

Fig. 7—Discharge at the White Alice Creek gaging station, October 1971 through February 1973.

between latitudes 25°25′N to 51°45′N and longitudes 177°02′W to 177°31′W.

Several samples of precipitation on Amchitka Island were taken by collecting drainage from the roof of the airport hanger. Values of the ratio Na^+/Cl^- for these samples ranged from about 0.9 to 1.3, which possibly indicates variability in salt-spray influence under differing wind conditions.

Sample suites E, F, and G in Table 1 have Na^+ and Cl^- contents (in terms of percent reacting values) that are intermediate between contents of these ions in continental precipitation and in oceanic water. The ratios Na^+/Cl^- for averages of these samples of Amchitka surface water do not show a clear similarity to oceanic water. In Fig. 8, however, Na^+/Cl^- ratios are plotted against specific conductances for individual samples. Although the data are scattered, it is evident that samples having lower conductance, i.e., those having dissolved less mineral matter from the island, have Na^+/Cl^- ratios that closely approach the ratio for oceanic water. This strongly indicates that salt spray does significantly influence the chemical character of precipitation on Amchitka Island.

GROUNDWATER

Groundwater investigations on Amchitka Island were conducted to provide information for assessing the feasibility of mining emplacement chambers for nuclear devices and for evaluating the possibility of migration of radioactive contaminants away from potential sites. The investigation included reconnaissance surface study of hydrologic features (springs, seeps, and perennial lakes and streams), long-term monitoring of water levels in test wells and other available holes, and detailed testing of deep (1000 to 2134 m) exploratory holes at actual and potential explosion sites.

Terminology and Measurement of Parameters

The configuration of the water table is basic to hydrologic investigations. For most practical purposes, the water table is the surface below which all openings in the soil or rock are saturated with water. Because capillary rise may cause fine-grained materials above the water table to be saturated with water at less than atmospheric pressure, the water table is best detected in the subsurface by

Table 1—Chemical Characteristics of Water Samples from Amchitka Island and Selected Other Sources

Sample source and reference*	Percent of cations†				Percent of anions†			Specific conductance‡	Sodium/chloride (Na^+/Cl^-)	Number of samples averaged
	Sodium (Na^+)	Potassium (K^+)	Magnesium (Mg^{2+})	Calcium (Ca^{2+})	Chloride (Cl^-)	Bicarbonate (HCO_3^-)	Sulfate (SO_4^{2-})			
Inland precipitation										
A	34.2	3.9	16.2	45.7	22.8	12.9	64.3	<10	1.5	*
Alpine lake										
B	e28.2§	e2.0	7.4	62.4	18.4	65.4	16.2	e45	1.5	Unknown
Oceans										
C	77.2	1.6	17.8	3.4	91.1	0.4	8.5	45,500	0.85	Unknown
Pacific Ocean precipitation										
D								e80 to e500	0.84	5
Amchitka Island										
E (streams)	64.2	2.3	14.7	18.8	55.1	36.5	8.4	237	1.17	14
F (lakes)	81.0	2.7	9.7	6.6	49.7	41.0	9.3	270	1.67	8
G (springs)	71.5	3.9	14.3	10.3	48.5	41.5	10.0	230	1.47	5

*A, average values for 1-year period in five-basin area of North Carolina and Virginia; data from Gambell and Fisher (1966, p. K33). B, European Alpine lake; data from Chebotarev (1955, p. 43). C, data from Ballance and Beetem (1972, p. 10). D, Rain samples collected in the Pacific Ocean on board the USCGS ship *Pioneer;* data collected by F. H. Rainwater and reported by Gambell and Fisher (1966, p. K25). E, F, and G, data from Ballance and Beetem (1972, pp. 10-12).

†100 times ratio of reacting value of individual ion to total reacting values of cations or anions.

‡Micromhos per centimeter at 25°C.

§e, estimated.

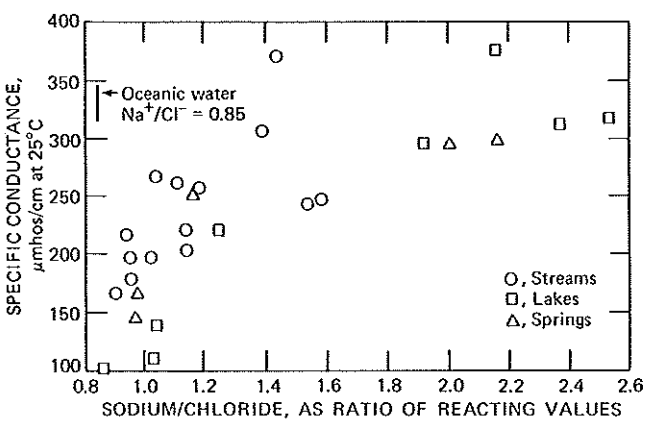

Fig. 8—Relation of the ratio Na^+/Cl^- to specific conductance of stream, lake, and spring water on Amchitka Island.

the standing water level in drill holes rather than by laboratory measurements of saturation in soil or rock samples. Springs, streams, and lakes that persist during prolonged dry periods usually indicate intersections of the water table with the land surface and groundwater discharge to the surface-water feature. The configuration of the water table defines the gravity-driven potential field that causes groundwater flow in the saturated zone.

Static head, or simply head as usually applied in groundwater hydraulics, is a measure of potential energy at any point within the groundwater body. It is the sum of the hydrostatic pressure (the height of a column of water that the pressure at the point will support) and the elevation of the given point above a datum, usually chosen as sea level. Rapidly flowing water, a rarity in groundwater, may have sufficient kinetic energy to require the addition of the velocity head to obtain total head. Head measurements at Amchitka were made during the testing of drill holes by isolating intervals at depth with pairs of hydraulically inflated packing elements (straddle packers) and measuring water levels in tubing open to the zone between packers. The hydrostatic component of the head is affected by the density of the water column in the tubing. To provide comparability among measurements at greath depth, one must normalize the apparent hydrostatic heads by correcting for the influence of the temperature and salinity on the density of the water column. In this chapter head is expressed as altitude (in meters) above sea level.

Groundwater flows in response to differences in head within the three-dimensional potential field. The hydraulic gradient is a dimensionless

quantity that expresses change of head per unit length of flow path. It is a measure of the rate of consumption of energy required to move water through soil and rock.

The volume of water (at existing viscosity) per unit time passing through a unit cross-sectional area of rock under a unit gradient is the hydraulic conductivity. Permeability is the more common term expressing essentially the same quantity, but, in the terminology of groundwater hydraulics, permeability is a property of the rock as determined with (or corrected to) a fluid having a viscosity of 1 centipoise. When expressed quantitatively, the distinction may be significant; in qualitative expressions, however, permeability and its derivatives are the more easily used terms.

The thickness of a rock unit multiplied by its average hydraulic conductivity is termed the transmissivity. Under field conditions average hydraulic conductivity is determined from measured transmissivity and thickness. The same episodes of straddle-packer testing as those used in measuring static heads were used on Amchitka to determine transmissivity. The usual technique was to swab (remove with rubber lifting elements on wire line) water from the tubing after closing ports that connect the tubing to the interval of hole between the packers. Opening the ports caused an immediate drop of head in the tested interval, and the subsequent recovery of head (water-level rise in the tubing) was analyzed by a curve-matching technique (Cooper, Bredehoeft, and Papadopulos, 1967) to determine transmissivity. Where a sufficient difference between the land-surface altitude and static head existed, similar slug-recovery tests were performed after the tubing had been filled with water.

Transmissivity is the most important parameter for estimating the sustained inflow that would occur while mining an underground emplacement. For the prediction of the rate of radionuclide migration, however, gradient, hydraulic conductivity, and effective porosity are needed. Porosity is the proportion of the volume of openings to the total volume of soil or rock. Effective porosity includes only that part of interconnected total porosity which, because of its relatively higher hydraulic conductivity, most readily transmits water. Fractures in rock of low to moderate primary permeability most commonly determine effective porosity, and the term fracture porosity is essentially synonymous with effective porosity for such rocks.

The units of hydraulic conductivity (k), volume per unit area per unit time per unit gradient (i), reduce to the units of velocity. Because flow occurs only through the pore spaces, and most rapidly through the effective porosity (n_e), the particle velocity (v_p) of water for use in predicting contaminant velocity (ignoring retardation by adsorption) is given by

$$v_p = \frac{ki}{n_e}$$

Shallow Groundwater System

The materials in the upper few meters to perhaps a few hundred meters beneath the surface of Amchitka Island are quite permeable and, where unsaturated, are capable of accepting recharge readily. These materials consist of tundra, soil, peat, and fractured and weathered volcanic rocks. The observed strong response of water levels in shallow observation wells to infiltration of precipitation provides evidence of the ease of infiltration. Fluctuations determined by periodic measurements in four closely spaced holes at the Long Shot site (see Fig. 1) are shown in Fig. 9.

Figure 9 also shows that, at the Long Shot site, heads decrease as the depth of penetration increases, which indicates downward flow. The greatest downward hydraulic gradient (about 0.05) occurs between depths of 30 and 90 m, which indicates either an increase in permeability or a reduced vertical (increased horizontal) component of flow at greater depths. For the groundwater to reach points of discharge (streams, lakes, and springs for the shallow aquifers and the coastline or beyond for the deeper aquifers), the initial downward flow must, of course, change to predominantly horizontal or upward flow.

The water table is at or very near land surface over most of the island, as indicated by the many perennial lakes and streams and by water levels in shallow holes. Surficial materials at many places are saturated except for about 2 months of each year when there is usually less precipitation. Consequently the configuration of the water table is essentially that of the land surface, although the water table has less relief than the land. In general, the hydraulic gradient is from the axis of the island toward the coasts. Many seepage points occur along the coasts at the contact of turf and underlying rock or along rock fractures. However, few major springs issue from the underlying consolidated rocks above sea level near the shoreline. This suggests that, although the hydraulic potential exists for oceanward movement of groundwater, the transmissivity of the rocks in the upper few hundred meters is not high enough for large rates of flow. Most groundwater beneath Amchitka apparently moves in very local systems to discharge in the lakes and streams, a conclusion supported by

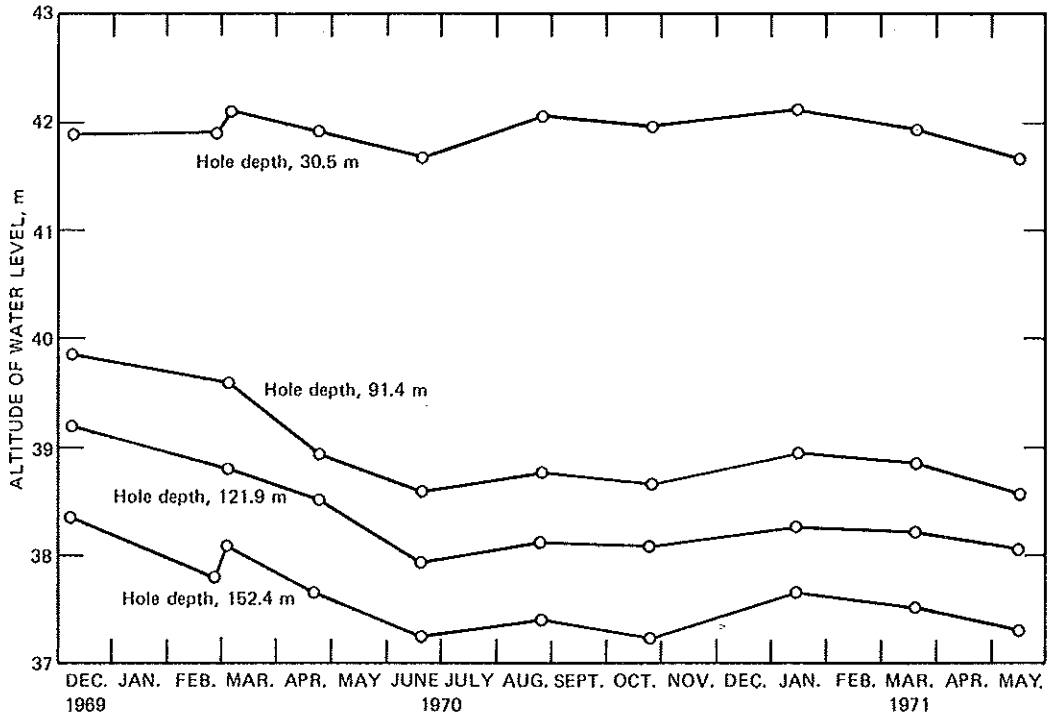

Fig. 9—Water levels in shallow holes at the Long Shot site.

the earlier observation that most precipitation on the island runs off in stream channels.

In the northwestern part of the island, where the slopes are steep and there are many cliffs, soil and peat are very thin or nonexistent. Water collects in small surface depressions perched above the water table. Some steep stream valleys have benches of accumulated erosional debris (colluvium) made up largely of angular rock fragments. At lower altitudes the surface of this colluvium is covered by soil and a thick mat of vegetation. Recharge from precipitation percolates through the mantle of vegetation and colluvium and flows downslope along the surface of the underlying less permeable volcanic rocks to issue as springs. One such spring supplied a military camp at Top Side (Fig. 1) during World War II.

Hydraulic Characteristics of Deep Rocks

Deep exploratory holes ranging in depth from 1000 to 2134 m were drilled at Sites B through F (Fig. 1). The holes principally penetrated volcanic breccias containing dikes, sills, and beds of poorly sorted volcanic sandstone, siltstone, and tuff. The youngest (uppermost) breccias are mostly submarine turbidites consisting of coarse fragments of volcanic materials often in a sandy to clayey matrix. The older (deeper) breccias generally contain more zeolite and chlorite in the fractures and cavities, which probably reduces the effective porosity and permeability of these rocks. These varied geologic conditions provide a complex framework for groundwater movement. Because the stratified rock units have greatly differing hydraulic properties, flow in the vertical direction is generally retarded throughout the island.

The exploratory holes at Sites B through F were tested both by pumping and by slug-recovery tests after swabbing water from or injecting it into zones isolated with straddle packers. Sites B and C, the eventual locations of the Milrow and Cannikin explosions, were tested more thoroughly than the others and thus provide the best data on the variation of the head and transmissivity with depth. The zones tested were generally about 60 m thick, although packer spacings were varied somewhat so that packers could be seated in suitably smooth parts of the drill holes.

Transmissivities determined from the packer tests vary over a range of five orders of magnitude, from about 30 m^2/day in a 60-m zone centered about 700 m below sea level at Site C to about 0.0003 m^2/day. Such a range is expected in stratified materials of various origins, mineralogy and mechanical properties.

Figure 10, which is based on measurements reported by Ballance (1972, 1973), shows that at Sites B and C there is a general decrease of transmissivity with depth, although the decrease is far from uniform. Transmissivities greater than 0.1 m^2/day in zones deeper than about 1000 m below sea level were observed commonly only at

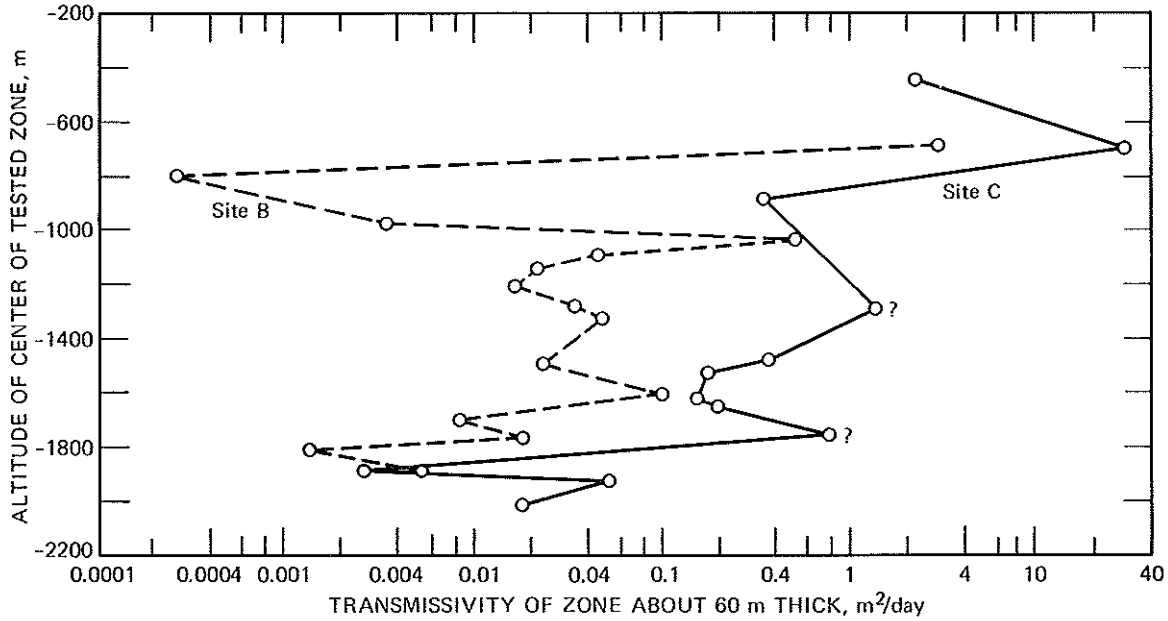

Fig. 10—Transmissivities determined from hydraulic tests of isolated zones in drill holes at Sites B and C. ? indicates possible bypass around packers during test, causing falsely high values for transmissivity. [Adapted from Ballance (1972; 1973).]

Sites C and E. Site F is the least permeable, no transmissivities greater than about 0.05 m^2/day having been measured in 15 intervals tested between altitudes of −211 and −1883 m. However, the interval from −486 to −1468 m was not tested, and the test in the deepest interval (−1886 to −1952 m) showed a transmissivity of about 0.15 m^2/day. Data obtained at Site D indicated low transmissivities similar to those at Site F.

Results of the hydraulic testing point strongly to fractures (joints and faults) as the primary avenues for fluid movement. The fractures tend to close under greater lithostatic loads at depth. In addition, the development of zeolites and chlorites in fractures in the deeper rocks further impedes the movement of water. Thus the decrease of transmissivity with depth is to be expected. Low transmissivities measured in boreholes may be misleading in fractured rocks, however, because dense but brittle rocks penetrated by the hole may be fractured a short distance away.

Temperatures in Drill Holes

During drilling of the deep exploratory holes, water was used as a circulating fluid through most of the intervals that were later tested hydraulically. The introduction of cold surface water to the deep formations undoubtedly lowered rock temperatures temporarily. In addition, the drill holes provided open pathways for water to move from aquifers of higher head to those of lower head.

Temperature profiles reported by Sass and Munroe (1970) were made in October 1968 at Sites B, C, D, and F. The profiles for Sites B, D, and F (shown in Fig. 11) show a uniform increase of temperature with depth. The rate of increase is about 28°C/km, which is similar to the geothermal gradient in many places in the world. Recovery from disruption of the normal thermal environment by drilling at these sites was probably

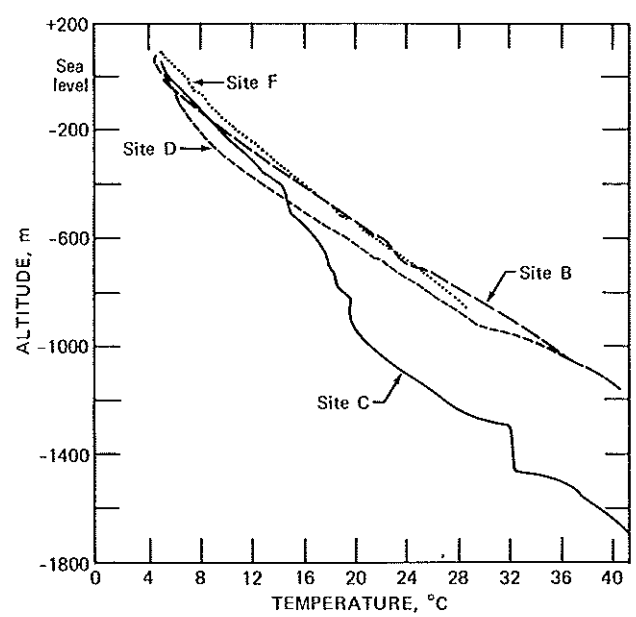

Fig. 11—Temperature–depth profiles in drill holes at Sites B, C, D, and F. [Modified from Sass and Munroe (1970).]

completed in less than 1 year; only 4 months elapsed between the completion of testing at Site D and the temperature survey.

However, the profile for Site C, measured about 12 months after the completion of hydraulic testing, indicates cooler temperatures below –400-m altitude and less uniformity than do the profiles from the other sites. This indicates that cool water from shallow aquifers was flowing down the hole and entering deeper rocks in which heads were lower. These data demonstrate that the hydraulic gradient at Site C is downward.

commonly referred to as the Ghyben–Herzberg relationship, after the two independent originators of the concept, W. Badon Ghyben in 1888 and B. Herzberg in 1901. In the Ghyben–Herzberg relationship, a balance of head is assumed to exist at the interface of freshwater and saltwater, the height of saltwater from the interface to sea level exerting the same pressure as a somewhat higher column of less dense freshwater. If specific gravities of 1.000 for freshwater and 1.025 for seawater are assumed, this head balance under static conditions would occur at a depth below sea level (A_i on

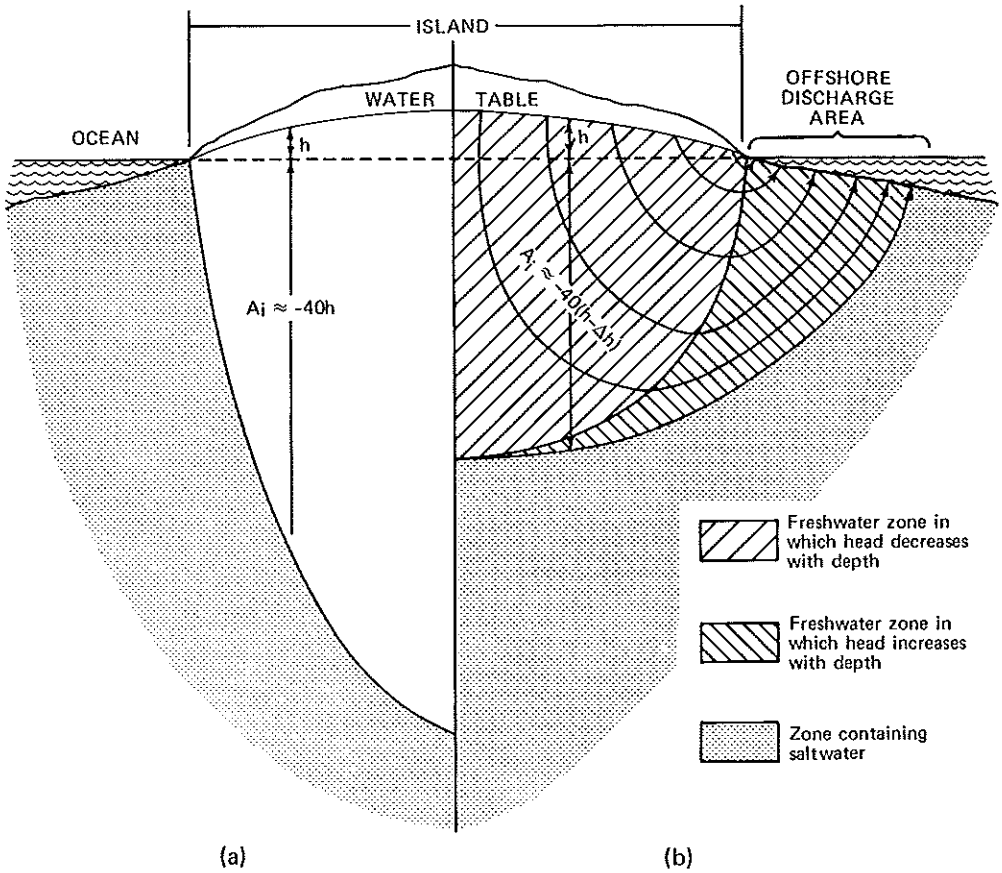

Fig. 12—Schematic comparison of positions of the interface between freshwater and saltwater under static and dynamic conditions. (a) Simplified approximation, assuming static conditions. (b) Approximation accounting for flow and head changes with depth.

Deep Circulation of Freshwater

Beneath oceanic islands and coastal areas, fresh groundwater flowing oceanward overlies saltwater that saturates openings in rocks at depth. In the ideal case of an island underlain by homogeneous and isotropic material, the freshwater body assumes a lenticular shape, bounded at its base by a concave-upward surface (Fig. 12). As noted by Todd (1959), the relationship between the altitude of the water table and the depth of the interface is

Fig. 12) equal to 40 times the height of the water table (h) above sea level. The resulting idealized lens takes the form shown in Fig. 12a.

In modern applications of the Ghyben–Herzberg relationship (Todd, 1959), it is recognized that such a lens could not be sustained under static conditions. The actual lens must extend out under the sea floor to provide a discharge area for the fresh groundwater (see Fig. 12b). Furthermore, as the fresh groundwater seeps through the rocks,

the head loss (Δh) due to friction reduces the pressure component of head at depth below that calculated for hydrostatic conditions. Consequently the interface between freshwater and saltwater must occur at a shallower depth than that predicted by the simplified Ghyben–Herzberg relationship, $A_i = -40h$. Finally, the interface is actually a zone of mixed freshwater and saltwater resulting from dispersion, ocean tides, seasonal fluctuations of the water table, and diffusion in response to salinity and temperature gradients.

Effects of Geology and Paleohydrology. Although the distortion of the simplified static lens by dynamic conditions is considered above, the conceptual model of fresh groundwater flow beneath Amchitka Island must be modified further to take into account the geologic framework as well as the hydrologic history of the island.

Downward and upward flow through stratified rock sequences requires large gradients as compared with gradients for flow parallel to stratification in the more transmissive units. Because the strata at Amchitka dip moderately (about 10° to 40° southwestward near Site C), even units that are several hundred meters or more beneath the surface at the center of the island probably intersect the sea floor. This geometric setting implies that most of the head loss in the deep groundwater system occurs during flow in the more-resistant downward direction whereas relatively little gradient is then required to expel the water to the sea through the aquifers. The result is that head declines with depth beneath the island at a greater rate than would be calculated for a homogeneous isotropic system. The actual depth of the freshwater lens, therefore, is less than it would be in the idealized setting.

Sea-level changes cause corresponding changes in the position of the Ghyben–Herzberg interface. However, the hydrology of Amchitka Island is not known in sufficient detail to predict the length of time needed to reestablish equilibrium flow conditions after significant changes in sea level. Gard (Chap. 2, this volume) indicates that sea level varied by probably several tens of meters as varying amounts of water formed ice during advances and recessions of Pleistocene glaciers. The last glacial advance, on the basis of ^{14}C dating of peat (Gard, Chap. 2, this volume), apparently ended about 10,000 years ago when sea level was about 30 m below that at present. For an unknown period before the continental glaciers had begun to melt, sea level was possibly as low as –90 m. As melting began on Amchitka, the potential recharge was probably so great that the water table was at the subglacial land surface, i.e., on the order of 10 m higher than the present water table, if the land surface was at the same altitude as it is today. If we estimate sea level to have averaged through several thousand years 10 m lower than it is at present, the freshwater head would have been about 20 m greater than at the present. Freshwater circulation beneath central Amchitka might have been as deep as 2500 m. However, Gard (Chap. 2, this volume) indicates that sea level has been essentially at its present level for the past 2000 to 4000 years. Whether the rocks beneath Amchitka are sufficiently impermeable or isolated from the oceans to have resisted adjustment of head to a rising or stable sea level in the past several thousand years is unknown, but intuitively it seems unlikely. A broad zone of mixing, relict saltwater in relatively shallow but impermeable rocks, and relict freshwater in deep impermeable rocks are among the complications that may have been caused by sea-level changes.

Salinity of Deep Groundwater. Samples of the water swabbed from intervals isolated by straddle packers in the exploratory holes at Sites B and C generally increased in salinity with depth of sampling. Dissolved-solids concentrations for these samples, reported by Beetem et al. (1971), are shown and compared with the concentration in seawater (about 35,000 mg/liter) in Fig. 13.

At an altitude between about –1050 m and about –1150 m, the dissolved-solids concentration at Site B reached the maximum observed, about 30,000 mg/liter. Considering that quantities swabbed were probably not sufficient to recover all the water that was injected during drilling, this

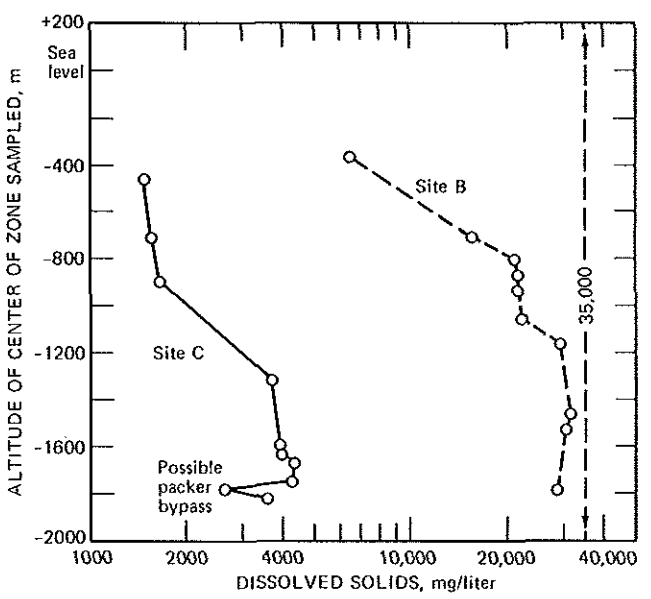

Fig. 13—Dissolved-solids concentrations of water samples from drill holes at Sites B and C.

concentration indicates that the interface between saltwater and freshwater is above −1150 m. The uniform concentration of about 21,000 mg/liter in the interval −800 to −1050 m may indicate water that was either diluted by drilling fluids or was drawn from a natural zone of mixing. These four samples were collected during tests conducted in a 24-hr period before the hole was deepened; the three samples immediately below (between −1150 and −1525 m) were obtained during a similar period a month later, whereas the deepest sample was swabbed after 3 weeks of additional drilling. Therefore the difference in dissolved-solids concentration between the zone −800 to −1050 m and the zones below cannot be considered significant unless it is strongly corroborated by other data.

The maximum dissolved-solids concentration in water samples taken as deep as −1800 m at Site C was only about 12% of the concentration in seawater (Fig. 13). Fresh surface water had been used in drilling the hole, but volumes of water similar to those lost in drilling were pumped from each interval of hole before hydraulic testing. Additional data were obtained in another hole only 35 m away.

The Cannikin emplacement hole at Site C was drilled over a 2-year period beginning near the end of hydraulic testing in the nearby exploratory hole. The emplacement hole, 2.3 m (7.5 ft) in diameter, was drilled with only minor losses of the mud circulant below an altitude of −1000 m. At the beginning of mining a chamber at an altitude of about −1725 m for the Cannikin device, a large inflow of mud, unhardened cement slurry, and water forced remedial measures and hydrologic monitoring. As reported by Ballance and Beetem (1972), the inflow soon cleared. The volume of water pumped from the chamber and attendant tunnels during the following 5 months exceeded 7000 m^3. The temperature of the discharge soon stabilized at about 41°C. The specific conductance of the water, about 6100 ± 600 μmhos/cm (at 25°C), remained about the same throughout the period. On the basis of chemical characteristics and temperature, Ballance and Beetem (1972) concluded that the inflow was derived from a zone at about −1650 m altitude. The specific conductance of the water was essentially the same as that of samples from the interval −1590 to −1750 m in the exploratory hole.

That the correlation of chemical data from the two holes is coincidental seems highly unlikely. We conclude that the data shown in Fig. 13 for Site C are substantially correct and that the freshwater lens extends to an altitude of at least −1700 m. The anomalously low dissolved-solids concentration in the sample from −1775 m is thought to be caused by dilution of the sample from water bypassing the upper packer during swabbing.

Head Relationships at Sites B and C. The correction of heads measured in straddle-packed intervals in the exploratory holes at Sites B and C was based on the salinity data in Fig. 13 and on two sets of temperature data. The maximum temperatures that might have predominated in the zones that are tested are those reported by Sass and Munroe (1970) and shown in Fig. 11. The minimum temperatures, caused by introduction of cold drilling fluids, are those determined in geophysical logs run before episodes of hydraulic testing.

The uncorrected and corrected head data for the two sites are shown in Fig. 14, beginning in the upper right corner of each graph. The uncorrected data show a distinct decrease of head with depth uniformly distributed at Site B but occurring mainly above −450 m at Site C.

Correcting the height of the water columns above the zones tested at Site B to an equivalent height of water at a specific gravity of 1.000 results in a significant increase of head because of the high salinity of the water. At an altitude of −1450 m, the correction is about +25 m; corrections for the possible temperature extremes, however, differ only by 4 m at that depth and are negative because water is less dense at temperatures above 4°C. The general downward gradient apparently persists after corrections at Site B, although under both of the extreme temperature assumptions the gradient appears to be slightly upward between −700 and −1050 m.

Because the water swabbed from intervals in the Site C exploratory hole was much less saline than that from Site B, the salinity component of the density correction is small. The temperature corrections dominate and result in corrected heads that are somewhat lower than uncorrected heads. The head values based on the minimum temperatures are believed to be the more realistic for zones below −1600 m because testing immediately followed the drilling of this interval, during which there was a large loss of fluids to the rock. The gradient is small in the downward direction, which is consistent with the temperature profile of Fig. 11.

Relation of Data to Ghyben–Herzberg Theory. Earlier in this chapter the altitude at which a balance of head would exist between freshwater above and saltwater below was expressed as $A_i = -40h$, where h is the corrected freshwater head at the depth of the interface. Because the temperature of the saltwater increases with geothermal gradient (28°C/km as determined from

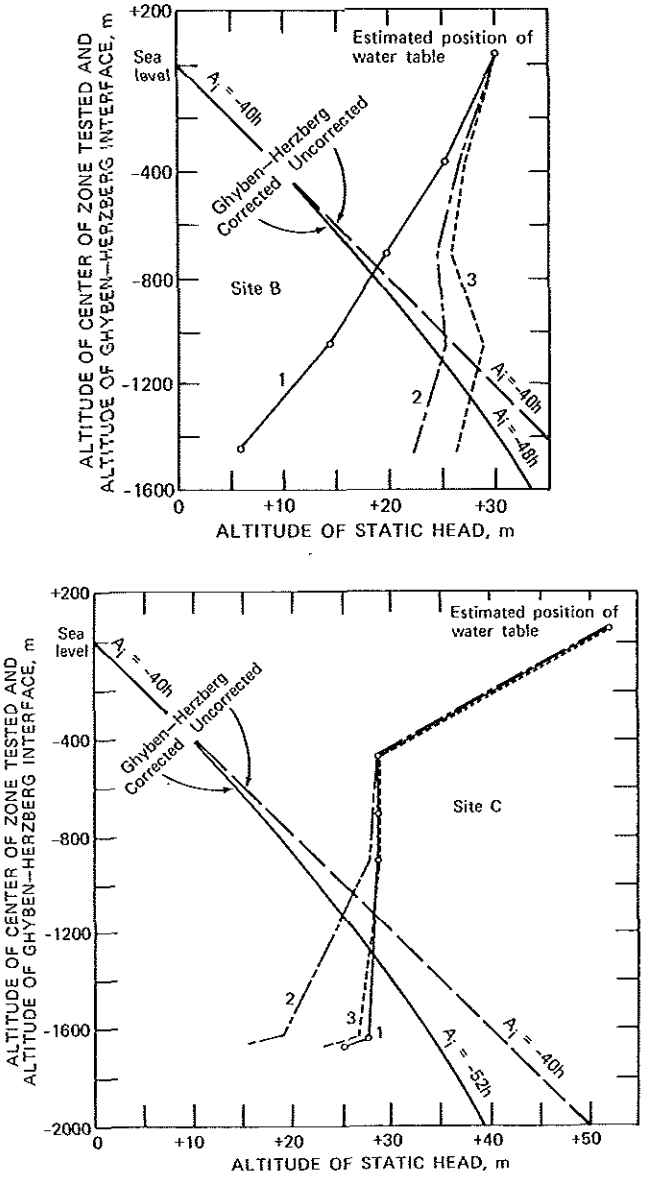

Fig. 14—Uncorrected and corrected static heads at Sites B and C and altitudes of Ghyben–Herzberg interface as a function of static head. Curve 1, uncorrected static heads. Curve 2, static heads corrected for salinity and maximum temperature. Curve 3, static heads corrected for salinity and minimum temperature.

Fig. 11), a density correction must be applied to the saltwater head also. As shown in Fig. 14, beginning at sea level the uncorrected Ghyben–Herzberg curve expresses the relationship $A_i = -40h$. The corrected curve was computed numerically in 50-m increments of depth and shows an increasing slope with depth. At −1400-m altitude, the slope is −48, whereas at −1800 m it is −52.

In theory the depth of the Ghyben–Herzberg interface should occur at the point of intersection of the curve expressing the corrected freshwater head with the corrected Ghyben–Herzberg curve. Head measurements (expressed as freshwater) below the depth of intersection, however, should coincide with the corrected Ghyben–Herzberg curve. As shown in Fig. 14, the head data from Sites B and C quite obviously do fall below the Ghyben–Herzberg curve. This is an enigma that apparently can be explained only in terms of inadequacy of data or test methods. Residual head drawdowns of 8 to 12 m in the lowermost zones of both holes, resulting from incomplete recovery from pumping before the swabbing tests, is a possible but too convenient explanation.

If the inconsistency of the data from the deepest zones is ignored, the head data suggest Ghyben–Herzberg interfaces at an altitude of −1000 to −1200 m at Site B and at an altitude of −1100 to −1300 m at Site C. When compared with the salinity data (Fig. 13), this range for Site B is reasonable if we attach significance to the salinity differences between the zone −800 to −1050 m and the zones below −1100 m. Earlier (see section on Salinity of Deep Groundwater) this difference was presented as probably not significant without strong corroboration. The head data do not provide sufficiently strong corroboration because of their inconsistency with theoretical head relationships below the freshwater lens.

There is one physically plausible explanation for the salinity difference at Site B, however. The sample at −720 m (Fig. 13) was obtained from a zone that has a transmissivity of about 3 m^2/day, a relatively high value for the deep groundwater system (Fig. 10). Tests in intervals at −800 m and −980 m, in contrast, indicated transmissivities that are among the lowest measured. Presumably freshwater can circulate with relative ease only to an altitude between −720 and −800 m. The zone from −800 to −1050 m, shown in Fig. 13 to contain water of apparently intermediate salinity, could reasonably be interpreted as a zone of mixing or diffusion above the Ghyben–Herzberg interface as selected by head criteria.

For Site B we are left, then, with the conclusions that a Ghyben–Herzberg interface does exist at an altitude not lower than about −1200 m, that the zone from about −800 to −1050 m may represent a zone of mixing or diffusion, and that the data are not sufficiently precise to eliminate uncertainties.

The data from Site C are even more perplexing. Figure 13 shows that the pattern of salinity change with depth at Site C, although the water was more dilute, is strikingly similar to that at Site B. Furthermore, in Fig. 14 intersections with the Ghyben–Herzberg line occur at similar depths at

both sites. Finally, an apparent deficiency of head exists below the intersection depths at both sites. Referring again to the discussion on salinity of deep groundwater, however, the salinity of the inflow to the Cannikin chamber so strongly corroborates the salinity data from the exploratory hole that we must conclude that the freshwater lens extends at least as deep as an altitude of –1750 m at Site C. It is possible to speculate that adjustment of the salinity interface has not occurred after deep flushing at a time of lower sea level. Supporting evidence is lacking, however. Quite possibly the head data are misleading, and the salinity data indeed show circulation of groundwater to at least –1750 m altitude.

EFFECT OF EXPLOSIONS ON DEEP GROUNDWATER FLOW

Nuclear explosions as large as Milrow (about 1 Mt yield) and Cannikin (approximately 5 Mt) have significant effects on hydrologic features. A complete discussion of these effects is beyond the scope of this chapter.

Disturbances of streamflow and oscillations of fluid pressure in the groundwater system in response to the Milrow explosion have been described by Ballance and Dudley (1970). Gonzalez and Wollitz (1972) have presented similar data for the Cannikin event and have related hydrologic response to seismic stress and motion. The thermal, hydraulic, and radiochemical processes acting in the Cannikin rubble chimney are described by H. C. Claassen (written communication, 1976).

The reports cited above discuss the relatively transient effects of Milrow and Cannikin. However, the penetration of the rubble chimneys deep beneath the surface of Amchitka Island has disrupted the geologic framework sufficiently that long-term effects on the deep flow system are a certainty.

The movement of water in the deep groundwater system under natural conditions is extremely slow, as indicated by the following four items:

1. Stream runoff is sufficiently great to remove most precipitation from Amchitka Island.
2. Transmissivities measured below altitudes of about –750 m are small as are downward hydraulic gradients.
3. The geologic framework suggests that vertical hydraulic conductivity is extremely small.
4. The dissolved-solids concentrations in samples from below altitudes of –400 m at Sites B and C are an order of magnitude or more greater than the concentrations in surface water and shallow groundwater.

However, if exit paths from the deeper aquifers to the oceans are available, which is probable based on currently known geologic conditions, disruption of the vertical resistance to downward flow by an explosion-produced rubble chimney would increase the depth of active or moderately active flow.

The introduction of a permeable vertical path would also decrease the head loss associated with downward flow. Because of the greater residual head at depth, the Ghyben–Herzberg interface must also move downward. Beneath Cannikin Lake, which now maintains a head at the surface of +35 m (115 ft) (Gonzalez et al., 1974), the permeable rubble chimney may allow most of this head to be applied to an altitude of at least –1800 m. From consideration of head relationships alone, the Ghyben–Herzberg interface could be depressed to below –1700 m, or well within the cavity region of the Cannikin explosion. The salinity data suggest that the interface might have been that deep even before the Cannikin explosion. In the altitude range of –1500 to –1800 m, which encompasses the cavity and lower rubble chimney, several zones were tested and found (Fig. 10) to have transmissivities between 0.15 and 0.7 m^2/day for 60-m depth intervals.

Data from Site B indicate that the rubble chimney from the Milrow explosion, which was detonated at an altitude of –1178 m in October 1969, opened hydraulic communication to relatively permeable zones at –700 and –1050 m altitude. The explosion cavity is within rock units having transmissivities of 0.04 m^2/day or less.

Groundwater Velocity

The possibility of freshwater circulation deep into nuclear-explosion sites makes it necessary to consider the velocity with which groundwater could flow and transport radionuclides from the explosion sites to points of discharge at the surface or on the sea floors. The parameters that must be evaluated to perform the calculations are effective porosity, hydraulic conductivity, and hydraulic gradient. Average hydraulic conductivity can be calculated as the transmissivity divided by the thickness of the interval tested. The data in Fig. 10 show the average hydraulic conductivity of the zones between –1500 and –1800 m to be about 3×10^{-3} m/day.

The hydraulic gradient from the Cannikin site (Site C) to the Bering Sea is the head (+35 m) of Cannikin Lake, less the head lost in downward seepage through the rubble chimney, divided by the length of the flow path from the lower rubble chimney to the discharge point. The probable flow-path length is 2500 m, a value chosen from a model presented by Fenske (1972) and consistent

with the geologic setting. If the hydraulic conductivity of the rubble chimney is on the order of 1 m/day, a value comparable to those of a uniform medium-grained sand or moderately fractured massive rocks, the loss of head in downward flow through 1800 m of the rubble would be less than 1% of the total head available. Consequently the average hydraulic gradient over the flow path from the lower rubble chimney to the Bering Sea is about 35 m/2500 m, or about 0.014.

The fracture porosity can be estimated from measured hydraulic conductivity and fracture spacing as observed in drill holes and mined chambers. The most intact rocks beneath Amchitka have fracture spacings of several meters; 10 m can be taken as an upper limit. The measured hydraulic conductivity is consistent with that of a moderately but not highly fractured massive rock; a fracture spacing of 0.5 m is a reasonable estimate for moderately fractured rock. The minimum average spacing—occurring in the basalt breccias penetrated by the Site C exploratory hole (Ballance, 1972)—is on the order of 0.05 m.

Snow (1968) related these parameters in the following equation, converted to units in use here:

$$n_f = 5.9 \times 10^{-4} \left(\frac{k}{d^2}\right)^{1/3}$$

where n_f is the fracture porosity (dimensionless), k is the hydraulic conductivity (meters per day), and d is the fracture spacing in the drill hole (meters).

The solution of Snow's equation for fracture spacings of 0.05, 0.5, and 10 m provides fracture porosities of 6.3×10^{-4}, 1.4×10^{-4}, and 1.9×10^{-5}, respectively. Corresponding average particle velocities are 0.07 m/day for the 0.05-m spacing, 0.3 m/day for the 0.5-m spacing, and 2.2 m/day for the 10-m spacing. The width of openings in a cubic set of uniform fractures, calculated from effective porosity and assumed spacings, would be about 5 μm for the closest spacing, 23 μm for the moderate spacing, and 63 μm for the 10-m spacing.

Snow's (1968) investigations in drill holes to depths of about 120 m at dam sites in igneous and metamorphic rocks indicate that fracture openings greater than 40 μm would be unusual below 100 m but that there is only a very gradual reduction of average fracture width below the 50-m depth. At depths as great as 1500 m, however, openings greater than 20 μm must be considered as highly improbable. It is more improbable, however, that the measured average hydraulic conductivity is concentrated in the interstices (between grains or crystals) of the basalts and basalt breccias at that depth at Site C.

The velocity range of 0.07 to 0.3 m/day, which correspond, respectively, to brecciated basalt and moderately fractured basalt, results in estimated travel times of 23 to 103 years over a 2500-m flow path. These estimates are based on the assumption that the hydraulic conductivities measured at depth at Site C are representative of the entire flow path. Since the southwestward dip of the geologic units provides probable intersection with the sea floor, thereby eliminating the need for cross-bed flow, this assumption is reasonable. It seems likely that water carrying the more mobile radionuclides, such as tritium, could begin to discharge on the floor of the Bering Sea within a century and possibly within a few decades.

The downward flow in the Cannikin rubble chimney will keep radioactivity concentrated near the base of the chimney, or below about −1500 m altitude. On the basis of the total transmissivity measured below this depth, the 0.014 gradient would allow this region to be flushed by a flow of about 20 m^3/day, a very low rate.

Among the factors that will lower the concentration of radioactivity in the water before discharge to the sea are:

1. Radioactive decay.
2. Adsorption on rock surfaces (except tritium).
3. Dispersive mixing with uncontaminated water in the rubble chimney.
4. Spreading of the contaminant plume, both by dispersive mixing and by divergence of flow lines from the chimney to a probably broad zone of discharge.

Although there are insufficient data to estimate the effects of these processes, the dilution will be large—from a few to probably several orders of magnitude. Further dilution by mixing of the slowly discharging groundwater with seawater will be sufficient that detection of radioactivity in above-background concentrations is considered very unlikely.

A similar analysis of the Milrow site provides comparable results. The moderately transmissive zones below an altitude of −1000 m, which before the explosion were below the freshwater lens, probably are now being flushed by chimney water toward the Pacific Ocean. The overall transmissivity of the zone intersected by the lower part of the rubble chimney is about the same as that at Site C, and the available hydraulic gradient is only slightly less.

CONCLUSIONS

Amchitka Island is drained principally by streams that carry direct runoff and sustained base

flow. The base flow is discharged to the streams and many lakes from a moderately permeable shallow groundwater reservoir. Because the water table is at or very near the land surface over most of the island, the shallow groundwater flow occurs within the tundra, soil, and peat as well as within the upper few hundred meters of underlying volcanic rocks. The quality of the surface and near-surface water is good. Salt spray driven by wind over the narrow island from the adjacent ocean influences the composition of rainfall, as indicated by ratios of sodium to chloride in water of the surface and shallow subsurface systems.

Geologic setting, hydraulic characteristics of the rocks, and the salinity of water within the deep groundwater system provide evidence that groundwater movement under natural conditions is very slow or nonexistent at the depths at which the Milrow and Cannikin nuclear explosions were detonated. The Milrow device was sited within nearly static saltwater below the lens of slowly circulating freshwater whereas Cannikin was probably within the freshwater lens.

Disruption of the rocks by rubble chimneys at both explosion sites is believed to have increased the depth and velocity of freshwater circulation. Although the data are sparse, it is estimated that, within a few decades to perhaps a century, water containing radioactivity from deep in the rubble chimneys will begin seeping slowly onto the ocean floor, where the radioactivity will be greatly diluted by mixing with ocean water.

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4

Weather and Climate

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Amchitka Island has a pronounced maritime climate. The day-to-day weather is marked by changeability because of the great frequency with which migratory pressure systems pass along the North Pacific storm track. In the absence of significant local effects, such as surface heating and nocturnal cooling, which exert a large influence on weather conditions at a continental location, the Aleutian weather results almost entirely from large-scale pressure systems and their associated weather fronts.

During the summer season fog predominates as a result of the advection of relatively warm, moist air over the colder ocean surface. The air in the air—sea interface layer is cooled to the saturation point, and extensive fog results. The summer fog often persists for days at a time.

The Air Resources Laboratory—Las Vegas (ARL—LV) experience during relatively short periods of residence on Amchitka in connection with Atomic Energy Commission (AEC) activities there bore out my hypothesis that climatological data available from a 5-year period in the 1940s adequately defined the local climate and weather. During most of the period that Amchitka was in use by the AEC, airways weather observations were made by airport control-tower operators during periods of tower operations. These data were not continuous, were not under ARL—LV control, and were not summarized. The control-tower data did, however, substantiate the validity of the earlier climatological data. Except for the solar-radiation data, data given here are from the 5-year nearly continuous weather observations of the 1940s. Table 1 contains general climatological data.

Solar radiation was not measured during military occupation. A pyranometer installed at the airport control tower measured the solar radiation, and the limited data obtained are included.

TEMPERATURE

The moderating effect of the surrounding seas is evidenced by the limited ranges of temperature at Amchitka (Fig. 1). The mean daily range is 3.9°C (7°F) or less in all months, and the annual range of the mean daily temperature is only 9.4°C (17°F). By contrast, a continental station (Saskatoon, Saskatchewan) at approximately the same latitude has an annual range of 36.1°C (65°F).

LOW CLOUDINESS

Clear skies are extremely rare at Amchitka (Fig. 2). Fog or clouds below 2972 m (9751 ft) above the airport elevation (67 m, 220 ft) cover more than half the sky most of the time. Low ceilings (more than half the sky covered) and fog occur with greatest frequency during the summer months. In the other three seasons, brief periods of clearing skies follow the passage of migratory storm systems.

FOG, RAIN, AND SNOW

Figure 3 points up the prevalence of fog during the summer months. The high frequency occurs because the seawater is colder than the air that flows over it. The air is cooled, condensing its moisture.

Although mean annual precipitation at Amchitka is not excessive, 828 mm (32.6 in.) compared with 991 mm (39 in.) for Seattle, precipitation in some form is experienced one-fifth or more of the time in all months, with the most frequent hourly occurrence during the summer months (Fig. 3). The average number of days per month on which precipitation in the indicated amounts is

Table 1—Climatological Data for Amchitka Island, Alaska, from February 1943 Through June 1948*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Temperature, °C													
Record high	7.2	6.1	9.4	8.3	9.4	13.9	18.3	15.0	13.9	10.6	10.6	7.2	18.3
Mean daily max.	1.1	1.7	2.8	4.4	5.6	7.8	9.4	10.6	9.4	7.2	4.4	2.2	5.6
Daily mean	−0.6	0.0	1.1	2.2	3.9	5.6	7.8	8.9	7.8	5.6	2.8	0.6	3.9
Mean daily min.	−2.2	−1.7	−1.1	0.6	2.2	3.9	6.1	7.2	6.1	3.3	1.1	−1.1	2.2
Record low	−8.9	−10.0	−6.7	−6.7	−1.1	0.0	2.2	3.3	2.2	−2.2	−5.6	−5.6	−10.0
Av. No. of days with a minimum of													
<−4.4°C	3	2	2	1	0	0	0	0	0	0	†	1	9
<−2.2°C	12	9	6	2	0	0	0	0	0	0	1	6	36
≤0.0°C	28	24	22	13	3	†	0	0	0	2	10	22	124
Av. No. of days with a maximum of ≤0.0°C	9	6	4	1	0	0	0	0	0	0	1	6	27
Precipitation, mm													
Mean monthly	71	51	33	58	41	25	89	104	74	97	71	114	828
Av. No. of days with													
≥0.25 mm	19	17	13	13	11	13	16	20	16	20	20	20	198
>6.35 mm	4	2	1	2	3	1	4	6	4	5	2	6	40
>12.70 mm	1	†	0	1	1	0	3	3	1	2	1	3	16
Percent of hours with rain	9	11	13	24	28	29	40	41	26	21	23	14	
Percent of hours with snow	18	24	16	9	2	†	†	0	0	1	5	15	
Snow depth at 0800 local standard time, cm													
Av. No. of days with depths of													
≥2.54 cm	17	13	1	†	0	0	0	0	0	0	3	7	41
>5.08 cm	15	10	0	†	0	0	0	0	0	0	2	5	32
>15.24 cm	4	3	0	0	0	0	0	0	0	0	0	1	8
>30.48 cm	1	0	0	0	0	0	0	0	0	0	0	0	1
Surface wind													
Mean speed, m/sec	11	11	11	9	8	7	7	8	8	9	9	11	9
Percent of hours with speed ≥14 m/sec	29	28	26	19	6	4	3	4	9	16	19	28	16

*From U. S. Department of the Air Force, no date (a) and no date (b).
†Less than 0.5 day or percent.

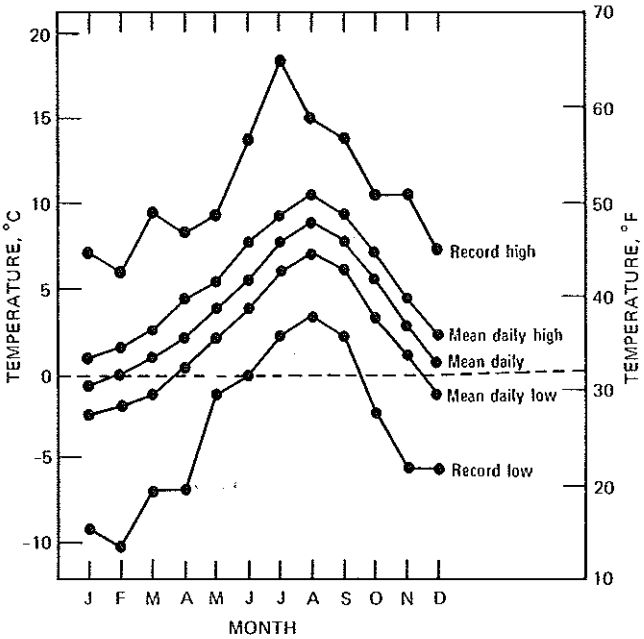

Fig. 1—Monthly temperature data.

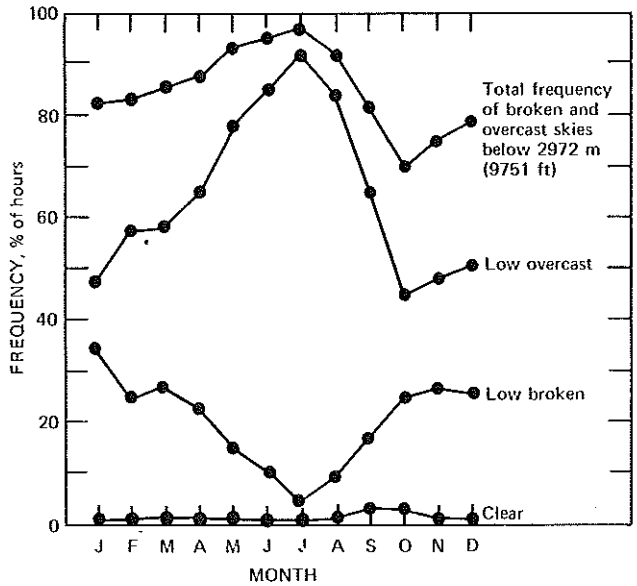

Fig. 2—Sky condition.

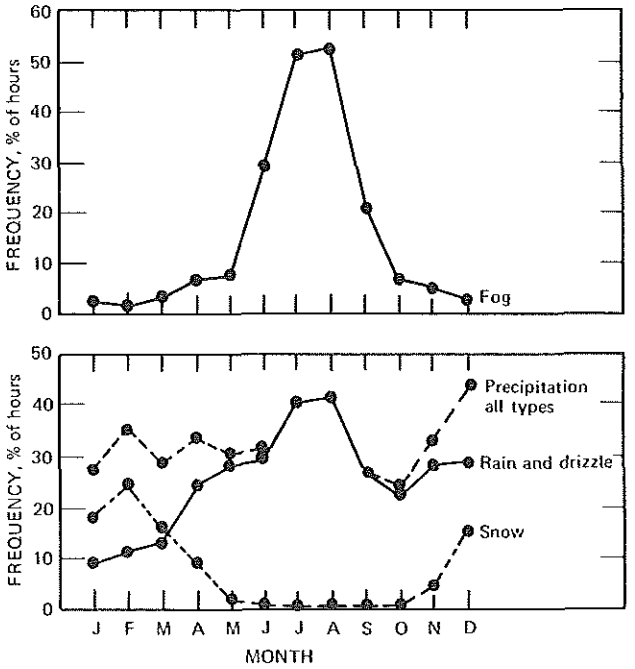

Fig. 3—Fog and precipitation frequency.

observed and the mean monthly precipitation (in millimeters and inches) are shown in Fig. 4. Data for the period October 1967 through June 1972 are given for comparison with mean monthly precipitation data for the 1940s. The mean annual total precipitation for February 1943 through June 1948 was 828 mm (32.6 in.); that for October 1967 through June 1972 was 953 mm (37.5 in.).

The 15% excess in mean annual precipitation of the later data over the earlier is not considered significant when one notes (from the later data) that the highest values in each month exceed the monthly means by values ranging from 20 to 107%.

SURFACE WINDS

The extreme variability of surface-wind directions at Amchitka is a result of the high incidence of migratory pressure systems. Figure 5 shows the seasonal paths of surface low-pressure centers. These storm tracks are based on data available from 1899 to 1954.

There is no prevailing wind direction as such at Amchitka, as shown by Fig. 6. There is little, if any, topographic channeling of the winds at the low end of the island where the data were taken. Summer winds tend to blow from the southwest quadrant because of the semipermanent high-pressure area that persists in the Gulf of Alaska during the summer months.

Figure 7 shows the monthly mean wind speed and percentage frequency of hours with wind speeds equal to or greater than 14 and 21 m/sec [32 and 47 miles per hour (mph), respectively]. Wind speeds may exceed 45 m/sec (100 mph) in the Aleutians. In January 1969 the wind speed exceeded the 100-knot (51 m/sec, 115 mph) instrument scale at the Amchitka base camp.

CLIMATE OF B AND C SITES

In a climatological sense, the data for the airport [elevation, 67 m (220 ft)] are considered entirely applicable to the B site [40 m (131 ft)] and the C site [63 m (207 ft)] (see Fig. 11, Chap. 1).

We have observed that over the relatively low southeast part of the island there is no significant spatial variability in the large-scale wind direction and speed. True, eddies may be induced by small hills, gullies, etc., quite near the ground in the microscale circulations, but no instrumentation sufficient to define these microscale circulation patterns was ever used at Amchitka.

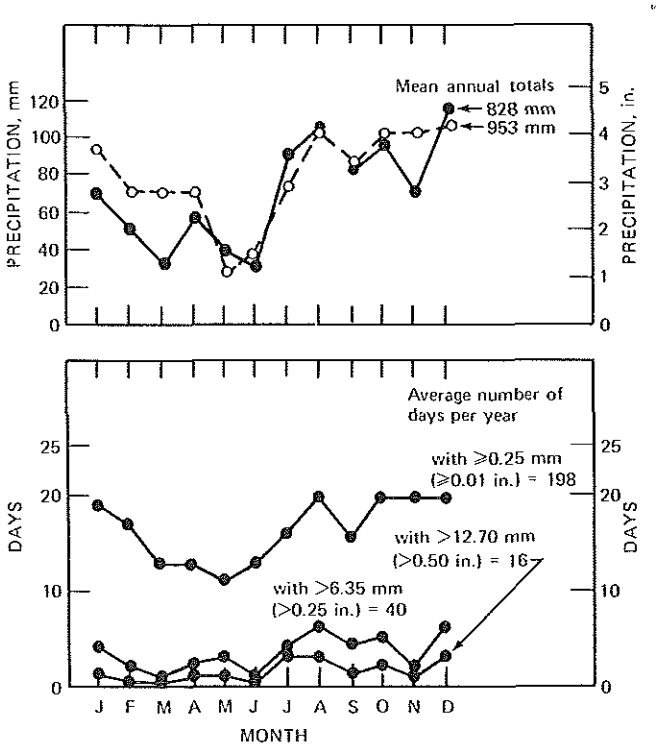

Fig. 4—Precipitation amounts and frequency of occurrence. ○---○, October 1967 through June 1972. ●—●, February 1943 through June 1948.

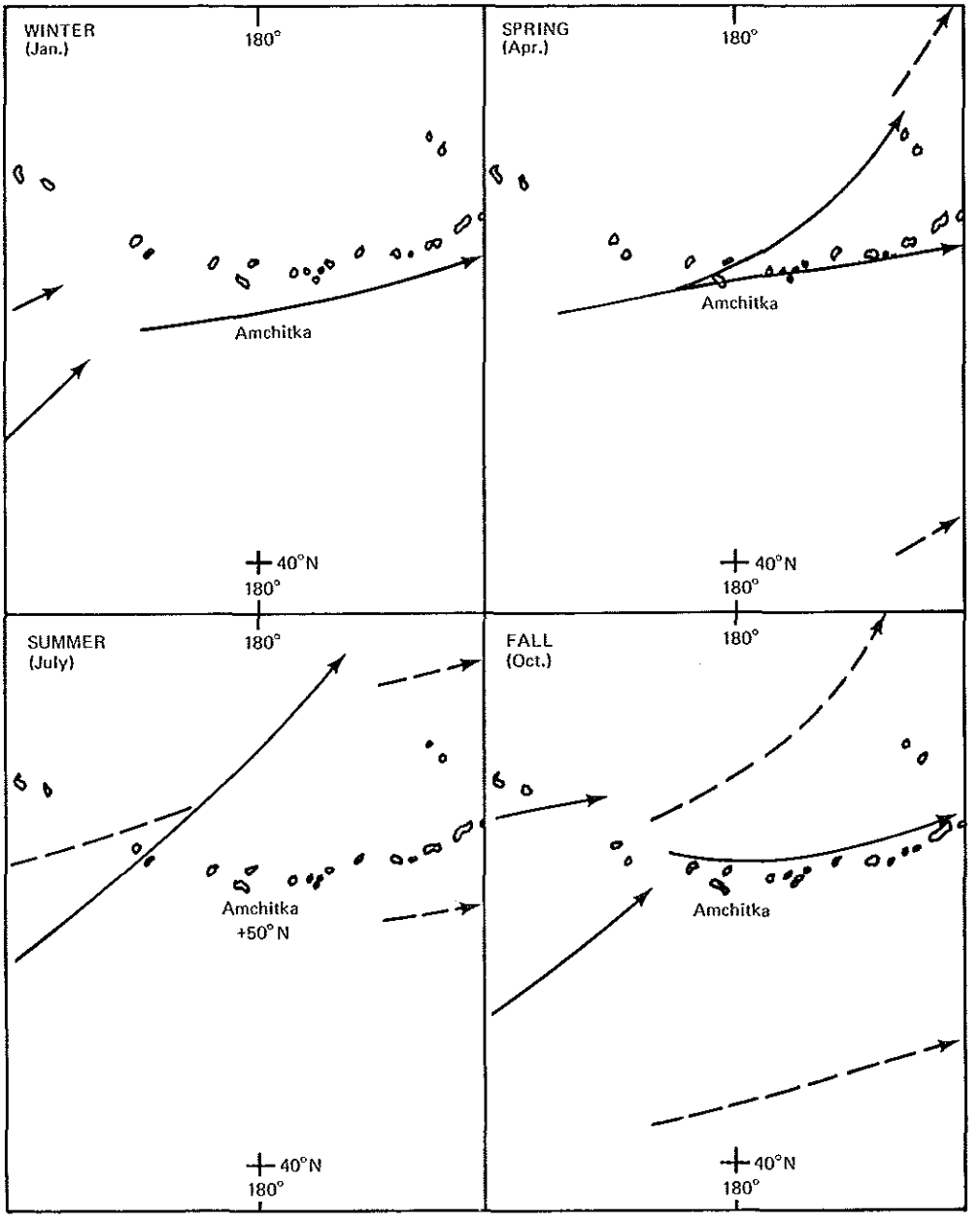

Fig. 5—Seasonal storm tracks, North Pacific Ocean (from Klein, 1957). Solid lines denote clearly defined (primary) tracks; broken lines denote less frequent or less well defined (secondary) tracks.

In a marine environment such as Amchitka's, one cannot conceive of significant temperature changes over such relatively short distances [B is 8 km (5 miles) and C is 16 km (10 miles) from the airport] or through a height change of only 4 to 27 m (13 to 89 ft), and, in the absence of pronounced terrain-feature differences, precipitation amounts or intensities would not be expected to vary beyond the limits of measurement accuracy.

Thus the long-term airport climatological data represent the best available data for the B and C sites.

CLIMATE OF THE HIGHLANDS

Climatological statistics presented here are applicable to the low southeast end of Amchitka for which long-term data are available. They only approximate conditions for the relatively mountainous areas of the island since most meteorological elements are affected by elevation, slope, and terrain shielding.

In general, one would expect the weather to be more severe in the highlands. Temperatures, in the absence of surface inversions, are usually lower

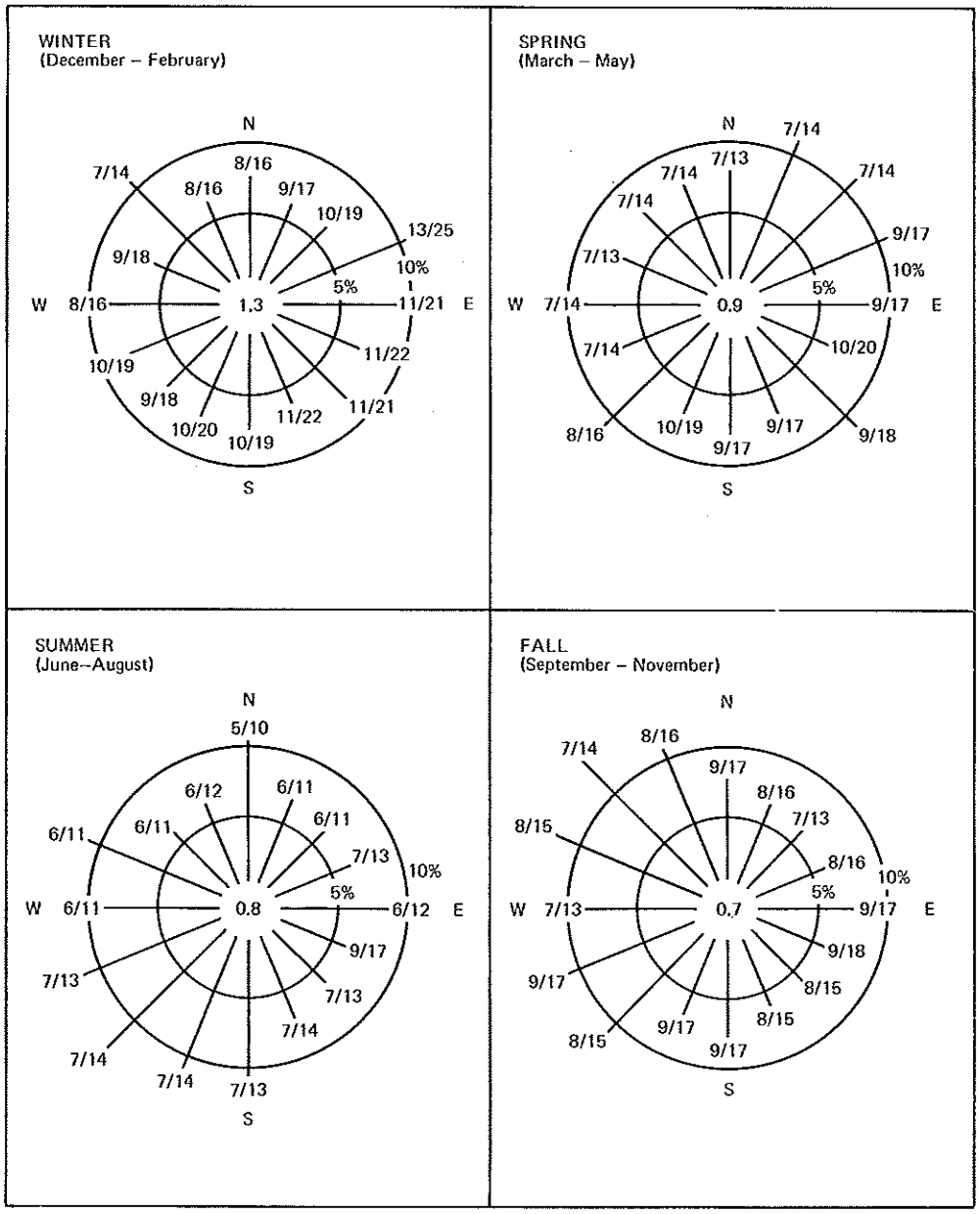

Fig. 6—Seasonal surface wind roses. The length of each direction bar represents the percent frequency of wind from that direction. Numbers at the end of each bar represent mean wind speed (meters per second/knots). The number in the center of the rose is the percent of calms.

with increasing altitude. Low clouds over the southeast end of the island would often be fog in the mountains. Moderate rain over flat terrain is often accompanied by heavier rain in nearby mountains, and, certainly, more snow accumulates and remains longer at high than at low elevations. The effect of elevation on temperature and the increase in wind speed caused by channeling over rugged terrain result in more severe storms in the mountains than in the lowlands.

SOLAR RADIATION

A pyranometer was installed at the airport control tower in February 1969 to obtain solar radiation data for the bioenvironmental programs. Fairly complete data were obtained from August 1969 through November 1971.

The pyranometer measures global solar radiation received on a horizontal surface. This includes both radiation received directly from the

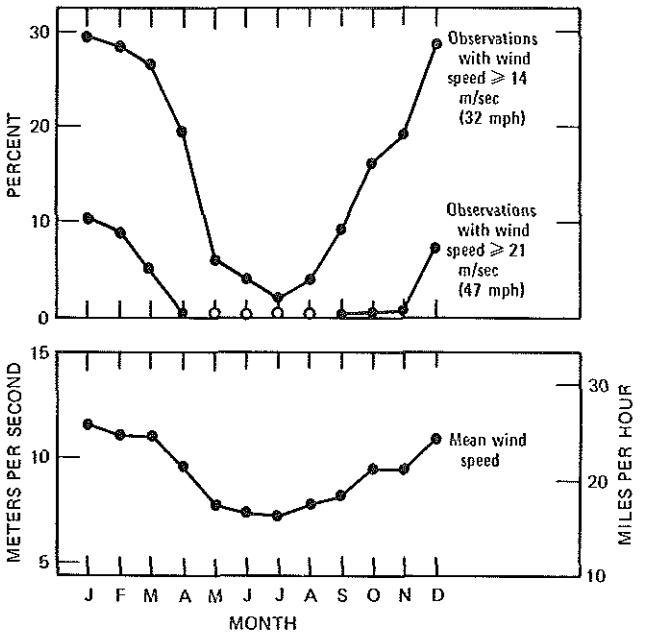

Fig. 7—Surface-wind speeds.

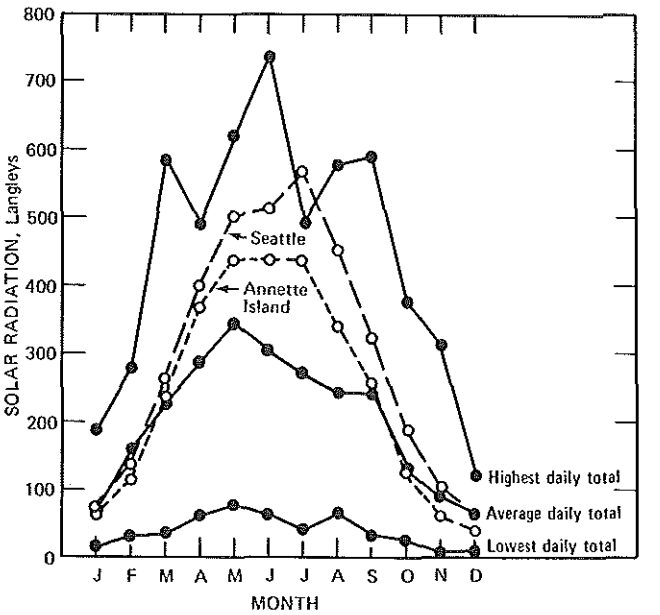

Fig. 8—Solar-radiation data.

solid angle of the sun's disk and radiation that has been scattered or diffusely reflected in traversing the atmosphere (sky radiation). The ratio of the sky radiation to the global solar radiation fluctuates markedly, from near unity when the sky is densely overcast to less than 0.1 under extremely clear conditions.

Figure 8 gives maximum, minimum, and average daily totals of solar radiation at Amchitka and, for purposes of comparison, the average daily totals for Seattle (~47.5°N) and Annette Island, Alaska (~55°N). The large differences between average daily totals for Amchitka and Seattle during the summer months may be accounted for by the fact that Seattle has a mean sky cover (sunrise to sunset) of about 50% (U. S. Department of Commerce, 1968) in summer, whereas fog predominates in the summer months at Amchitka.

The Amchitka data must be used only in a qualitative sense because of several uncertainties. Pyranometers in continuous operation require frequent inspection and cleaning (daily or oftener). There is no assurance that this was done since care of the pyranometers was by control-tower operators whose primary concern was certainly not accurate solar-radiation measurements. Frozen precipitation on the exposed envelope affects instrument accuracy, a factor that should be considered during the winter months. For these and other reasons, the data are not to be considered comparable with data from an observatory where particular emphasis is placed on obtaining solar-radiation data.

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5

Prehistoric Human Occupation of the Rat Islands

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Prehistoric Rat Islanders had an almost exclusively marine adaptation to their island group of 10 large to small islands. A large part of the Aleut population lived on Amchitka but interacted widely within the group for subsistence and social reasons.

Most previous archaeological investigations in the Rat group have been on Amchitka. Stress is placed in this chapter not on resulting artifact collections but on determinants of site location and how prehistoric Aleuts subsisted. Island size and shape, isolation, ecologic richness, and vulcanism are environmental variables thought to be important in differentiating one island from another. For any one island, such considerations as accessibility, exposure, resources, and defensibility make some coastal areas more suitable for village locations than others. Most Rat Island sites are relatively low sites with easy access to the sea.

Subsistence is organized into eight major procurement systems of hunting, fishing, and gathering on open seas, littoral zones, or inland areas. These eight systems provided a stable subsistence pattern that, in turn, supported a large maritime population. Biotic variations between the Rat Islands suggest that Amchitka, Kiska, Rat, and Buldir were the most rewarding islands to exploit.

Because of their primitive technology and manner of building, prehistoric Aleuts had only limited long-range impact on the islands they occupied or on the fauna and flora they utilized. Their impact on the Rat Islands was indeed small when compared with that of modern man, especially World War II personnel.

Rat Island culture was similar to that developed in adjacent island groups. Conformity of artifact styles throughout the western Aleutians indicates the extensive social interaction that occurred among communities of this same area.

Modern man's impact on the western Aleutian Islands is all too obvious. Artifacts of our civilization are unavoidable to today's visitor. World War II roads, quonset huts, gun emplacements, recent Atomic Energy Commission (AEC) construction, and plastic trash accumulating on beaches from offshore fishing fleets all give evidence of man's intermittent presence.

Given the present scars on this fragile, subarctic biome, one might wonder about the counterparts deep in the area's prehistory. What debris and constructions did ancient Aleuts leave on the shores, and what were their collective effects on local ecosystems? We can provide only partial answers to these queries, and they are outlined here. This chapter summarizes what is known of human spatial factors, exploitation patterns, and cultural interaction. Our attention is focused on the reconstruction, incomplete as it is, of prehistoric Aleut participation in the prevalent marine ecosystem. Specifically, this participation is viewed within the Rat Island group, one of the major island clusters comprising the Aleutian archipelago. Thus this approach is simultaneously ecological and regional.

HUMAN ECOLOGY

Owing to the extensive environmental studies of Amchitka Island under AEC sponsorship, that island stands out as the best studied of any in the Aleutians. Scientists have accumulated much information about the island's physical environment and the biota inhabiting it and the surrounding seas. Because the majority of the biologic studies stress an ecological perspective, it is appropriate that man's participation also be summarized from the perspective of human interaction in various ecosystems.

Man adapts, as other organisms, by genetic and physiologic means, but man principally adapts through cultural mechanisms and therefore is unique among all life native to the islands. Such adaptive mechanisms are treated here to demonstrate how prehistoric Aleuts subsisted in the various ecosystems discussed in the other chapters of this book. It is subsistence that impinges most on the collateral Amchitka studies.

However, this summary describes not the totality of studied ecosystems but rather those in which man principally interacted. In delimiting man's

niche, we selectively integrate the relevant ecologic factors cutting across disparate ecosystems but characterizing man's existence. In this manner habitats and ecosystems treated by other investigators will be referred to only as they are exploited or affected by man.

This summary does not attempt to recreate all aspects of Aleut culture through archaeological or ethnohistorical approaches. For instance, we have no living Aleut population subsisting at a hunting and gathering level similar to that of the past. Therefore we cannot study ongoing Aleut energy flow as has been done among other contemporary hunters or farmers (Kemp, 1971; Rappaport, 1971) to discern past subsistence or ecologic interaction. At best, we can combine our archaeological and ethnohistorical data to suggest the general marine exploitation patterns followed by ancient Aleuts. Midden remains display direct evidence of subsistence, and therefore it is this broad area that we shall emphasize.

MARINE ADAPTATION

Today's visitor will note that the total native occupation of the western Aleutian Islands for several millennia left an insignificant physical record compared with modern occupations. Nevertheless, some alterations resulting from consistently occupying specific localities have had long-term effects. House construction and midden enrichment make these localities apparent today.* Most impact, however, was of a short-term nature, especially the impact relating to hunting and collecting, and demonstrates the close and direct interaction Aleuts had with various organisms and inorganic raw materials.

Besides interacting at a lower and less-intense technologic level than modern occupants have, prehistoric Aleuts interacted with a basically different aspect of the physical environment, the marine part, and less with the terrestrial part. The Aleuts had an almost total commitment to the sea. Land was a stable base of operations and retreat from foul weather, but, in subsistence terms, land was only important as it formed beaches that could be combed, lookouts for animal activity at sea, or natural concentration areas for marine mammals, birds, and fish.†

Travel depended on large and small skin boats, the majority of food was secured from the ocean, and many raw materials were derived from sea-mammal exploitation. To the degree that Aleut technology via watercraft made essentially all the coastline accessible, the varied marine habitats along these shores were exploitable. Thus man, as the most flexible or generalized omnivore, was able to expand his dependence in more-varied habitats than any other Aleutian animal. At the same time, Aleuts essentially ignored many natural communities studied recently by ecologists because these could contribute few food resources. Exploitation of natural terrestrial communities was generally inversely proportional to their elevation above sea level and their distance from the shore.

Our ultimate measure of successful adaptation is found in the evidence of man's spread and the duration of his occupancy throughout not only this island group but also the entire archipelago. Aleuts lived on all large and most small islands and did so almost continuously for at least 2500 years in the west and 4000 years in the east.

AMCHITKA AND THE RAT ISLANDS

Amchitka has been the focal point of recent AEC-sponsored research, but, because man traveled widely in skin boats, prehistoric Aleuts cannot be adequately studied from one island locale. We may understand the characteristics of Amchitka's site distribution, population size, and subsistence patterns only in the regional framework of the entire Rat Island group.

The Rat Island group is clearly separated from adjacent island groups by Amchitka Pass on the east and the wide interisland passes surrounding Buldir Island to the west. This island group forms a natural spatial unit in which to operate, although Buldir is comparatively isolated and is included in the Rat group somewhat arbitrarily. Because danger from boating accidents is largely a function of water distance and turbulence, we may safely presume that early Aleuts also moved less frequently across these major passes than among the Rat Islands proper. Tides and currents between the Pacific Ocean and the Bering Sea in these passes today present the same boating problems faced by past kayakers. Within the Rat group, however, travel was relatively easy. On clear or semiclear days, other islands loomed large on the horizon (see island profiles on pp. 6 to 8 in Murie, 1959). In summary, water barriers around the Rat group created human behavioral boundaries that limited intergroup interaction.

Travel within the Rat group was not only possible but was required. Interisland travel, for

*Midden sites are pockmarked with house depressions; have lush dark-green vegetation stands dominated by *Heracleum lanatum, Angelica lucida, Ligusticum hultenii, Elymus arenarius mollis, Claytonia siberica,* and *Achillea borealis;* and have soils of high porosity, low temperature, and high organic matter, calcium, nitrate, and phosphorus (Bank, 1953). Figure 5 in Chap. 1 illustrates the manner in which midden sites stand out on the coastal landscape.

†For a discussion of island ecosystems and human adaptations to them, see Fosberg (1963).

example, was a requisite part of subsistence exploitation. The Rat Islands are dissimilar in their food animal population sizes and in the presence or abundance of various rock and mineral resources serving as essential raw materials. A normal seasonal round would typically take an Aleut hunter, if not his family, to several islands in pursuit of foodstuffs and materials. Feasts or festivals often occurred between villages from different islands.

Volcanic eruptions in any of the group's several volcanoes likely caused a mass exodus to nearby islands for safety from raining ash. Attack from outside Aleuts also could have forced villagers to flee to another island for refuge.

Thus, to understand the relationship between Amchitka islanders or any other island population within the entire Rat Island sphere, we must approach the whole island group as an integrated series of ecosystems.

Finally, this chapter admittedly contains some necessary speculation owing to the incomplete archaeological record and our difficulty in interpreting that record. Precise delineation of settlement and ecologic factors is accordingly limited. Relatively few sites have been excavated in the Rat group, and a larger sample would permit interpretation and explanation at a higher level of confidence.

HISTORY OF ARCHAEOLOGICAL RESEARCH

Archaeological investigations of the Rat Islands span a period of a century. Dall (1877, pp. 47-48 and 51; 1878, p. 8) first excavated at Constantine Harbor, Amchitka (Site 3), in 1873. Hrdlička (1945, pp. 220-237 and 347-364) dug on Kiska and Little Kiska in 1936 and at Amchitka Sites 2 and 3 in 1938. World War II brought a large military population to the islands, which caused the most extensive damage to prehistoric sites since their initial occupation (Guggenheim, 1945). Summaries of archaeological investigations during and prior to 1945 in the western Aleutians are found in McCartney (1967, pp. 10-20), Turner (1970, pp. 118-119), Desautels et al. (1971, pp. 20-21), and Fuller (Chap. 7, this volume).

The interest of AEC in Amchitka as a testing ground renewed archaeological reconnaissance under the aegis of that agency. Fieldwork during 1968, 1969, and 1971 centered primarily on (1) inventorying all sites seen on the surface today,* (2) making test excavations in some of these sites, and (3) evaluating the effects of nuclear detonations on such sites. Results of the AEC-sponsored research are presented in publications by Turner (1970), Desautels et al. (1971), Cook, Dixon, and Holmes (1972), and Merritt (1972). These results are summarized in the sections that follow.

Other recent archaeological research includes site surveys in the Rat group. Bank (n.d.) inventoried four sites on Rat Island and four on Kiska Island during the 1950s. McCartney (1972, pp. 25-26) surveyed 22% of the Rat group coast in 1972 by boat and added five possible sites on Little Sitkin, Khvostof, and Segula islands.

The only archaeological excavations and testing within the Rat group have occurred on Amchitka, Kiska, and Little Kiska. The coastlines of all the islands except Semisopochnoi have been surveyed for sites, but islands other than Amchitka have not been surveyed with equal rigor. Additional sites on these other islands will undoubtedly be found in the future.

1968 Reconnaissance

During 1968 Sense and Turner began with the Guggenheim (1945) site inventory of 40 known sites and expanded the total to 76. W. S. Laughlin, R. F. Black, and L. M. Gard also assisted Sense and Turner in their testing of 14 of the sites. Approximately 1400 stone and bone artifacts came from these tests, but their descriptions have not been published (Desautels et al., 1971, p. 21).

Turner (1970) briefly described test excavations at Sites 1, 2, 3, 13, 14, and 15 and human skeletons and fragments from Sites 3, 14, 15, 16, and 23. He estimated, on the basis of midden accumulation rate, that Amchitka sites dated to as long as 2500 years ago. This figure is substantiated by radiocarbon dates from lower levels of Sites 31 and 36 (range, 890 ± 90 to 2550 ± 95 B.P.; Desautels et al., 1971, p. 384). No sites as large as those known in the eastern Aleutians (e.g., Chaluka on Umnak) were noted.

The most important summation provided by Turner is that regarding determinants of site location. He notes that (1) site distribution is not random, most sites occurring in the southeastern half of the island; (2) sites typically were protected in embayments, were close to freshwater and food-rich intertidal habitats, had water approaches protected by kelp beds, and had easy access to the beach; and (3) no correlation was apparent between sites and driftwood sources or gross geologic formations. These site characteristics are explored at greater length in this chapter.

The 1968 collections have not, to date, been fully analyzed and published; they are now in the possession of the University of Alaska Museum

*Site locations on Amchitka are indicated in Fig. 1.

with the other AEC-sponsored collections. I have not personally inspected any of these collections.

1969 Excavations

The report of Desautels et al. (1971) is the primary descriptive document for Amchitka excavations and artifacts. Six sites (10, 14, 31, 35, 36, and 60) were tested during 1969, and 6800 artifacts were recovered from these tests. These six sites were chosen because they seemed most likely to be disturbed by nuclear detonations at the central and southeastern portions of Amchitka. Two additional sites (77 and 78) were added to the site inventory.* Six radiocarbon dates were determined, three each for Sites 31 and 36. Site 31 dates range between 600 BC and AD 1060 and come from a depth of 70 to 190 cm; Site 36 dates cluster between 295 and 105 BC, all being from 210 to 270 cm deep (Desautels et al., 1971, pp. 38, 48, and 384). The report fully presents the stratigraphy and features for the midden tests. Almost all the features are fire hearths (Sites 31, 35, and 36) or burials under wooden covers or within wooden sarcophagi (Sites 10 and 14) [similar burial features are described by Dall (1877, pp. 62-63; 1878, p. 8), Jochelson (1925, pp. 45-46), Weyer (1929), and Hrdlička (1945, pp. 179-180)]. Three skeletons, one adult male, one adult female, and one child, were found in Sites 10 and 14. No houses were uncovered.

The large artifact collections include 11 iron fragments, primarily of knife blades, and some of these, if not all, are of prehistoric age. These iron fragments are from Sites 14, 35, and 36. The artifact analysis is a formal, hierarchic classification of descriptive categories including four levels. No major stylistic or cultural changes were noted by the excavators in any midden sequences. A late artifact complex was suggested for the period AD 1000 historic contact. This complex includes nine classes or general techniques from specific kinds of bone needles to "new styles of bone ornamentation."

A faunal analysis of Site 31 debris indicates that the bone sample breaks down into approximately 85% fish, 10% sea mammal, and 5% bird bones by weight. Of the sea mammals, 59% are sea otter, 33% are harbor seal, 6% are sea lion, and 2% are fur seal by bone count (Desautels et al., 1971, pp. 314-340 and 359-367). Whale bones are also found in low unspecified frequency (Desautels et al., 1971, pp. 38-39). Sea urchins comprise over 90% of the marine invertebrate remains. This analysis is consistent with the midden matrixes of other eastern and western island groups.

1971 Excavations

Additional site excavations were made in 1971 at Site 32 in the middle of the Pacific Ocean side of Amchitka (Cook, Dixon, and Holmes, 1972). This site was considered to be endangered by the projected 1971 Cannikin detonation. The major contribution of this work was the excavation of a complete house dating to about AD 1500. Four radiocarbon estimates date the Site 32 midden between AD 85 and 1750. A total of 546 artifacts were recovered in the 1971 tests.

Of a total of seven possible houses noted at the site, only one was completely excavated. This house is the only fully uncovered house yet described in detail in the chain. Another house or two have been fully excavated at Chaluka midden, Umnak, but no details have been published. Previous tests at other Amchitkan sites have uncovered only portions of house features. The Site 32 house measures 7.5 by 6.0 m in outside dimensions, was built directly on bedrock, and was built almost entirely of driftwood rather than whale bones. Because of the rock base, which prevented drainage, the structural members of the house have been preserved by groundwater saturation since the house collapsed. The Aleutian pattern of covering house roofs with sod made it possible for the wet sod to seal in and protect the wooden wall and roof pieces from wind dispersal or weathering.

The site reports by Desautels et al. (1971) and Cook, Dixon, and Holmes (1972) are important contributions to western Aleutian archaeology. Only Jochelson (1925, pp. 24-26) and Spaulding (1962) report on systematic site excavations in the

*Of the 78 sites thus far designated, 2 (Sites 20 and 21) are of historic age. Sites 24, 77, and 78 are designations for blowouts (areas of wind deflation) atop a high bluff at the center of the Bering Sea coast. Besides the fact that no midden debris or recognizable features were noted by Sense or Desautels at these blowouts, the "artifacts" alone are questionable. Because there are essentially no recognizable Aleut artifact forms among the illustrated examples (Desautels et al., 1971, pp. 376-383) which relate to the other midden sites, we must assume that, if these are, in fact, human occupation sites, they are much earlier than the middens that are as much as 2500 years old. If we assume that these pieces represent a prior and heretofore unrecognized Aleutian culture, they should show some relationship to the only early human assemblage in the chain, the Anangula core and blade industry off Umnak (McCartney and Turner, 1966). However, no prismatic blades, polyhedral cores, transverse burins, and related tools were found at Sites 24, 77, and 78. Some cobble hammerstones are individually similar to recent specimens. But, taken as a tool complex, these pieces are not recognizable as a human tool assemblage. They are quite likely naturally fractured rock fragments (eoliths) and must be held in abeyance until further proof of their human origin is offered. Excluding these 5 sites, the Amchitka site total described here is 73.

Near Islands to the west. Hrdlička's (1945) excavations on Amchitka, Kiska, and Little Kiska were never properly documented. No archaeological reports are available from the adjacent Andreanof group to the east except Jochelson's (1925, pp. 26-29) short section on Atka excavations.

Although the two recent Amchitka reports shy away from cultural comparisons and syntheses of the Amchitka collections within the extant literature on Aleutian and southwestern Alaskan archaeology, they do provide us with accurate and specific archaeological information for these broader cultural comparisons.

Detonation Effects

Merritt (1972) provides a short summary of the effects that the three nuclear detonations [Long Shot (1965), Milrow (1969), and Cannikin (1971)] had on archaeological sites. Such sites are particularly vulnerable because they often rest at the unstable edges of coastal marine terraces that are slowly eroding. Ground shocks can easily cause rock falls and mass wasting at the island's periphery.

No documented damage to sites resulted from Long Shot, probably because of its low yield. Milrow caused rock and turf slides on both the Pacific Ocean and the Bering Sea coasts. Some 1968 excavation profiles caved in as a result of that test. Cannikin caused the coastal bluff at Site 32 to slump, destroying approximately 5% of the site. The excavation profiles at Site 32 also slumped from the ground-wave shock. Of 10 other sites near the test point, only 1 (Site 67) showed evidence of shock damage.

It is too early to observe possible long-term effects of the three nuclear detonations on the island's margins. Undoubtedly the resulting ground-wave shocks are responsible for putting additional cleavage cracks through sites resting on unstable terraces. Such disturbances could likely go undetected beneath the thick surface vegetation. However, no comparative, long-term records of site and coastal slumping are available from other islands, and therefore it is unlikely that damage from shock effects will be measurable in the future.

If any Aleutian Island had to be chosen as a test site, we recognize with hindsight that Amchitka was a fortunate choice. Amchitka has a greater-than-average number of prehistoric sites representing a large aboriginal population. Thus archaeologists now have a newly inventoried site series available with which to plan further research. The artifact samples and excavation details thus far collected from a few of these sites will serve as an important nucleus for future cultural analyses.

SITE CHARACTERISTICS AND DISTRIBUTION: THE HUMAN SPATIAL DIMENSIONS

As a natural geographic unit, the Rat Islands* constitute an archipelago of 10 large to small islands totaling approximately 1000 km^2. These islands are distributed irregularly as exposures of the Aleutian ridge between the Andreanof and Near Island groups. The islands vary horizontally between rounded, linear, or irregular shapes and vertically from low to high. The highest point on Little Kiska is less than 61 m (200 ft) in elevation, whereas peaks on Kiska, Segula, Little Sitkin, and Semisopochnoi reach about 1220 m (4000 ft).

Numbers and Kinds of Archaeological Sites

To date, 86 definite prehistoric sites plus five possible sites have been located in the Rat group (McCartney, 1972, pp. 25-26). The possible sites were noted during a 1972 U.S. Fish and Wildlife Service survey of the Rat Islands but have not been confirmed by shore inspection.

The majority of the sites (73) are found on Amchitka or on offshore islets around Amchitka (Desautels et al., 1971, p. 23). This Amchitka total excludes 2 historic sites (20 and 21) and 3 sites of dubious authenticity (24, 77, and 78) from an original total of 78. These 92 site locations are shown in Fig. 1.

Most of this section treats the Amchitka sites, although comparative notes on other Rat Islands are included. The emphasis on Amchitka derives from the intensive site surveys of that island over the past five years. Amchitka is the only major island of the Rat group on which all large midden sites appear to have been discovered. Therefore this island provides a unique opportunity for the study of site locations in the western chain. An occasional camp site may be added in the future, but it will not significantly alter our generalizations about site distribution. The only large island in the eastern chain to be completely surveyed for sites recently is Akun (Turner, 1973).

*The Rat group islands are here considered to number 10, including Buldir. These are all islands measuring more than 1.6 km (1 mile) long. Several islets smaller than 1.6 km in maximum dimension include Bird Rock off Amchitka and Pyramid Island between Davidof and Khvostof. Three islets off Amchitka's shore, including Bird Rock, have one or more sites, but these are tallied with Amchitka proper. Buldir is the most isolated island, about halfway between the Rat and the Near Islands, but it is considered to be one of the Rat group (Orth, 1967, p. 166).

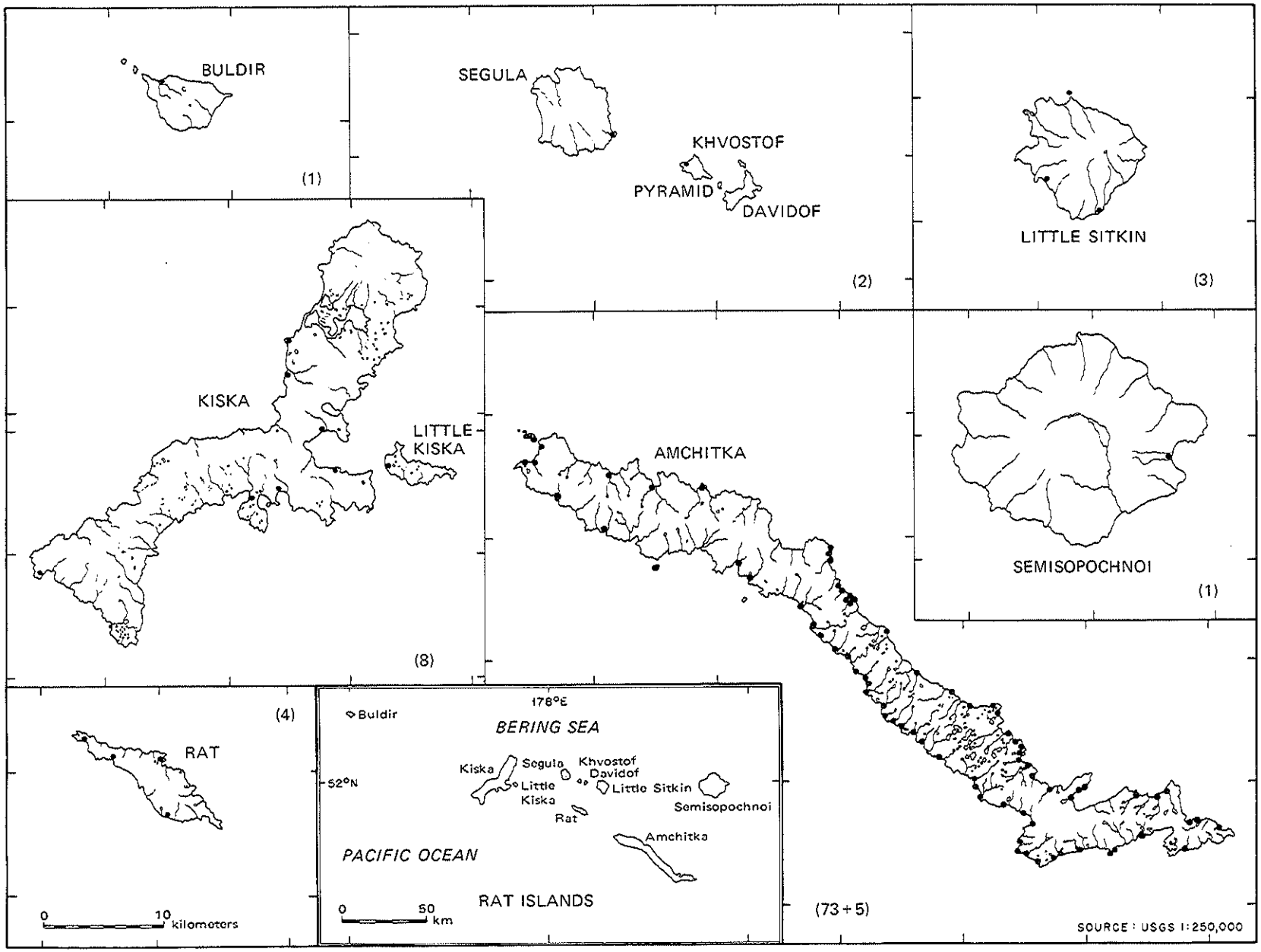

Fig. 1—Maps of the Rat Islands showing known archaeological sites (dots). Known site totals are given in parentheses. Islands less than 1 mile (1.6 km) long are not included.

Although we have close to 100% of all Amchitka sites to analyze, we know little about how each functioned or differed from others. We must presume that large midden areas represent stable villages that were occupied for most, if not all, of the year. Small sites are presumed to have been seasonal camps, such as fishing stations, but sites do not aggregate into clearly separable types on the basis of size, depth, elevation above the beach, sampled artifact content, or other obvious characteristics. Therefore this section is devoted to a review of spatial variables or determinants in an attempt to better understand why Aleuts established sites where they did.

Three related factors restrict our current knowledge of site function. Most sites have never been systematically excavated for archaeological data that would bear on the question of function, seasonality, and duration of occupation. Second, the World War II military occupation is estimated to have damaged 60% of Amchitka's sites (Desautels et al., 1971, p. 2), leaving, in some cases, no undisturbed strata to be tested today. Third, the 1968 artifact samples from 14 different sites have gone unpublished. Specific information about intersite variation that might have come from such an analysis is therefore not available.

Because we cannot ascertain specifically how past Aleuts moved from base settlements to seasonal camps during the yearly subsistence round, we must consider each site a cultural entity by itself, representing a distinctive social/political group over an unspecified period. Yet, in at least seven instances on Amchitka, two sites are located very close together (<0.5 km or 0.3 mile). If these were occupied contemporaneously, these double sites may have been different occupation areas for the same people. Six of these double-area sites (2-3, 6-43, 22-23, 31-56, 32 high and low, and 35-36) comprise a high area and a low area essentially side by side. It is possible that the different elevation areas represent a seasonal shift up and down a common slope (Desautels et al., 1971, p. 347). The seventh site pair (72-73) is an example of two high sites.

Because the distance separating any site pair is so slight, it appears unlikely that the sites represent simultaneous but discrete political/social groups. As an alternative, however, these site pairs may have been occupied sequentially, with a later village or camp being established in proximity to, but not directly on, a former settlement.

Since we lack precise cross dating between any of these site pairs or analytical tools for discerning if the same group occupied two slightly separated areas, we assume here that each individual area represents a different settlement at different periods of time.

The following summary excludes those site-location determinants related to the Aleut spiritual world or those which have no clear ecological significance. While stressing a kind of mechanistic approach to man's use of the physical and biological environment, we recognize that other cultural pressures exist for establishing communities, moving about, and exploiting certain ecosystems. A village may have been consistently occupied in part because strong ties to ancestors or spirits residing there dictate such a behavior. One food resource may have been overlooked in lieu of another because of taste preferences. Motivation for moving an encampment may have sprung from desires to "keep moving" rather than depletion of the local food supply.

In short, man has many complex inducements guiding behavior, and we should not minimize nonecological cultural pressures when viewing man interacting in the Aleutian environment. But, because we have little knowledge of nonecological factors, the determinants described here portray man interacting with spatial and ecological limitations.

Interisland Determinants

Of first interest in inspecting the Rat group sites is why 80% of them fall on Amchitka. The fact that Amchitka is a relatively large island is insufficient to explain the site concentration. A partial explanation is that site surveying has not taken place as intensively on the other islands as it has recently on Amchitka. But a more critical factor appears to be operating; i.e., the other islands are not as suitable for human occupation.

On probing into differential site suitability and irregular site distribution of past Aleuts, we find several overriding patterns. First, different islands were not occupied with equal intensity. Second, on the same island site distribution was never uniform along the coast, and sites were never located in the interior. Third, on the coast only lower benches and terraces were commonly occupied. Finally, even in these lower coastal zones, still other considerations apparently influenced the location of a habitation site.

In this section some of the key determinants that help explain the utilization of the land mass for seasonal or year-round settlements are examined. Variation between islands is treated first, followed by variation around the same island.

Future field observations and excavations should be directed at testing these determinants as hypotheses. Enough evidence is available to suggest

strong positive associations between site localities and these variables, but greater analytical precision and model testing may permit us to derive causal explanations for the phenomena observed.

Island Size and Shape. Depending on its size and shape, one island may provide greater or lesser coastal living space to prehistoric inhabitants than another island. Perimeter is a function of size, but it also increases with the degree of deviation away from circular plans and/or smooth coasts. A narrow island or one with convoluted and indented margins will have a greater perimeter than a round island or one with unindented coasts. As a measure of the relationship between area and coastal length, a ratio or *index of irregularity* is calculated for each of the Rat Islands to show their degree of deviation from circular, regular coastlines (Table 1). Because area and linear measures are not proportional, this index is necessary to compare islands of differing shape and shoreline indentation regardless of island size. This table clearly shows that Amchitka (298.4 km^2), Kiska (296.6 km^2), and Semisopochnoi (238.6 km^2) are the largest islands, but Semisopochnoi is distinguished from the former two by having a lower index figure (4.69). Semisopochnoi's circular shape, relatively regular coast, and comparatively small perimeter confirm this low index. Besides Amchitka and Kiska, Rat Island also has a larger index (7.02) than most, indicating that it falls between Amchitka and Kiska on the one hand and the rounder islands (3.94 to 5.07) on the other. Although Rat has less area (30.3 km^2) than Segula (36.5 km^2), it has a larger index because of the longer coast.

Table 1—Rat Island Area and Perimeter Measures

Island	Area,* km^2	Perimeter,† km	Index of irregularity‡
Amchitka	298.4	194.7	11.27
Kiska	296.6	160.9	9.35
Rat	30.3	38.6	7.02
Little Kiska	8.8	17.7	5.96
Davidof	4.7	12.9	5.94
Segula	36.5	30.6	5.07
Khvostof	2.6	8.0	5.00
Little Sitkin	68.8	39.4	4.75
Semisopochnoi	238.6	72.4	4.69
Buldir	20.2	17.7	3.94

*Calculated from USGS 1 : 250,000 maps; approximate accuracy, ±3%.

†Calculated from the following: Little Sitkin, 1 : 20,000 map; Davidof, Khvostof, Segula, and Semisopochnoi, 1 : 25,000 map; Kiska, Little Kiska, and Rat, 1 : 63,360 maps; Amchitka, approximately 1 : 103,000 map; Buldir, 1 : 250,000 USGS map; Buldir perimeter is the least accurate owing to the small scale of the map used.

‡Index of irregularity [perimeter/$(\text{area})^{1/2}$] is a measure of overall shape, including coastline indentations; coastline indentations cannot be meaningfully partitioned from overall island configuration. However, it is the general configuration of the land mass comprising the island, and not coastal irregularities, which influences the resulting index the most. For comparison, a circle has the most economic ratio of coastline to area (3.55); Amchitka has one of the highest for all the Aleutians (11.27). Almost all other islands will fall between these extremes. These indexes can only be interpreted in an ordinal manner, and their value is in judging relative shape deviations among islands.

In terms of human occupation, island area alone is not so important as perimeter or index of irregularity. Only the coast or periphery is utilized for subsistence, and therefore island perimeter is a more meaningful figure than area. The greater the coast length per unit of area, the larger the potential population that could be supported by resources along it.

Given the limited size range of Aleutian Islands, the index figures make it possible to compare the likelihood of travel across any island if elevation and terrain are disregarded. Distances across islands will be less on islands with higher indexes. Although sites are not found inland, away from the coast, the ability to traverse an island's interior may have been crucial when considering escape from attackers arriving by boat or exploitation of additional coastal zones. However, elevation and topography *are* important in determining the ease with which Aleuts might cross from one side to another. Vertical shape, therefore, may be rather important under certain cultural conditions.

Most of the Rat Islands are volcanic cones (Buldir and Segula), calderas (Little Sitkin and Semisopochnoi), or caldera remnants (Davidof and Khvostof) (Coats, 1950, pp. 38 and 43). Kiska has a volcanic cone on the northeastern end. Amchitka, Little Kiska, and Rat have no active volcanoes or resulting cones. All the islands are mountainous except for southeastern Amchitka, northwestern Rat, and Little Kiska, which have low marine terraces or platforms of less than 91-m (300-ft) elevation. Thus island crossings were relatively easy over the last three islands but were rigorous over the former seven islands.

Isolation. The Rat Islands are irregularly scattered along this part of the archipelago (Fig. 1). We would expect the most isolated island or islands to support the least population insofar as isolation should be inversely related to group safety in attacks and to food sharing and other social interaction during periods of stress. Occupying part of an island nucleus or cluster would therefore be of advantage, in contrast to occupying an island

frontier where no nearby island could afford safety.

Table 2 shows the minimal distances between islands. It is clear that Semisopochnoi and Buldir, respectively, on the east and west ends of the island group, are the most isolated. The remainder form a central core or island network in which the maximum distance traveled to participate would be 27.4 km.

Table 2—Interisland Distances

Island	Minimum distance to next closest island,* km
Buldir	117.5 (to Kiska)
Semisopochnoi	53.9 (to Amchitka)
Kiska (and Little Kiska)	27.4 (to Segula)
Amchitka	21.7 (to Rat)
Rat	13.7 (to Davidof)
Segula	5.6 (to Khvostof)
Little Sitkin	5.6 (to Davidof)
Davidof	1.6 (to Khvostof)
Khvostof	1.6 (to Davidof)

*Map reference, USGS 1 : 250,000.

As a correlate of isolation, direct visibility between Kiska and Buldir is lacking at sea level. To see Buldir's almost 671-m (2200-ft) peak from sea level as a kayaker would, the boater would have to be within at least 104.6 km of Buldir (U.S. Coast Pilot 9, 1955, endpapers). Since the actual distance between Kiska and Buldir is 117.5 km, a boater would have to be at least 12.9 km west of Kiska to glimpse Buldir on the horizon. However, Buldir could be seen from a higher vantage point on Kiska. The remaining islands, excluding Rat, Khvostof, and Davidof, would be mutually visible to boaters offshore any island. Murie (1959, pp. 6-8) demonstrates the between-island views of this central-island core. Of course, Aleutian weather is rarely clear enough to afford good visibility over the longer interisland distances.

Although we are only considering one variable here, isolation, note that Buldir and Semisopochnoi have but one reported site each.* Buldir has been closely surveyed on foot, but Semisopochnoi probably possesses a few more sites. If not the only causal factor, isolation at least appears to be positively associated with low population density.

Ecology. Past Aleuts surely distinguished one island from another on the basis of subsistence abundance. Yet such distinctions are impossible to reconstruct directly thousands of years later. All the larger Rat Islands offer varied shorelines that are habitats for marine mammals, fish, invertebrates, birds, and algae. Thus these islands seem to provide a suitable ecologic situation for prehistoric Aleut occupancy.

One meaningful measure of relative richness may be shallow waters around island peripheries. Pinnipeds, sea otter, inshore fish, kelp, and invertebrates occupy shallow coastal waters where they could be used by Aleuts. Estimates of shallow coastal waters are given in Table 3. Shallow waters are here arbitrarily defined as <30 fathoms; the 30-fathom contour marks the maximum sea otter feeding depth (Kenyon, 1969, pp. 66-69).

By calculating a ratio of area to circumference, we see that Rat Island has more shallow coastal water per shore kilometer than any of the other islands. Little Sitkin, Davidof, Khvostof, and Segula have the least. We might expect a greater relative abundance of food and material resources to be found off Rat, Buldir, Amchitka, and Kiska. But, in absolute figures, there is greater area found around Semisopochnoi (80 km^2) than around Buldir (32 km^2).

Because no one island stands out as being totally depauperate of Aleut food staples, the key consideration is not if but *how much* Aleut subsistence could be supported on any particular island.

Table 3—Estimated Shallow Coastal Waters for the Rat Islands

Island	Coastal area with water depth <30 fathoms,* km^2	Island perimeter,† km	Ratio of area to perimeter
Rat	88	38.6	2.28
Buldir	32	17.7	1.81
Amchitka	329	194.7	1.69
Kiska and Little Kiska	228	178.6	1.28
Semisopochnoi	80	72.4	1.10
Little Sitkin	36	39.4	0.91
Davidof and Khvostof	17	20.9	0.81
Segula	22	30.6	0.72

*Coastal areas are calculated from USCGS 1 : 300,000 map (No. 8864, 1965). Because the submarine ridge connecting Rat and Kiska is less then 30 fathoms, the 30-fathom area around these islands is arbitrary at one end of each island. The only check on these figures is an Amchitka estimate of 376 km^2 (110 sq nautical miles; Kenyon, 1969, p. 150) within the 30-fathom contour. The earlier estimate may be more accurate in absolute terms, but the area estimates in this table are accurate relative to one another since they are all made on the same map.

†Perimeter estimates are from Table 1.

*The single Buldir site is a small one found by Jones (1963, p. 84). The Semisopochnoi site was reported in 1971 by T. R. Merrell (written communication, 1975).

The ecologic factor was critical to Aleuts but unfortunately eludes us now. There is danger in assuming that site density on an island is a direct indicator of ecologic richness and diversity; some islands may have offered poor village locations yet may have been intensively exploited by transient marine hunters and gatherers from nearby islands. In the exploitation section below, modern animal population estimates are given as one indicator of differential island resources.

Vulcanism. Volcanic eruptions can, at the least, destroy food resources for several months and cause dire psychological trauma to local inhabitants. Three Rat Islands, Kiska, Little Sitkin, and Semisopochnoi, have volcanoes that were active during the historic period (Coats, 1950, p. 38, Table 2). Other volcanoes occur on Buldir and Segula. All these may have erupted occasionally during man's 2500+ year occupancy of the Rat group. Aleuts living on these islands or on islands downwind would be especially affected by ashfalls. The volcanic cone islands are arranged in an east—west line from Semisopochnoi to Buldir. The dominant upper-air winds are toward the east and northeast, and therefore ashfall effects were probably minimal on Rat and Amchitka, which are located to the south of the volcano line. Effects of ash fallout on flora and fauna are outlined by Wilcox (1959), Malde (1964), and Elliott (1886, p. 161).

Intraisland Determinants

The following factors are thought to be important determinants of where habitation sites will occur on the coast of any particular island. They are usually interrelated but are discussed here as independent variables.

Accessibility. Aleuts as maritime travelers could encircle and utilize essentially the entire edge of an island in a skin boat, weather and water conditions permitting. However, shoreline use adds the vertical dimension that restricts movement more than does the water surface. Three related factors are critical in occupying a shore as a village area or regularly for any other purpose: (1) beach configuration, (2) height of living space above the beach, and (3) slope angle between the beach and the living space. We are concerned here only with the attitude of land meeting the water in the vertical plane; horizontal shoreline configurations are treated in the next section.

At one extreme we find gently sloping, sandy or cobble beaches with storm benches above them. Such driftwood-strewn beaches give easy access to higher marine terraces or other level plateaus only a short vertical distance above the active beach. Such a situation would be perceived as an easy landing locale not only by ourselves but also by past Aleuts; sites are likely to be found in such beach areas. At the other extreme we readily find sections of shoreline that are sheer rock cliffs rising out of the water in an almost perpendicular manner to a height of over 50 m. Obviously, no landing is possible at this kind of shore, and no villages will be located where such conditions exist. Between these extremes are located most of the Rat Island and other Aleutian sites.

Six major shore-profile types are presented graphically in Figs. 2 and 3. These types illustrate the variables of accessibility. Some of the shore profiles shown are from the Rat Islands and others are from the eastern islands. These profiles include all the major shore forms for the entire island chain.

Almost all settlements are found on Type 1, 2, or 3 shores. These have the minimum requirements of a beach for landing skin boats, a roughly level to gently sloping plateau or tableland into which houses were excavated and where village activities occurred, and a short vertical distance between the beach and the living area. Of course, shortcomings in one or two of these requirements may be offset by others if they make the site especially amenable to human occupation. The upper limit of Amchitka house sites appears to be about 30 m above high tide except for Site 75 (68 m, see discussion below).

Types 4, 5, and 6 shores are inaccessible because there is no beach to land on, a sheer cliff to scale, or no level living area short of climbing hundreds of meters up a steep incline if then. In other words these shores cannot be occupied with ease.

Any one island may evidence all six shore profiles illustrated at one or more spots along its coast or it may be fairly uniform in shore type. Volcanic cone islands, like Semisopochnoi, Segula, or Buldir, are rather uniform in steep, constructional shores. Amchitka is generally uniform in the Type 3 manner. However, islands such as Kiska or Rat show great variety in their shore configurations. As will be demonstrated later, these shore profiles become important when one tries to determine where man might have lived on these coasts and therefore how many people might have optimally occupied an island. In other words much of an island's shore may be safely excluded from the search for habitation sites because such areas are virtually impossible to occupy from the sea surface. Burial and other special sites may indeed be found atop high steep coasts, and searches for such nonhabitation sites should be conducted.

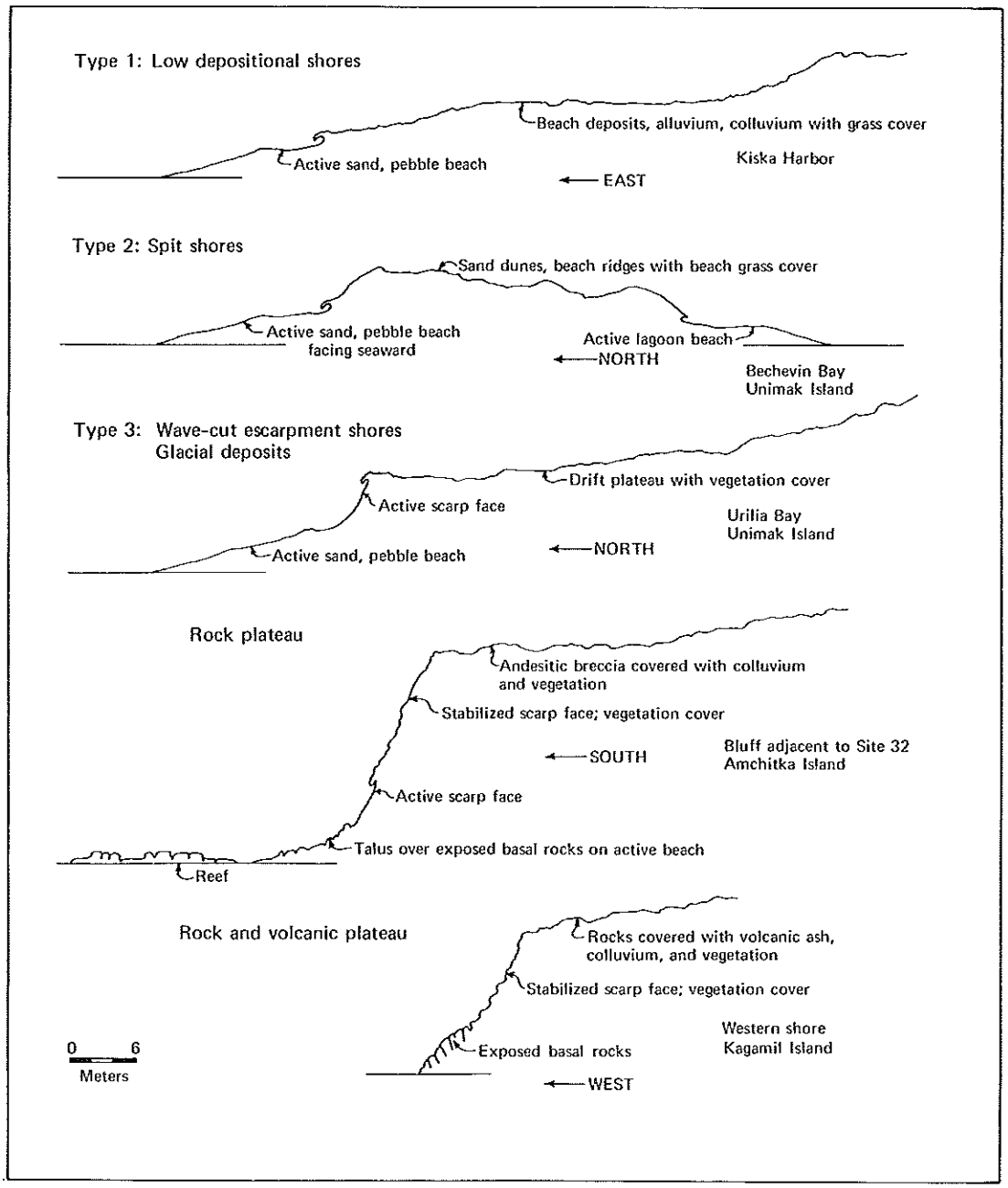

Fig. 2—Types of Aleutian shore profiles on which archaeological sites occur. Types 1 to 3 are low coasts with landing edges and flat living spaces above.

A survey of the 10 Rat Islands shows that only part of any island's shore is relatively low in the manner of Types 1, 2, or 3. Table 4 summarizes these low coastal zones. The table illustrates that, although suitable low coasts vary between 0% for Davidof and Khvostof and 59.5% for Amchitka, percentages cluster at 5 to 24% and at 38 to 60%. Except for Amchitka and Rat, the average low coast for the 6 remaining islands is 13.7%. Therefore, taking accessibility as a major prerequisite for site suitability, we find only a small part of most islands suitable for village or camp localities.

When low-coast percentages are compared with actual known site distribution (Fig. 1), the sites almost always fall along low coasts. The majority (82%) of Amchitka sites are found on the southeastern 60% of that island, which is lower than the northwestern end. Coastal cliffs are higher on the northwest, except at the extreme tip, and inland terrain ranges between 183 and 366 m (600 to 1200 ft); southeastern terrain ranges between 30.5 and 91.5 m (100 to 300 ft). On other islands sites are almost invariably found at mouths of stream-eroded valleys as they front on the sea or on low

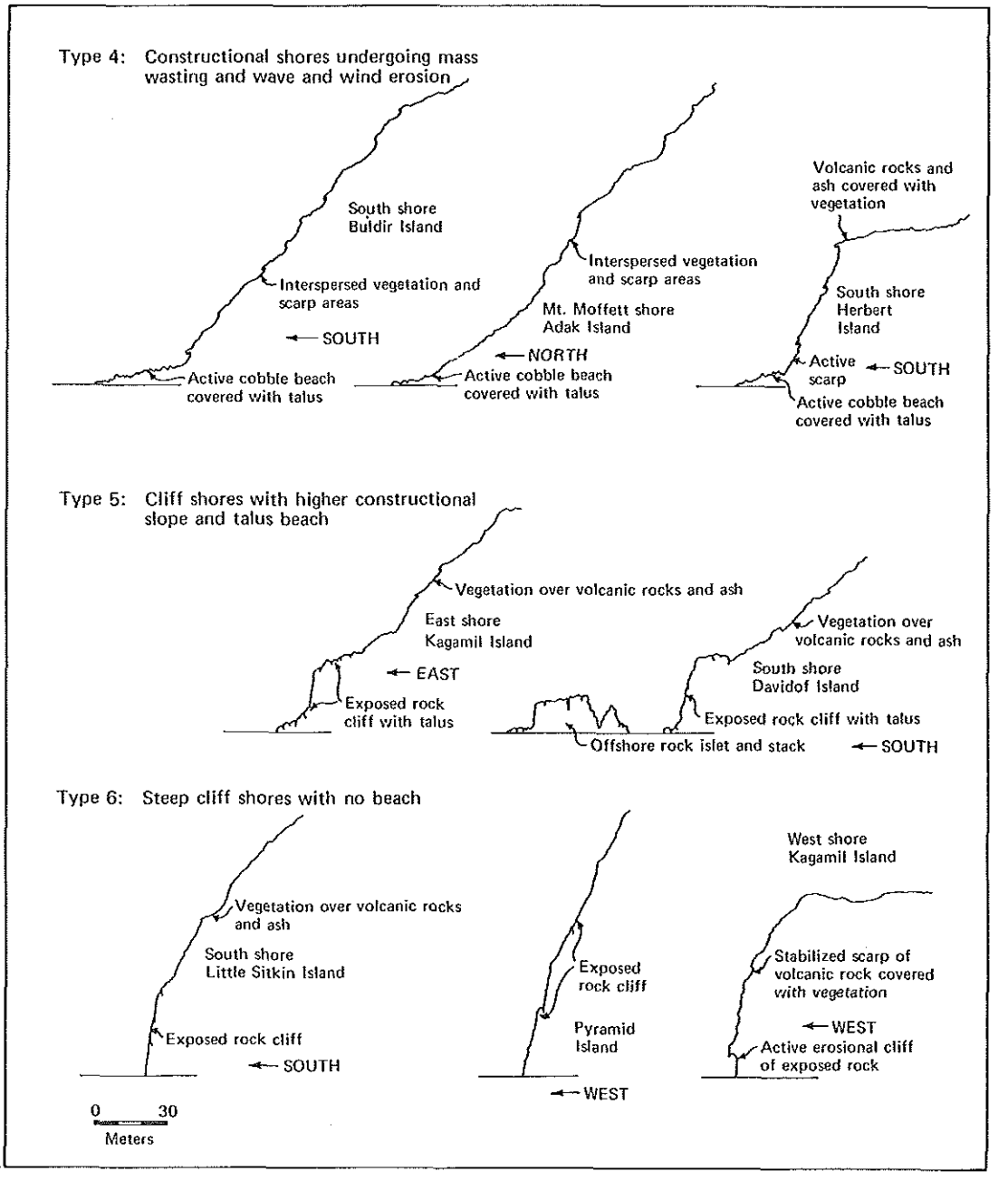

Fig. 3—Types of Aleutian shore profiles on which archaeological sites do not occur. Types 4 to 6 are too high and/or too steep for human occupation.

terraces. Again we must remember that intensive site surveys comparable to those on Amchitka have not been conducted on the other Rat Islands, but recent surveying and records of previous investigators (McCartney, 1972) all corroborate the low coast–prehistoric site association.

In speculating about the total number of prehistoric sites in the Rat Islands, we use Amchitka as our referent because we know the locations of essentially all the sites (N = 73). If we compare numbers of sites to low coast, we find a ratio of about 0.63 site per low-coast kilometer. Using this ratio and disregarding other island determinants outlined above, we may project a total of 110 sites for the Rat Islands. We already have 73 for Amchitka plus 19 found on seven other islands. We might expect to find about 18 additional sites on islands other than Amchitka in the future. If accessibility is, in fact, shown to be the most critical factor in site location, then this postulated total capacity for sites would be approximately accurate. If we assume a 110-site total for all the Rat Islands, Amchitka will have about 66% of these sites. Amchitka, Kiska, and Rat, the

Table 4—Low Coast Distribution on Rat Islands

Island	Perimeter,* km	Low coast suitable for sites,† km	Percentage of total perimeter	Major low coast areas
Amchitka	194.7	115.8	59.5	SE 60% of the island.
Rat	38.6	14.5	37.6	SE end near Ayugadak Pt.; NW 30% of the island.
Segula	30.6	7.2	23.5	S coast; NW coast between Zapad Head and Gula Pt.
Little Kiska	17.7	3.2	18.1	W end of the island.
Kiska	160.9	23.3	14.5	Kiska Harbor on the E; W coast between Witchcraft Pt. and Vulcan Pt.
Semisopochnoi	72.4	8.0	11.0	Alluvial valleys on E and W bays.
Little Sitkin	39.4	4.0	10.2	Williwaw Cove on the N; Sealy or Prokhoda Pt. on the SE.
Buldir	17.7	0.8	4.5	NW alluvial valley.
Davidof	12.9	0	0	
Khvostof	8.0	0	0	

*See Table 1 for map source.

†These approximate figures are estimated from the same map sources as in the preceding footnote; low coasts are here taken to be coastal zones of <30 m elevation, comprising flat marine terraces, alluvial terraces, or sloping sand and cobble beaches. Only general coastal areas are measured; a small, isolated spot may be suitable for a village but may not be detected on the maps used for checking these coasts.

three islands with the maximum low coasts, will have about 87% of all Rat Island sites.

Recent AEC study of Amchitka has made that island our best reference base for site distribution. Additional site surveys on other Rat Islands may test this coast–site relationship for the entire group. By checking and adjusting the regularity of this relationship within the Rat group, one may find such a ratio to be of great value in testing site–population capacities in other parts of the chain.

We have referred (Table 4) to low coasts being limited to approximately 30 m above sea level. There is no clear division at this elevation, but most Amchitka sites appear to have this elevation as an upper limit. Desautels et al. (1971, p. 22) note that sites fall into two general classes on Amchitka, high bluff sites and low beach terrace sites. Site elevations are shown in Fig. 4. There are discrepancies in height and size estimates between Desautels et al. (1971) and preliminary survey records of 1968 (Sense and Turner, 1970). Figure 4 treats the preliminary survey elevation estimates; precise site measurements will probably alter these figures slightly.

The elevation distribution shows a break at 13 m, those below referred to as low sites and those above as high sites [low coasts (<30 m) are not to be confused with low sites (<13 m) as discussed in the text]. Slightly over half of these total sites are low sites. Almost all the sites at 8.9 m or less are found on or behind beach storm terraces; half the sites between 9 and 12.9 m are on beach terraces and half are on low bluffs.

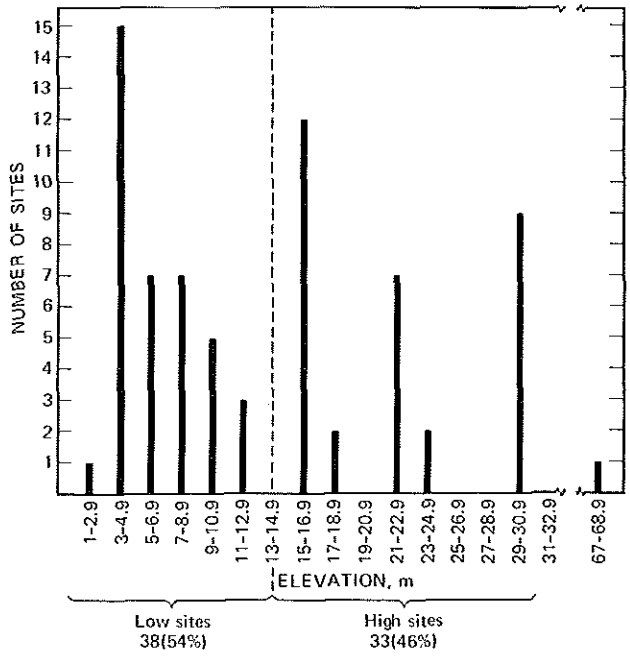

Fig. 4—Histogram of Amchitka site elevation frequencies based primarily on 1968 site survey forms. Measured from approximate high-tide line.

The high bluff sites fall predominantly at three elevation levels, 15.3, 22.9, and 30.5 m, reflecting the natural elevation of different parts of the island's periphery, or possibly reflecting the general use of rounded elevation estimates in units of 50, 75, and 100 ft, respectively. There appears to be less of a height continuum for high sites, but

precise measurements of elevation may show more variation than is reflected in these figures.

The highest site (Site 75; 68 m) is found on Windy Island off the Pacific coast of Amchitka. The site is atop a hill on this islet which falls directly to the low beach below. The elevation alternatives for a camp are therefore severely limited.

Exposure. Site exposure may be measured roughly in terms of protection offered from wind and other weather elements as well as by aspect, i.e., direction faced in relation to the trend of the seacoast.

Settlements theoretically could be established (1) on straight regular coast, (2) on headlands and points, or (3) on embayments. Although we find all three situations in the Rat Islands, the large majority of Amchitka sites is found in concave embayments (see Fig. 1). By settling in bays, bights, or coves, Aleuts found protection from the ever-present wind along beaches isolated between headlands. Bay shores are almost universally lower than headland shores on either side because headlands are formed by steep, resistant rock exposures while bayhead shores are formed by alluvium and beach deposition. Thus bayhead shores are typically Type 1 profiles, and headland shores are typically Type 5 or 6 profiles.

Beaching a skin boat would be simpler in the quiet waters of such embayments, especially if an exposed reef or kelp beds prevented breakers from entering the beach area. Reefs 30 to 90 m wide are almost always found before Amchitka's sites, and kelp beds almost totally surround the island. Operating from the head of a bay, a villager would survey a curving shore that could be exploited easier than a straight or convex coast since he could travel by skin boat across the water at chords to the curved shore.

The index of irregularity described earlier will suggest the degree to which one island is likely to have greater or lesser local protection for shore use. The higher the index, the greater the probability that there will be numerous coves and embayments offering protection from the wind and weather.

The ethnohistoric literature is confusing about the relation between site location and coast configuration. Veniaminof (1840, Vol. II, p. 200) states that villages (age unspecified) are "laid out. . .for the most part, in bays and gulfs in order to have as convenient a landing station as possible." Jochelson (1925, p. 23), however, states that "ancient Aleut villages" were normally located "on narrow isthmuses, on necks of land between two ridges, on promontories, or narrow sandbanks." Although it is true that such localities often have old sites, isthmuses, necks, and spits are relatively rare on any Aleutian island. The Amchitka site distribution substantiates Veniaminof's observation that protected embayments are where sites were usually located.

Another variable of site exposure is aspect, or direction faced in relation to the sea. Aspect and its relation to wind and storm directions during the seasons the site was occupied would be important insofar as it influenced the ability to survey the sea surface and easily encounter sea mammals. Figure 5 is a directional rose indicating percentage directions toward which Amchitka sites face. Site

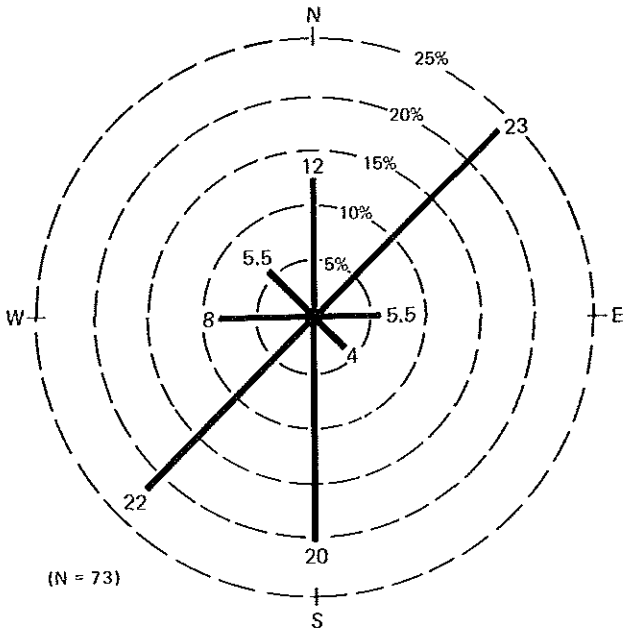

Fig. 5—Directional rose showing frequencies of the way Amchitka archaeological sites face the open sea.

facing is defined as the direction perpendicular to the shore immediately adjacent to the site looking outward from the site.

The two major directions faced, southwest and northeast, are perpendicular to the long axis of the island. However, more sites face south than north, making the orientation toward S–SW slightly predominant over that toward N–NE. If we tally sites on the two long sides of Amchitka, we find 31 or 44% facing the Bering Sea and 40 or 50% facing the Pacific Ocean. Two other sites face the northwest at that end of the island. There is no significant association between ocean frontage and site elevation; of 39 Pacific Ocean sites with elevation data, 20 or 51% are low and 19 or 49% are high. Bering Sea and Pacific Ocean site frequencies correspond closely to present-day sea otter distribution (Bering Sea, 40%; Pacific Ocean, 60%) (Estes and Smith, 1973, p. 65). Whether

distributions of sites and sea otter are meaningfully associated, however, is impossible to determine on current evidence.

The relative proportion of sites on the Pacific Ocean and the Bering Sea is of interest because Veniaminof (1840, Vol. II, p. 200) states that during the early nineteenth century "the greater number of villages" faced the Bering Sea. Sarichev (1807, p. 72) earlier reported that Fox Island settlements were not located on the southern or Pacific Ocean coasts. Amchitka sites, at least, do not corroborate these conclusions for the prehistoric period.

Resources. Resources (food, water, and raw materials) are grouped here as a major determinant of site establishment. Yet resources and defense, described next, appear to be more problematic as determinants than those already discussed. Behavior patterns surrounding resource use and defense are understood only indirectly. We can only roughly assess past resource abundance at any particular coastal area on the basis of modern abundance. Likewise, the efficiency with which Aleuts may have procured such resources can only be assumed.

Resource availability and original population size should be directly related. Large villages require abundant resources for support. We have some direct evidence of resource utilization from the archaeological site record, but exactly how a particular resource was used is not clear in all cases.

Beginning with food, we may presume that some coastal areas were favored variously for their sea lion rookeries, seal hauling grounds, sea otter—kelp beds, urchin and shellfish habitats, fishing spots, bird rookeries, plant collecting zones, etc. Yet how important these specific resource areas were to people choosing a site locality is difficult to evaluate because we have almost no historic-period settlement data for comparison.

Aleuts probably avoided living immediately adjacent to sea mammal or bird rookeries to avoid disturbing these animals. To choose a site just for its access to marine invertebrates or summer plants would seem unlikely, although these food organisms were usually available (Veniaminof, 1840, Vol. II, p. 200). Access to a major resource like whales could not be facilitated except in a gross manner as in choosing a site overlooking an interisland pass where cetaceans commonly travel. Since the Aleuts were quite mobile in skin boats for almost all the year, we must not consider them bound to specific areas for resources. Hunting and fishing from boats required extensive travel, often around or out from more than one island.

Further, any shifts in submarine and terrestrial habitats may have caused corresponding shifts in animal occupation of such habitats over several millennia of human occupation. We cannot assume that present habitats have gone totally unchanged over time.

Freshwater close to a site, preferably in the form of a stream, was desired (Veniaminof, 1840, Vol. II, p. 201). Certainly a number of Amchitka sites typically have streams adjacent or close to them. Living by streams may also be important because of salmon spawning in some of them during the summer, thus concentrating a valuable food resource. However, drinking water from streams is not considered to be critical owing to the wet climate and abundant springs and seeps that are almost ubiquitous to the Type 1 and 3 shores.

Nonfood material resources usually come from animals eaten, especially sea mammals and birds, or from driftwood abundantly scattered on beaches. Stone and mineral resources were collected at localized areas, often away from the shoreline, and therefore would hardly be determinants for more permanently occupied sites.

Considering only resource exploitation, we may expect coastal hunters and gatherers to arrange their villages at unequal intervals around these islands. More than an upper threshold number of villages per coastal length or people per village would strain the resource network too much, and population declines would result.

One measure of resource abundance might be the ratio of sites per total island perimeter. This may be expressed as the distance between sites. Given Amchitka's 73 sites and the estimated island perimeter of 194.7 km, we find an average intersite distance along the coast of 2.67 km. If we measure straight-line distances between adjacent sites, however, we find a mean intersite distance of 2.09 km and a range of 0.2 to 10.5 km. These figures, of course, ignore a time dimension in that not all sites were simultaneously occupied.

Defense. Veniaminof [1840, Vol. II, pp. 184-186 (cited in Hrdlička, 1945, pp. 144-148)] reports late prehistoric internecine contacts between islanders and describes defensive refuges as steep offshore islets providing temporary fortresses that were easily defensible. Coxe (1787, pp. 110-121), among others, describes early Aleut—Russian conflicts that amply demonstrate the Aleuts' warring abilities. Jochelson (1925, p. 23) reports that sites were chosen especially for their defensive potential in case of attack. But, as remarked above, Jochelson's interpretations of what coastal terrain constitutes appropriate habita-

tion sites is questionable. Still another question is whether a defense variable was important during the entire Aleutian occupation. Prehistoric warfare has not yet been identified in the archaeological record.

Most Amchitka sites are not located on narrow spits or points assuring easy escape by some "back way," nor are they usually found above high precipitous cliffs serving as natural defenses. It is clear from Veniaminof's record that the normal habitation site is not, at the same time, the defensive refuge, or "fort." Rather, such refuges were steep coastal spots or islets close to the village which offered protection only under attack. Therefore defensive elements, such as sheer cliffs and high elevation, were not normal determinants of midden site placement.

We note, however, that in contrast to Amchitka and other narrow islands, being able to escape attack by walking across the island to a friendly village is not possible on many islands. High volcanic cone islands would present a poor opportunity for cross-island travel. Hiding in high-elevation caves or other redoubts among interior rugged peaks would be an alternative in seeking safety.

DEMOGRAPHY

Aboriginal population cannot be ascertained directly but can be estimated on the basis of site size and ethnographic analogy to historic sites.

Amchitka site size distribution is given in Fig. 6, which is based on 1968 preliminary survey figures. Sites are separated between high and low sites as previously described to discriminate relationships between site size and elevation. Sites vary widely in size from 25 to 2500 m^2. Eighty-three percent (59) of the sites are less than 800 m^2 in area. The most frequent size class is 200 to 300 m^2 for both high and low sites. There appears to be no positive correlation between size and elevation since the distributions of both high and low sites follow one another closely.

Another measure of population size or site duration is depth of cultural debris. Large or stable settlements should evidence greater depth than small or more transient ones. The majority of Amchitka sites have not been tested, and only depth approximations can be made. Of 72 sites for which depth has been estimated, we find a mean depth of 1.2 m and a range of 0.2 to 3.8 m. Only 15%, or 11 sites, have estimated depths of 2 m or greater. Unfortunately we have no comparable figures from other major islands with which to contrast these depth estimates.

On the basis of present estimates, there appears to be no correlation between depth and size of sites. This may be the result of inaccurate depth estimates, or it may mean that large village populations lived at settlements for a relatively short period. As will be demonstrated later, site size, if not depth, is helpful in deriving a site population.

Many educated guesses enter into the prehistoric population estimate for Amchitka and the other Rat Islands. If we look to the extant ethnohistoric literature describing early historic

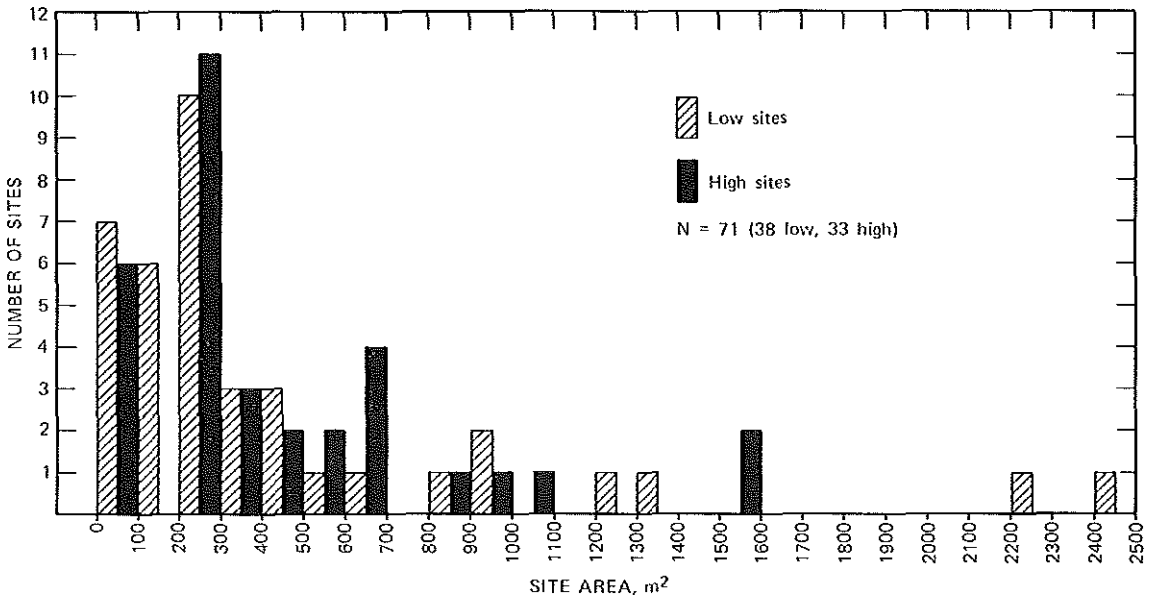

Fig. 6—Histogram of Amchitka site size frequencies based primarily on 1968 site survey forms.

(AD 1750 to 1800) house and village sizes, we are confounded by two problems. First, most of the literature describing Aleut dwellings deals with the eastern islands. And, in late prehistoric times, the single-family *barabara* was replaced or supplemented by a much larger multiple-family *barabara* housing as many as 100 or more natives (Coxe, 1787, pp. 119 and 214; Lantis, 1970, pp. 172-174). The only fully excavated house in the Rat Islands is the 400-year-old wooden structure described earlier (Cook, Dixon, and Holmes, 1972, pp. 91-101), which was of single-family size. We have no direct evidence of the larger multiple-family houses occurring in the western Aleutians, although they may eventually be found. Therefore large multiple-family dwellings of the eastern islands cannot be meaningfully compared to small, single-family dwellings of the western islands during the late prehistoric and early contact period.

A second pitfall lies in taking village size during the late eighteenth or early nineteenth century Russian period as indicative of the precontact village size. As Jochelson (1925, p. 119) points out, the Russian colonists congregated the Aleut population at particular village locations for easier exploitation and administration. Population decline was great during the first 40 years of contact, and the population sizes of established Russian-period villages may not represent those of previous villages. Veniaminof (1840, Vol. II, pp. 202-203) does show that during 1825 to 1830 the average village size was 55, with a range between 13 and 196. Suggestions of Unalaska village size during the last quarter of the eighteenth century range between 32 and 45 (Lantis, 1970, pp. 173-174).

The number of persons per household, or single-family dwelling, times the number of houses provides one estimate of site population. But three factors cannot be controlled. We do not know exactly how many houses existed at a particular site, how many houses were simultaneously occupied, or how many persons lived in a house.

At this point the single excavated house from Site 32 is relevant. This wooden structure measures 6.0 by 7.5 m in outside dimensions (Cook, Dixon, and Holmes, 1972, pp. 91-101). This house occupies 45 m^2. If the upper midden area of the site in fact measures 300 m^2 as reported in the 1968 survey, then only seven houses of roughly equal size could fit into the site area. In fact, the excavators report seven depressions at this upper bluff area. We may only surmise the number of occupants living in the house, but, taking the bench sleeping area available, it would appear that six to eight adults would be a maximum number. None of the other six house depressions were radiocarbon dated; so we cannot verify their simultaneous occupation.

However, let us speculate on some possible population sizes. If all seven houses held six to eight persons each, we would estimate the upper midden population at 42 to 56. The lower midden area next to the stream at Site 32 may or may not have been occupied at the same time. Cook, Dixon, and Holmes (1972, pp. 5-6) give no specific site sizes for either the upper or lower midden areas, nor do they indicate whether possible house depressions were found in the lower midden.

Since the most prevalent site size on Amchitka varies between 200 and 300 m^2, we might expect these settlements to have between 24 (four houses times six occupants) and 56 (seven houses times eight occupants) total population. If we assume that 45 m^2 is typical for Amchitka house space and that as many houses as possible will cover any site, then Amchitka's 73 sites (33,044 m^2) should have about 734 total houses. Further, assuming six to eight persons per house and that all houses were simultaneously occupied, we arrive at an upper limit of between 4400 and 5900 persons for Amchitka.

Going beyond Amchitka, we noted above that about 37 (33%) sites should be found in the Rat group besides Amchitka's 73 (67%) sites. We have no accurate size estimates for non-Amchitkan sites, but, if we assume an equal population density, then we would estimate that an additional 2200 to 2900 persons occupied the other islands. This would bring the Rat Island total population to between 6600 and 8800. However, we have no current way of knowing how many sites were occupied simultaneously. Sample calculations for 100%, 50%, and 25% are as follows:

1. Rat population (100% of sites occupied concurrently): 6600 to 8800.
2. Rat population (50% of sites occupied concurrently): 3300 to 4400.
3. Rat population (25% of sites occupied concurrently): 1650 to 2200.

Which of these estimates is most realistic? If we accept the judicious opinions of Veniaminof (1840, Vol. II, p. 177), Lantis (1970, p. 174), and Polonskii (cited in Fedorova, 1973, p. 160) that the total precontact population for the archipelago fell somewhere between 12,000 and 15,000, then clearly the first estimate is too high. Because the Rat group constitutes only about 11% of the chain's total coastline, the lowest figure (1650) fits best if we assume a uniform relationship between number of sites and kilometers of coastline. If continued scholarship substantiates the approximate 15,000 chain maximum, our largest error in

calculating population is probably in assuming simultaneous site occupation.

Given at least 2500 years of Aleut occupation, the 25% rate seems reasonable for simultaneous site occupancy. On Amchitka this 25% rate could be accounted for in the following way. Eighteen sites of 61 persons each would comprise 1100 people (67% of the Rat Island population of 1650 and 25% of the Amchitka sites of 73). These 18 villages would be separated from one another by 10.8 coastal kilometers (based on the 194.7-km circumference). Every person would be dependent on an average coastline stretch of 0.18 km. Given the kinds of marine resources actually depended on and the sea space used, this area is realistic.

The preceding numerical speculations are presented as just that. But we need constantly to examine population variables to learn more about the ecological capacity to support human groups.

MARINE ADAPTATION AND EXPLOITATION PATTERNS

Aboriginal man living in the Aleutian chain had no choice but to depend on marine resources for survival. Food and raw materials came predominantly from the sea; a native could not survive on terrestrial organisms alone. Besides comprising the principal larder, the sea provided for transportation between island masses and was an important determinant of weather affecting those islands.

This section treats the manner in which man used the marine environment for food, raw materials, and travel. This utilization is organized through subsistence procurement systems, the direct interactions man had with marine ecosystems. Finally, an assessment of prehistoric man's impact on his physical and biological environment is also provided.

Resource Utilization

Habitats. Cultural adaptations to habitats and their associated biota dictate that hunters and gatherers shall live near the seashore in this and similar archipelagoes. The littoral zone and the open sea surface are by far the most important sources of food and raw material; inland terrestrial habitats contribute more raw materials than food.

Three major macrohabitats can be isolated with examples of particular habitats within these categories: (1) *open seas* (inshore and offshore zones; many distinctive areas discriminated on the basis of currents, tides, and waves), (2) *littoral zone* (sea cliffs, beaches, reefs, and islets or rocks; other areas discriminated on the basis of elevation, angle, rock structure, etc.), and (3) *terrestrial areas* (low terraces or tablelands, mountains, lakes, streams; other zones discriminated on the basis of elevation, slope, drainage, etc.). All these habitats were exploited with differential intensity through the various procurement systems described later.

By using skin boats Aleuts maximized their exploitation of marine resources. Their mobility enabled them to sample more diverse marine habitats and prey species than any other competing Aleutian predator. Man could hunt sea mammals on the sea surface, catch fish deep beneath the surface, collect invertebrates from the intertidal zone, snare birds from a sea cliff, or dig roots in an island's interior. On any island or island group, then, man's exploitative capacity made him the most successful omnivore at the highest trophic level in the food web.

Aleuts were specialized in subsistence to the degree that procurement systems dealt with relatively few kinds of animals and plants. However, they were not so specialized that population decline was inevitable if one or two animal species failed to appear over a brief period. Within maritime limitations, Aleuts subsisted on a broad range of organisms in diverse habitats.

Water Travel and Resource Accessibility. Interaction among inhabitants of the Rat Island group was stressed in the introduction. The obvious mechanism for such interaction was interisland travel by skin boats. Whether by small kayaks (*baidarkas*) or large umiaks (*baidars*), male hunters and fishermen or entire families could exploit essentially all the Rat Island coasts and intervening and surrounding waters for food and raw material. We have demonstrated that not all the Rat Islands were inhabited as densely as Amchitka. However, all the islands were probably exploited for food and other materials to some degree. Although steep coastal profiles prevent persistent land occupations, these coasts may be abundant sea bird, sea mammal, and fish habitats. Further, skin boats not only open up more different kinds of habitats than those exploitable by land-bound hunters and gatherers but also make more similar habitats available. If one sea lion rookery or bird colony was temporarily vacant, then similar localities were available to the boatmen on the same or a nearby island.

Finally, in their skin boats Aleuts could travel with almost equal ease in any direction on the sea surface, weather permitting. Therefore, with good visibility between the Rat Islands, we must presume that boating between islands was as likely as travel around islands. Aleuts living on the northwestern end of Amchitka could reach Rat Island with less effort than paddling to the southeastern

half of Amchitka. Or Aleuts camped on the northwestern end of Kiska could cross to Segula for hunting quicker than they could travel to southwestern Kiska. A predilection to traveling around an island mass is consonant with a land-based world view but not to one based on full maritime adaptation.

Procurement Systems

Analysis of Aleut adaptation shows that there existed several major ways of procuring food and raw materials. Rather than applying a specialized technology and behavior pattern to procure each animal and plant species used, Aleuts transferred these patterns to several habitat-related species. These ways of subsisting or acquiring requisite materials from the environment are called procurement systems (McCartney, 1975, pp. 295-300). Flannery (1968) applied this same general ecosystem concept to Mesoamerican cultural development.

A system is conceived to be "an intercommunicating network of attributes. . . forming a complex whole" (Clarke, 1968, p. 42) or "a functioning set of elements that are interrelated so that change in one affects the others" (Redman, 1973, p. 16). And, of course, systems pertain in this instance specifically to networks or functional sets of procurement elements. As part of every procurement system, we find the following elements: (1) a habitat where sought-after organisms or materials occur; (2) the organisms or material proper; (3) the implements or tools used to extract the organisms or materials from the habitat (technology); (4) the dynamic extraction process; (5) the prerequisite knowledge and skill guiding the extraction process and application of technology (techniques); (6) the human procurers who singly or in groups represent larger kin or residential units as families or villages; (7) the food or raw-material products that emerge as usable input into subsistence, or the component parts of an extracted organism after additional processing (e.g., butchering); and (8) the time during which the preparation, extraction, and processing occur, or duration and seasonality. From the archaeological record, we only observe directly remains of organisms used, inorganic materials, and tools; but organisms and materials can usually be associated with particular kinds of habitats if not exact localities. Ethnographic and ethnohistoric documents shed light not only on tools but also on process (4), know-how (5), organization of hunting and gathering groups (6), resulting products (7), and amount of time and seasonality involved (8).

The usefulness of procurement systems as heuristic devices lies in their inclusion of (1) primary interacting elements into integrated wholes, (2) process or interaction between elements, and (3) ecologic relationships between cultural and biological spheres. These systems, though abstractions of human behavior, reflect as realistically as possible the manner in which Aleuts interacted with their islands and surrounding seas. They suggest the major subsistence themes and at the same time show the patterned, nonrandom behavior in relation to the environment. Procurement systems are the cultural adaptations or survival schemes that most directly and abundantly extract required nutrients and other resources from the environment. Systems are complex, and therefore we cannot analyze them reduced to their separable parts. In other words, the organization of the parts is the target for study. Finally, by integrating archaeological and ethnographic data, we can synthesize the bare archaeological finds into a dynamic cultural process.

Aleutian Procurement Systems. Aleutian procurement systems, as typical of most held by hunters and gatherers, are largely determined by habitat, seasonal occurrence of important species, and specific animal behavior. As a result, Aleuts had relatively little latitude for effectively manipulating their environment. They raised no crops, kept no domesticated animals with the possible exception of dogs, and had no sure method of food storage. Their adaptive flexibility lay not in juggling a particular system but in switching systems if one failed to produce necessary food or materials.

Eight procurement systems are tentatively suggested for the Aleutian chain. These systems fall in inclusiveness between higher level divisions (hunting, fishing, and gathering) and lower level divisions (e.g., winter sea otter hunting, summer halibut fishing, etc.) and are a compromise in degree of specificity. These eight systems reflect the majority of procurement patterns for the entire chain, although some island population will be expected to deviate slightly from these as local conditions demand.

Although these systems have been distilled from historic-period literature, they are thought to have considerable antiquity. Because the archipelago falls beyond the southerly limit of west Alaskan drift ice and is dominated by maritime climate rather than continental climate, temperature and other weather fluctuations over the past several millennia probably caused only minor deviation from today's pattern. Modern biota are shown in the midden debris to have had very little change in character for thousands of years. Therefore procurement methods are presumed to have been relatively stable as well.

The Aleutian procurement systems and major habitats are as follows:

Hunting:

1. Sea mammal hunting offshore (inshore and offshore waters).
2. Sea mammal hunting onshore (active beach, low terrace, islets, or rocks).
3. Bird hunting on water (inshore, offshore, lagoons, and inland lakes).
4. Bird hunting on nesting sites (sea cliffs and other island margins).

Fishing:

5. Fishing offshore (offshore waters from boat).
6. Fishing onshore (stream mouths and inshore waters with hook and line or nets).

Gathering:

7. Intertidal and beach collecting (active beaches and intertidal zones or reefs).
8. Onshore collecting (sea cliffs and island interiors).

Figure 7 illustrates a composite habitat profile indicating where the systems interact. Figure 8 illustrates these systems as part of a total ecosystem equilibrium model; likely causes of disequilibrium are also indicated.

In Fig. 8 food primarily and raw materials secondarily affect the population of a region like the Rat Islands. Feedback adjustments are shown with food supply controlling extraction techniques and raw materials controlling technology. In other words, amounts of food directly limit (–) or expand (+) the intensity of food exploitation through the eight systems. With the exception of system 8, raw materials are usually derived from the by-products of food animals extracted through the remaining seven systems. Therefore feedback (0) to technology shows the flow of animal by-products to finished tools rather than suggesting that a shortage of raw materials will intensify extraction systems to provide those supplies. Probably small amounts of food and/or raw materials derive from exchange or trade of a formal or informal nature. This input and output is diagramed to reflect such flows of goods (see Cultural Patterns and Interaction section).

The double arrows between habitat and techniques reflect the interaction between these two elements; the effects of man's exploitation of the various habitats are outlined below.

The population of a village or community, however transitory, is largely a function of food

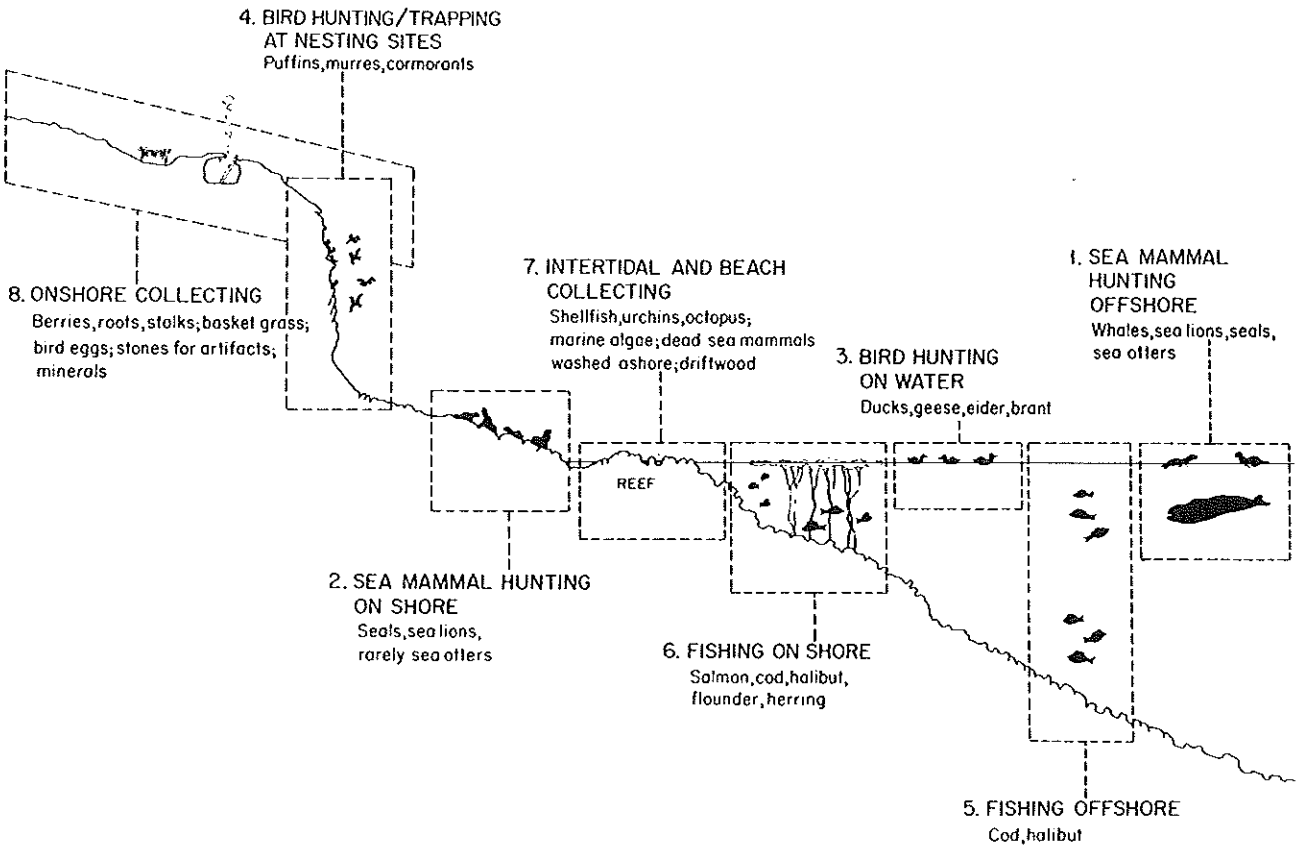

Fig. 7—Composite profile of an island edge showing habitat locations of the major procurement systems described in the text.

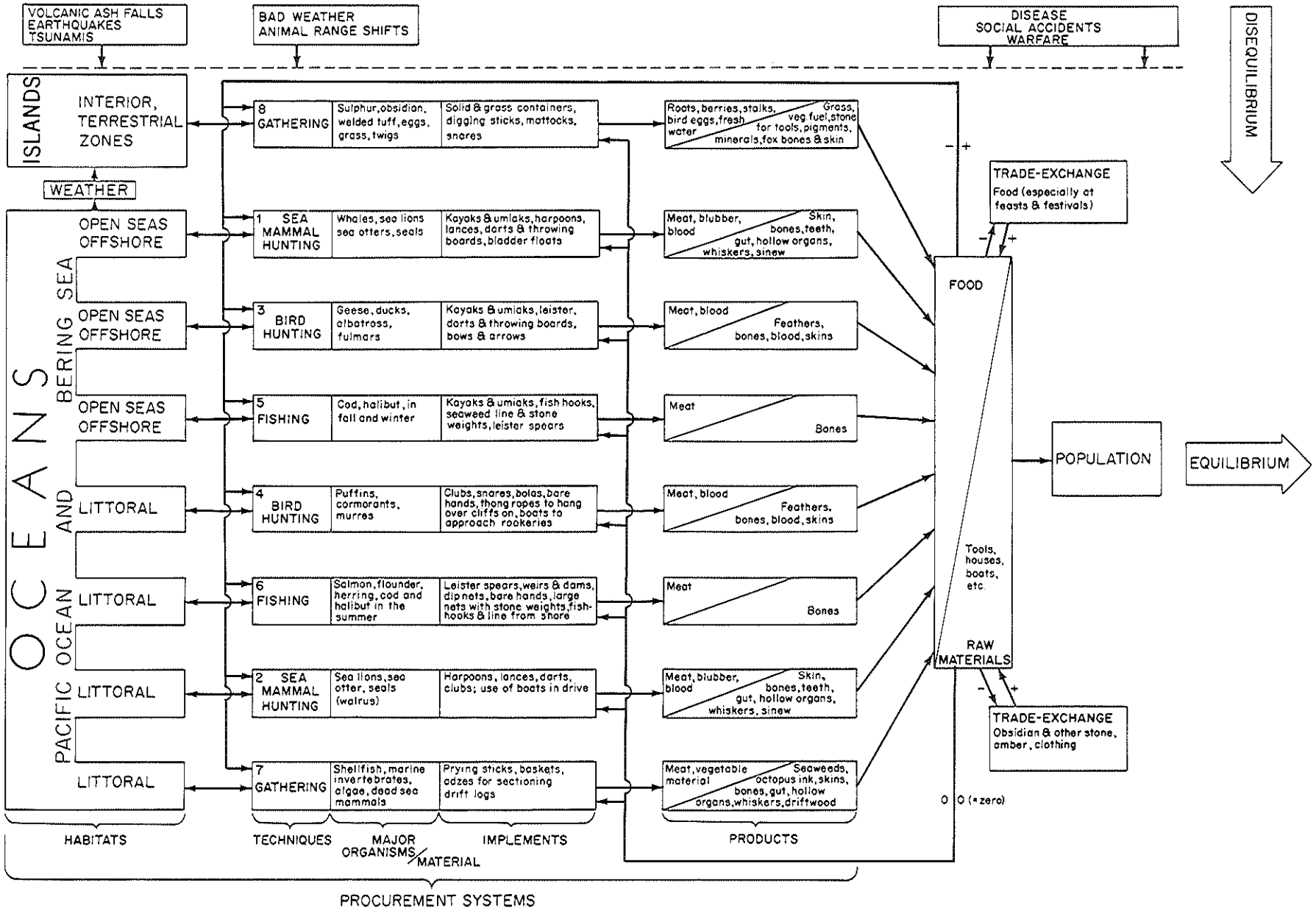

Fig. 8—Schematic representation of Aleutian procurement systems and their interrelationships. Local or regional population equilibrium results from the successful exploitation of marine and terrestrial habitats; disequilibrium or population decline results from environmental effects shown at the top of the diagram.

and raw materials to meet the needs of sustenance, shelter, and mobility. An important consideration in our model is that isolation from external cultural influence and insulation from vagaries in food supply (based on relatively stable marine habitats) translate into a relatively stable human population. The human carrying capacity is high as are all Pacific coastal groups because of abundant marine resources. Population size will also reflect the minimum food supply rather than the maximum amount available during the most productive season, or potential population adjusts to the minimal food supply (late winter and early spring) to sustain the population through the annual cycle. The effects of positive feedback are therefore restrained by habitat and organism limits.

Disequilibrium or a decrease in population can result from three areas of influence. Such interrelated physical phenomena as ashfalls, earthquakes, and tsunamis, characterizing the Pacific Ocean rim, can quickly interrupt normal marine and terrestrial ecosystems by altering habitats or causing massive die-offs. Bad weather, certainly a relative term in the Aleutians, can restrict exploitation by keeping Aleuts off the ocean surface; or slow to rapid and transient to permanent shifts in animal ranges can affect available food and raw-material resources. Finally, diseases, group accidents, and warfare can affect population directly by killing natives or by indirectly making it impossible for dependents to survive without primary providers in the family. Unfortunately evidence of such disequilibrium is difficult to detect in the archaeological record. The most massive and best-known state of disequilibrium resulted from Aleut–Russian contact of the eighteenth century when disease and genocide were particularly acute.

Table 5 summarizes the major techniques and implements used in procurement. This table places many archaeologically derived artifacts into activity spheres or contexts which stress their use rather than form. Figure 8 shows the kinds of products that result.

Rat Island Systems. How well do these eight systems describe prehistoric subsistence and ecologic exploitation in the Rat Islands? They appear to be the best models we have at present.

Note that the citation examples in Table 5 span 200 years since Russian contact and specifically describe procurement techniques from throughout the chain. There is a preponderance of examples from the eastern islands for which we have more sources, but we find subsistence uniformity throughout the chain and over time largely because the physical environment and biota are fairly uniform throughout. Of course, minor abundance variations will occur from island group to island group, but differences are considered here much less significant than general uniformity. Because the Rat group constitutes a major segment of this archipelago, the presumption here is that prehistoric Aleuts in that group participated in these systems as much as did any other island group population.

The archaeological record at least shows the use of the procurement implements included in Table 5 rather than some radically different tool assemblage. We cannot, as yet, derive total systems from the archaeological records. However, since the Rat Island artifacts, features, settlement patterns, habitats, and species correspond closely to those of other parts of the chain, we can safely assume that past exploitation techniques also conformed to the Aleutian subsistence pattern, which is the total of these eight individual systems.

Rat Island Food and Material Resources

Food. Consider the food limitations of aboriginal Aleuts. [See Zimmerman (1963, p. 57) for similar native food restrictions in the Hawaiian Islands as typical of other Pacific island groups.] There are no terrestrial mammals found west of Unimak Island and the tip of the Alaska Peninsula besides foxes, lemmings, mice, and shrews (Clark, 1945, pp. 48-49; Murie, 1959), and even these were not to be found in the Rat Islands. No domesticated crop plants were known, and the damp climate precluded storing dry plant products for long periods. Unlike the Alaskan interior, which has relatively high summer temperatures, the small island masses of the Aleutian chain are dominated by the cold north Pacific Ocean waters with summer temperatures of about 40°F. Amchitka is about the southernmost point in Alaska, but the sea environment negates any appreciable summer warmth. Low insolation may be equally as important as temperature in limiting plant growth.

The few native plants that do cover the islands provide little caloric input, and these are only available during the summer months.

Thus sea resources, directly or indirectly, become human food staples. Sea mammals, fish, and marine invertebrates variously provide meat, blood, and fat. Marine algae are a source of vegetable matter. The most important birds by size and abundance are those dependent on marine organisms. Terrestrial plants, as mentioned above, are controlled by a maritime climate. Survival in the chain, then, depends on some mix of hunting, fishing, or gathering these marine-related organisms over the annual cycle.

Table 5—Procurement System Techniques and Implements

1. System: Sea-mammal hunting offshore
   Techniques
   Sight and surround animal with boats; tire diving animal (except large whales); harpoon and spear animal or club it in water; large whales wash ashore when dead, but smaller sea mammals must be dragged or carried to shore.
   Implements
   Kayak/umiak (paddles and oars, sucking-tube bailers, sponges, gut kamleika suit,* wooden visor hat, stone ballast, and other boat accoutrements).
   Harpoon (toggle head with end blade or point, loose shaft, socket piece, wooden shaft, long thong line, and bladder float or nontoggling but detachable harpoon head with barbs, sometimes with end blades or points, socket piece, wooden shaft, long thong line, and bladder float).
   Spear/lance (nondetachable barbed head, often with end blade or point, socket piece, and wooden shaft).
   Harpoon dart (nontoggling harpoon head, socket piece, wooden shaft, some with feathers, and thong line between head and shaft; propelled with throwing board).
   Club.
   References
   Cook, Clerke, and Gore, 1818, p. 37; Coxe, 1787, pp. 62, 87, and 120; Elliott, 1886, pp. 140-141, 151-152; Heizer, 1943, 1960, p. 134; Jochelson, 1933, pp. 11, 24-25, and 55-58; Langsdorff, 1817, pp. 340-343; Ransom, 1946, p. 614; Sarichev, 1807, p. 74; Turner, 1886, pp. 200-201; VanStone (Choris), 1960, pp. 155-156; Veniaminof, 1840, Vol. II, pp. 105-106, 132-133, 217-225, 231, 245-248, 342-344, 388, and 395-396.

2. System: Sea-mammal hunting onshore
   Techniques
   Surprise seals, sea otters, or sea lions on island shore or on islets or rocks; hunters approach by foot or boat, depending on locale; kill animals by harpooning, spearing, or clubbing; possibly nets for entangling used prehistorically; decoy seals.
   Implements
   Kayak/umiak (as in sea-mammal hunting offshore).
   Harpoon, lance and/or spear (as in sea-mammal hunting offshore).
   Club.
   Net.
   (Decoy).
   References
   Elliott, 1886, pp. 142-144 and 366-368; Veniaminof, 1840, Vol. II, pp. 344-345, 362-363, 383-384, and 388.

3. System: Bird hunting on water
   Techniques
   Stalk birds resting on sea surface or lakes or surfacing; capture birds by darting with leister† or shooting with arrow; kill birds by breaking their necks; secondarily, net birds on lakes from blind.
   Implements
   Kayak/umiak (as in sea-mammal hunting offshore).
   Leister darts (multiple-pronged wooden darts propelled with throwing board).
   Bow and arrow (barbed head or point, usually with no end blade, wooden shaft with feathers; short wooden bow).
   (Net with trip line).
   References
   Cook, Clerke, and Gore, 1818, p. 37; Coxe, 1787, p. 215; Jochelson, 1933, p. 11; Sarichev, 1807, p. 74; Turner, 1886, p. 140.

4. System: Bird hunting at nesting sites
   Techniques
   Sheer bird cliffs approached by boat from below or from above by rope; snares set at burrow entrances or on ledges where birds perch; strangled or snared birds collected later; or birds clubbed on nest or caught with hands and killed by breaking their necks; bolas, handnets, and leisters used to down flying birds around rookery; birds also captured away from the nesting areas.
   Implements
   Kayak and/or umiak (as in sea-mammal hunting offshore).
   Ropes of thong or seaweed.
   Collecting container of woven grass or stretched gut.
   Snare.
   Club.
   Bolas (stones and thong).
   Hand net/loose net.
   References
   Coxe, 1787, p. 86; Elliott, 1886, p. 209; Jochelson, 1933, pp. 8, 10, and 53; Sarichev, 1807, p. 70; Staehlin, 1774, p. 28; Turner, 1886, pp. 117-118, 130, 137, and 141; VanStone (Choris), 1960, p. 155.

5. System: Fishing offshore
   Techniques
   Fishing from boats with hook and line or sometimes spearing with leister spears; club used to kill large fish (halibut).

(Table continues on page 82.)

Table 5—(Continued)

Implements
Kayak/umiak (as in sea-mammal hunting offshore).
Fish line (bone one- or two-piece fishhook, long seaweed and/or kelp or sinew line, stone weight).
Leister spear (multiple prongs on wooden shaft).
Club.
References
Cook, Clerke, and Gore, 1818, p. 37; Coxe, 1787, pp. 82, 87, and 215; Elliott, 1886, pp. 168 and 212-213; Jochelson, 1933, pp. 5, 8, 11, and 51; Langsdorff, 1817, pp. 333-334; Turner, 1886; Veniaminof, 1840, Vol. II, pp. 248-249.

6. System: Fishing onshore
Techniques
Fishing with hand lines from shore; catching salmon, Dolly Varden trout, and other massed fish at stream mouths with nets, leisters, and with hands; dams and weirs sometimes used.
Implements
Net of sinew or vegetable material (large nets used with stone weights and possibly wooden floats).
Fishing line (as in fishing offshore); sometimes used with bladder floats for sets.
Leister spears (as in fishing offshore).
(Kayak/umiak possibly used prehistorically in setting nets out from a beach).
References
Cook, Clerke, and Gore, 1818, p. 37; Coxe, 1787, pp. 62 and 82; Jochelson, 1933, pp. 7, 11, and 51-52; Ransom, 1946, p. 608; Sarichev, 1807, p. 71; Turner, 1886; Veniaminof, 1840, Vol. II, pp. 248-249.

7. System: Intertidal and beach collecting
Techniques
Combing exposed reefs and intertidal shores for urchins and other marine invertebrates and algae; combing active beaches for washed up sea mammals, birds, fish, and driftwood.
Implements
Prying implements for removing shellfish and invertebrates from rocks.
Grass baskets or stretched gut containers (adze, maul, and wedge for sectioning logs on the spot).
References
Elliott, 1886, pp. 214-215; Jochelson, 1933, pp. 8 and 11; Ransom, 1946, pp. 609-611 and 616-617; Staehlin, 1774, pp. 29 and 36-37.

8. System: Onshore collecting
Technique
Collecting terrestrial plant materials, bird eggs,‡ stone tool materials, minerals, etc., from specific localities landward from the active beach.
Implements
Baskets, nets, and other containers.
Cordage (sinew or grass for bundling gathered materials).
Mattock (bone head hafted to wooden handle).
Unhafted probe or digger.
Maul (stone hammerhead hafted to wooden handle; for breaking up stone materials).
References
Cook, Clerke, and Gore, 1818, pp. 39-40; Coxe, 1787, pp. 62, 69, 86, 196, and 213; Elliott, 1886, pp. 148, 168-169, 181, and 222; Jochelson, 1933, pp. 7-8, 10-11, and 59-63; Langsdorff, 1817, pp. 334-335 and 343; Ransom, 1946, pp. 613 and 619; Sarichev, 1807, p. 70; Turner, 1886; Veniaminof, 1840, Vol. II, pp. 94-95, 109, 229, and 232-233.

*Waterproof parka of stretched gut.
†Spear with multiple side or end prongs.
‡It may be argued that bird egg collecting from bird colonies on shore should be placed under bird hunting at nesting sites rather than here, especially if techniques of habitat exploitation are stressed.

I have summarized the Aleut food sphere elsewhere (McCartney, 1975, p. 315) and restate the conclusions here. Besides the fact that food staples are of marine origin, with sea mammals, fish, and birds providing the greatest input, most of these foods are also transient and are only found at particular times during the year. Because of the cyclical and sometimes migrating nature of the fauna and the sharp seasonality of the flora, there is an uneven food supply from one month to the next. At the poorest month (about March), "crisis" foods, such as shellfish, sea urchins, and algae, become especially important for survival into the next productive period. Part of this low ebb of food is due to inadequate storage techniques for preserving seasonal foods into later months. Fat or oil from sea mammal blubber is a necessary part of the diet; a constant diet of lean meat or vegetable products does not provide the requisite caloric fuel for survival. Finally, the annual dependency on marine resources from small shellfish to the largest whales plus such incidentals as land plants demonstrates how Aleuts had to exploit their total archipelago environment.

Many of the above characteristics may also apply to Northwest Coast Indian groups. According to Piddocke (1965, p. 247):

> . . .the abundance of the resources of the Kwakiutl has been somewhat overestimated and its significance misinterpreted. It was great enough to support a population larger than the usual size reported for hunting and gathering societies; but this population lived sufficiently close to the margins of subsistence so that variations in productivity which fell below normal could threaten parts of the population with famine and death from starvation.

Just as "starvation was no stranger to the Kwakiutl" because of "prolonged periods of bad weather which prevented hunting and fishing, and the failure of fish runs," so Aleutian starvation was known for much the same reasons (Veniaminof, 1840, Vol. II, p. 186, cited in Petroff, 1884, p. 151; Jochelson, 1925, p. 43; 1933, pp. 8 and 11).

Fauna from only one Aleutian site has been studied for quantitative estimates of food consumed. Denniston (1972, pp. 180-220) calculated the amounts of protein, carbohydrates, fats, and kilocalories available from the Ashishik Point (Umnak) faunal collection. She also computed the relative amounts of food that could have been derived from the major types of animals represented in her excavation units. Weights of edible products derivable from invertebrates, birds, fish, and sea mammals were in the ratio of about 1 : 2 : 36 : 52, respectively. This ratio does not necessarily hold for the relative amounts of protein, carbohydrates, and total calories supplied by the different animal groups, but still it is a more precise estimate of the Aleut diet than that suggested by the ethnohistoric literature (McCartney, 1975, pp. 293-295). This ratio of 1 : 2 : 36 : 52 for the various food sources is our best estimate of relative source importance for the entire chain, including, of course, the Rat Islands.

Table 6 lists the identified faunal organisms from Rat Island sites and from Near and Andreanof sites for comparison. Most of the faunal debris has not been studied quantitatively, nor have all low-frequency species been identified. Sea mammals and birds particularly were used not only for food but also for raw materials (skins, feathers, gut, bones, teeth, etc.), and some species may have been gathered more for one requirement than for the other. A comparison between these Rat Island species and a more complete listing of Aleutian species known to have been utilized aboriginally (McCartney, 1975, Table 1) shows a high correspondence. All species considered to be important because of their size and/or number are found in the few Rat Island sites sampled. We find substantiation therefore for the uniformity of faunal exploitation throughout the chain and, by implication, the uniformity of techniques required in procuring these species.

Materials. Aleuts used a wide range of raw materials for their tools, clothing, decoration, boats, houses, and other equipment for adapting. Three major categories with types of material and some finished products are given in Table 7.

Archaeological remains are usually stone, bone, and tooth, and only occasionally water-soaked wood (for wood, see Cook, Dixon and Holmes, 1972; Turner, 1973, p. 9).

Besides driftwood and stone (systems 7 and 8), most of these raw materials for manufacturing are primarily from sea mammals and secondarily from birds. An example of the intensive utilization of sea lions and resulting materials is described by Elliott (1886, pp. 369-370).

Island Resource Locations. The Rat Islands vary today in richness and abundance of species, and this disproportionate distribution undoubtedly occurred in the past. This section outlines the major resources available on the various islands as a suggestion of probable prehistoric exploitation. However, several considerations should be kept in mind in reviewing resource localities.

1. We cannot presume that modern faunal distribution exactly matches that of several thousands of years ago. Modern distribution data, however, provide the best indication of past fauna available. Since animals pursued are habitat specific, we know that there is no random distribution of sea mammals, fish, birds, invertebrates, algae, and terrestrial plants today or in the past. Modern habitat locations are assumed to correspond closely to past locations on the same island.

Population sizes for most of the species hunted, fished, or gathered have not been drastically reduced from the prehistoric period with the exception of whales and pelagic fish, which are taken by the high-seas fisheries. Sea otter populations have rebounded in the Rat Islands since they were placed under protection in 1911, and harbor seals and sea lions have not been exploited for pelts in a way comparable to the controlled fur seal harvesting in the Pribilofs. Except for islands on which foxes are found, bird colonies are relatively free of disturbances. Marine invertebrates, algae, and terrestrial plants are thought to be essentially unchanged since the prehistoric period. Because Aleuts have not depended on these major food animals for over half a century and because the Aleut population over that period was but a small fraction of the prehistoric population size, Aleuts have probably not seriously affected faunal totals in recent years.

Table 6—Identified Faunal Remains from Rat Island Midden Sites

Species	Rat Island sites			Comparative sites	
	Amchitka Site 31 (Desautels et al., 1971, pp. 314-340)	Little Kiska and Amchitka (Hrdlička, 1945, pp. 613-616)*	Little Kiska (Friedman, 1937)†	Attu, Amchitka, Adak, and Kiska (Dall, 1877, p. 50)‡	Attu and Atka (Jochelson, 1925, pp. 25, 27-29)§
Sea mammals					
Sea otter (*Enhydra lutris*)	59% of sea mammals (744)¶	X (common) L. Kiska**			X Attu, Atka
Hair or harbor seal (*Phoca vitulina*)	33% of sea mammals (418)	X (most abundant) L. Kiska		X	X Atka
Northern sea lion (*Eumotopias jubata*)	6% of sea mammals (79)	X (common) L. Kiska		X	X Attu, Atka
Northern fur seal (*Callorhinus ursinus*)	2% of sea mammals (30)	X (common) L. Kiska		X	? Attu, Atka
Walrus (*Odobenus rosmarus*)		X (1 bone) L. Kiska		X	
Pacific harbor porpoise (*Phocoena vomerina*)		X (occasional) L. Kiska		X	
Dall porpoise (*Phocoenoides dalli*)		X (occasional) L. Kiska			
Whales	X			X	X Attu, Atka
Land mammals					
Dog (*Canis familiaris*)		X (5 innominates) L. Kiska			
Fish					
Rock greenling (*Hexagrammos lagocephalus*)	X (abundant)				X Attu
Red Irish lord (*Hemilepidotus hemilepidotus*)	X (abundant)				
Pacific cod (*Gadus macrocephalus*)	X (abundant)			X	X Attu, Atka
Pacific halibut (*Hippoglossus stenolepis*)	X			X	X Attu, Atka
Rockfish (*Sebastes* sp.)	X				
Salmon (*Oncorhyncus* sp.)				X	
Unidentified herring, sculpins, and flounder				X	X Atka
Marine Invertebrates (in descending order of Site 31 abundance)					
Green sea urchin (*Strongylocentrotus* sp.)	X	X (very abundant) Kiska and L. Kiska		X	X Attu, Atka
Limpet (*Acmaea scutum*)	X	X Amchitka		X	X Attu, Atka
Limpet (*Acmaea pelta*)	X	X Amchitka		X	X Attu, Atka
Blue mussel (*Mytilus edulis*)	X	X Amchitka		X	X Attu, Atka
Giant horse mussel (*Modiolus modiolus*)					X Attu
Mussel (*Modiolus vulgaris*)				X	
Butter clam (*Saxidomus giganteus*)				X	X Atka
Bent-nosed clam (*Macoma nasuta*)				X	
Clam (*Mactra ponderosa*)					X Attu, Atka
Pearly monia (*Pododesmus macroschisma*)	X				
Black katy (*Katharina tunicata*)	X				X Attu

Hairy triton (*Fusitriton orgeonense*)	X				
Sitka periwinkle (*Littorina sitkana*)	X	X Amchitka		X	X Attu
Channeled dogwinkle (*Thais canaliculata*)	X				
? (*Thais lima*)		X Amchitka		X	
Island scallop (*Calamys islandicus*)	X				
Northern opal-shell (*Epitonium wroblewskii*)		X Amchitka			
Rock cockle (*Protothaca staminea*)				X	
Whelk	X				
? (*Volutopsius rebularis*)	X Amchitka				
? (*Collisella pelta*)				X	
Barnacle (*Balanus* sp.)	X				
Birds (by family, in descending order of Site 31 abundance)					
Phalacrocoracidae (cormorants)	37% of first 6 families (250)	X (occasional) Amchitka	24% of bird bones (132)		X Attu, Atka
Anatidae (swans, geese, ducks)	35% of first 6 families (235)	X (abundant) Amchitka	34% of bird bones (185)	X	X Attu, Atka
Alcidae (murres, murrelets, auklets, puffins)	11% of first 6 families (77)	X (rare occasional) Amchitka	22% of bird bones (118)	X	X Attu, Atka
Procellariidae (shearwaters, petrels)	7% of first 6 families (47)	X (occasional) Amchitka	X (2 bones)		X Attu
Diomedeidae (albatrosses)	6% of first 6 families†† (36)	X (common) Amchitka	12% of bird bones (68)	X	X Attu, Atka
Laridae (gulls, terns)	4% of first 6 families (28)	X (rare) Amchitka	3% of bird bones (16)	X	X Attu
Gaviidae (loons)	X (less than 4% each)		1% of bird bones (6)		
Podicipedidae (grebes)	X				
Falconidae (falcons)	X				
Accipitridae (eagles)	X		1% of bird bones (3)	X	
Corvidae (ravens)	X	X (rare) Amchitka	3% of bird bones (15)		
Strigidae (owls)			X (1 bone)		
Fringillidae (sparrows, longspur, buntings)					X Attu

*Little Kiska Site at west end of the island, sampled in 1936; Amchitka Sites 2 and/or 3, sampled in 1938; birds = 10 species.

†Friedman's Little Kiska sample is that excavated by Hrdlička in 1936; 34 species; R = 1-132; the following 7 species total 408 bones (75%) in descending order: Pelagic Cormorant, Pacific Eider, Short-tailed Albatross, Emperor Goose, Horned Puffin, Crested Auklet, and Tufted Puffin.

‡Dall does not specifically identify the source of his material; at least some comes from Amchitka and/or Kiska; with the exception of urchins, the remaining invertebrates "do not form altogether more than one-tenth of one per centum of the stratum."

§Jochelson's specimens from Attu and Atka; frequencies not specified.

¶Individual bones, not individual animals; whale fragments not included in counts.

**No details about Hrdlička's Amchitka faunal samples, but sea otter and harbor seal are the most abundant sea mammals.

††Turner (1970, p. 121) also notes the abundance of albatross bones in Amchitka middens.

The modern distribution and census figures for these animals and plants, then, ought to be a clue to their location and relative abundance in the past.

Table 7—Major Raw Materials and Important Products

Vegetable	
Driftwood	Boat frames, house frames, burial sarcophagi, harpoon shafts, clubs, bowls, trays, spoons, handles, throwing boards, masks, and some firewood.
Grass	Baskets, mats, cordage, nets, cloaks, house coverings, lining, and insulation material.
Twigs	Fuel and cushioning.
Kelp/algae	Fishing and other lines.
Other	Dyes and medicinal herbs and plants.
Animal	
Skins	Clothing and boat coverings.
Gut/internal organs	Kamleikas, windows, containers, drumheads, and harpoon floats.
Sinew	Nets and cordage for lines and lashing.
Bones	House frames, boat pieces, tools, weapons, spoons, and containers.
Teeth	Tools, decoration, and gaming pieces.
Feathers	Decoration.
Whiskers	Decoration.
Blubber	Lamp oil and waterproofing for skins.
Blood	Glue.
Inorganic	
Ocher and/or other minerals	Paint.
Sulfur	Fire starting.
Stone	Tools, bowls, lamps, weights, ornaments, fish weirs, house foundations, boat ballast, and storage-pit liners.

2. Island size and species abundance are not always proportional to one another. Sufficient evidence of this is seen in the size of Buldir's sea lion colony or Khvostof's and Davidof's puffin colonies (see Table 8).

3. Because fish and sea mammals are the two most important food sources, we can only partially estimate their abundance by observing animals from shore. In other words, Aleuts were often seeking the best hunting and fishing waters (systems 1, 3, 5, and 6), not the land masses with the most organisms on shore. Whales and porpoises are always water bound, and migrating fur seals rarely haul up while moving through the chain's passes. Sea otters and harbor seals are so wary that they are less frequently surprised on shore than encountered in the water. Because these species cannot be fixed to an island but rather are fixed to specific water habitats, we realize that shore counts can only suggest abundance for a surrounding water space or for species procured from shore (systems 2, 4, and 7).

Table 8 summarizes the present-day distribution and abundance of the major Rat Island resources that were important items of subsistence for prehistoric Aleuts. Because not all the islands have been surveyed with equal intensity for comparable species, only a few generalizations can be derived from the present quantitative data. Occurrence only is considered in Table 8, and seasonal variation is ignored; maximum animal population estimates are given rather than minimums or means. For the most part, all these species are recognized in prehistoric midden debris (Table 6).

A few generalizations are as follows: (1) The best sea lion islands are, in order, Buldir, Semisopochnoi, Kiska, Amchitka, and Rat. (2) The most sea otters are found around Amchitka, Kiska, and Rat Islands. (3) The best harbor seal island is probably Amchitka. (4) Fur seals may have been more abundant on and around Buldir if that suggested rookery is accurately identified (Table 8). (5) Most colony birds, except puffins, which center on Khvostof and Davidof, and cormorants, which center on Amchitka, are concentrated on Buldir. (6) Duck and geese estimates are available only for Amchitka, but, because these birds primarily occupy littoral waters or shores, they should be most abundant on islands with the greatest perimeter [Amchitka (195 km) and Kiska (161 km) stand out in shoreline length]. (7) Stream runs of salmon and Dolly Varden are probably most abundant on Amchitka, Kiska, Rat, and Semisopochnoi, roughly in that order; no comparative measures of major inshore and offshore fish species are available. (8) Major differences in whale, fish, invertebrate, algae, terrestrial plant, and driftwood distribution are unknown; the last four could be grossly compared by island size and circumference. (9) No land mammals, with the possible exception of dogs, are known on any of the islands preceding Russian rats and later introductions. (10) Although sulfur was limited to Little Sitkin, Khvostof, and Davidof, volcanic ejecta is more abundantly distributed; basalt and

Table 8—Major Rat Island Resources

Organic Resources

Sea mammals

Sea lions: Estimates given in descending order. Buldir, 3450; Semisopochnoi, 1590; Kiska, 1470; Amchitka, 900; Rat, 570; Little Sitkin, 335; Segula, 250; Rat Island total, 8565; major rookeries fairly evenly spaced around any one island; many offshore rocks and islets have sea lions; usually stay in waters of <50 fathoms (Kenyon and Rice, 1961; Kenyon and King, 1965; Sekora, 1973).

Sea otters: Estimates for 1965 given in descending order. Kiska, 1652; Amchitka, 1525; Rat, 435; Semisopochnoi, 271; Little Sitkin, 180; Segula, 75; Khvostof and/or Davidof, 52; Buldir, 30; other Amchitka estimates: about 1961, 4000 to 7000; 1970, 4000; 1970–1972, 7601; Rat Island total, 4196+; Rat and Delarof Islands total, 23,000 to 32,000; almost all islands have sea otters offshore, especially in waters of <30 fathoms and where kelp beds are extensive. (Kenyon, 1969; Spencer, 1969; Estes and Smith, 1973; Sekora, 1973).

Harbor seals: Amchitka has an estimated 1200; other Rat Islands combined have 1600; usually found in waters of <30 fathoms (Sekora, 1973).

Fur seals: Rarely haul up in the Aleutians when migrating through to and from Pribilofs; only known possible Aleutian rookery is Buldir; only hunted offshore in other areas; most fur seals use eastern rather than western island passes (Murie, 1959; Sekora, 1973).

Birds

Auklets: Total Rat Island estimate, 631,000; individual island totals given in descending order: Kiska, 125,000 to 400,000; Segula, 70,000; Buldir, 40,000 (Sekora, 1973).

Murres: Total Rat Island estimate, 30,600; individual island estimates: Buldir, 30,000; Semisopochnoi, 700 (Sekora, 1973).

Puffins: Total Rat Island estimate, 28,000; individual island totals given in descending order: Davidof, 7720; Khovostof, 6540; Semisopochnoi, 2200; Pyramid Island (near Davidof), 1500; Amchitka, 1300; Kiska, 1000+ (Sekora, 1973).

Kittiwakes: Total Rat Island estimate, 40,000; Buldir, 35,000 (Sekora, 1973).

Gulls: Total Rat Island estimate, 6500+; Buldir, 5000; Amchitka, 3000 (Williamson and Emison, 1969; Sekora, 1973).

Cormorants: Total Rat Island estimate, 2400; Amchitka, 1600; Semisopochnoi, 700 (Williamson and Emison, 1969; Sekora, 1973).

Fulmars: Total Rat Island estimate, 250 (Sekora, 1973).

Harlequin Duck: Amchitka total, 3500 (Williamson and Emison, 1969).

Common Eider: Amchitka total, 1500 (Williamson and Emison, 1969).

Emperor Goose: Amchitka total, 5000 (Williamson, Emison, and White, 1971).

Common Goldeneye: Amchitka total, 4000 (Williamson and Emison, 1969).

Bufflehead: Amchitka total, 2000 (Williamson and Emison, 1969).

Rock Ptarmigan: Amchitka total, 1800 (Williamson and Emison, 1969).

Fish

Salmonids: Approximate number of streams potentially suitable for salmon, in descending order: Amchitka, 30; Kiska, 27 plus 2 lagoons and 3 landlocked lagoon lakes; Rat, 7; Semisopochnoi, 7; Segula, 3; Little Sitkin, 3; Little Kiska, 3; Buldir, 1; Khvostof, 1; Davidof, 0; Amchitka has 21 streams supporting pink and a few coho salmon plus Dolly Varden; red salmon are known from Semisopochnoi; Kiska supports coho and probably pink salmon plus Dolly Varden in at least three areas (USGS Bulletin 1028 maps; Neuhold, Helm, and Valdez, 1971; A. C. Hartt and C. A. Simenstad, personal communication, 1974).

Inorganic Resources

Sulfur: Large deposit on Little Sitkin; sulfurous fumaroles on Little Sitkin, Davidof, and Khvostof; for fire making (personal observation; Sekora, 1973).

Pumice/scoria ejecta: Semisopochnoi, Little Sitkin, Davidof, Kiska, Segula, and Buldir probably all have surface pumice and/or scoria for abraders and other implements (Sekora, 1973; L. M. Gard, written communication, 1974).

Lignite: Amchitka; for labrets and other carved ornaments (Sekora, 1973; L. M. Gard, written communication, 1974).

argillite have an even wider distribution; no obsidian source is known.*

From these distributional data, sketchy as they are, we conclude that sea mammal, fish, and bird foods and materials are more abundant on Buldir, Amchitka, Kiska, Semisopochnoi, and Rat Islands. Because Buldir was so isolated and afforded only limited coastal living space, however, it attracted few, if any, permanent human residents. The interrelated dimensions of island size, circumference, and irregularity appear to determine abundance of primary species except for Buldir. Buldir's sea mammal and bird populations may be a function of isolation where scarcity of land concentrates populations. Inorganic materials as a group are more localized than are organic materials. A resource such as sulfur lends itself to trade because its acquisition can be more closely controlled.

*L. M. Gard (written communication, 1974) states that obsidian is common in the upper part of the Amchitka Formation (see Chap. 2) but is unsuitable for tool manufacture because it tends to shatter into small pieces. The rarity of obsidian in Amchitka artifact collections confirms the unsuitability of local obsidian.

Human Impact on the Environment

All the evidence one can muster suggests that prehistoric Aleut occupation throughout the chain had little lasting impact on island terrain. Remaining testimony of past physical alteration is limited to such slowly decaying features as house ruins, midden debris, burial sarcophagi, or mummy burials in caves and crevasses. If unbuffered by thick calciferous deposits (urchins, shellfish, mammal, and bird bones) or not waterlogged, organic materials quickly decay, leaving little or no residue. Thus the most apparent relics of past occupation one notes today are the coastal midden sites, which are covered with luxuriant vegetation because of their added soil nutrients. As pointed out in the introduction, the ancient village remains are rather insignificant compared with modern excavations and land-surface alterations.

Unlike Eskimos of the Canadian Arctic, who built so many features of stone (e.g., burial cairns, boat supports, markers, meat caches, etc.), Aleuts rarely used beach boulders except for house-wall foundations. Driftwood was the abundant raw building material, and, unless covered with sod and waterlogged, pieces would soon blow away or decay.

Aleut impact on past biota, however, is more difficult to evaluate and can only be postulated. The first colonization by man of the chain, as yet poorly documented archaeologically, undoubtedly had a significant impact on various species incorporated into the contemporary procurement systems. Nonetheless, we have no pre-man baseline against which to judge man's initial effects. If species easily preyed on by man were present in the western Aleutians, such as the sluggish northern sea cow and the flightless spectacled cormorant, both found in the Commander Islands at Russian contact (Stejneger, 1936, p. 351), then Aleuts probably affected their rapid demise.

More important than initial impact was the continuing interaction between Aleuts and available species for several millennia since. In general, archaeologists consistently see stability and equilibrium in the archaeological record; rapid population decline or expansion of Aleuts (and hence their supportive species) has not been documented. Several conditions relating to populational stability and ecologic adjustment are germane and are outlined below.

1. Resources available during the worst part of the year ultimately regulated population size. The bleakest period was during late winter and early spring when stormy seas prevented Aleuts from hunting and stored food had been depleted (Veniaminof, 1840, Vol. II, pp. 46-47, 196-197, and 234-235; Jochelson, 1933, p. 11). This is the Aleutian version of Liebig's law of the minimum. Aleuts never devised an effective leveling system to spread the abundance of late spring, summer, and fall throughout the annual cycle. Thus population leveled off, not because marine foods were exhausted but because storage techniques were insufficient and/or weather precluded the normal dependence on hunting and fishing in marine habitats. In other words, confinement to land was very restrictive to a people used to extracting food, mainly sea mammals and fish, from the sea. Population size probably never rose to the point that major staples were being overly taxed.

2. Given the hunting, fishing, and gathering subsistence techniques and their primitive if efficient technology, it would be extremely unlikely that prehistoric Aleuts could have caused drastic reductions in animal or plant resources. Sea mammals from sea otters to whales were abundantly available at Russian contact. There were no pan-Aleutian endangered species until the *promyshlennik* (Russian fur trapper and trader) arrived. Fish and algae were essentially limitless given the technology used to extract them. Perhaps overindulgence in egg collecting or bird snaring at a colony site or overcollecting sea urchins and shellfish might cause short-term declines in those shore localities, but such fauna would probably rebound rapidly if left alone for several years. Terrestrial plants never figured too importantly in the diet, and only grasses constituted a major raw-material resource. The majority of plants used had leaves, stalks, twigs, or berries removed without disturbing the root structure. Therefore these plants were not removed from their respective plant communities. Only a few plants provided roots (e.g., the Kamchatka lily, *Fritillaria camschatcensis*) for food, and only the collecting of these plants would cause their removal.

3. Aleuts depended heavily on migrating marine species for food and materials. Whales, fur seals, many birds, and salmonids were available in a cyclical fashion and were not year-round residents. Therefore, although migratory sea mammal, fish, and bird populations might be considered finite on an island's shore for any one day, week, or season, a seemingly infinite number of these animals passed through this archipelago filter over the course of a year. Like mainland Eskimos exploiting migratory caribou, Aleuts sampled from a large faunal universe not bound by sharp limits. The Aleut influence on the north Pacific marine fauna was insignificant when compared to European-controlled whaling, other sea mammal hunting, and

fishing, which reached this area during the eighteenth century.*

4. Finally, Aleut population stability was both enhanced and undermined by food sharing as one kind of reciprocity (see, for example, Sahlins, 1972, pp. 215-219 and 235-236). Prior to the late winter food shortage was a period of relative abundance. Winter was the time for large feasts or festivals in which whole villages participated. Other villages from the same or different islands were invited as guests (see, for example, Coxe, 1787, pp. 199-201; Veniaminof, 1840, Vol. II, pp. 85-91 and 208). This pattern follows the common Eskimo messenger feasts of mainland Alaska (see, for example, Nelson, 1899, pp. 357-363; Spencer, 1959, pp. 210-228), at which time food consumption and sharing is an important function. It is obvious from the following passage from Veniaminof (1840, Vol. II, pp. 85-86) that such festivals paralleled the Northwest Coast potlatches in their spirit of rivalry:

> The formal festivals consisted of scenic stage representations. These were always held in the winter and alternated between one settlement and another. They were organized by the entire population and for them each and every inhabitant gave almost all that he had—*particularly in the way of food supplies.* Thus after each festival everyone of them inevitably went hungry in the full sense of the word. Such a famine was not considered a shameful thing but one of glory. Each settlement, in its turn, sought to outdo each other in the invention of scenes, in the artistry of staging, and in the profusion of their hospitality. (Emphasis added.)

Therefore sharing available food resources in early winter enabled many Aleuts to gain from the accumulations of a few. Hunger and privation, however, were the rewards for feast givers prior to the beginning of the spring food cycle.

In sum, prehistoric Aleuts possessed neither domesticated crops nor animals and could only collect food, not produce it. Like other hunters and gatherers, little control could be exerted over potential dietary resources. Over thousands of years of occupation, human population equilibrium was reached on the basis of hunting and gathering. Disequilibrium must have been the exception rather than the norm; as illustrated in Fig. 8, such disequilibrium derived from upsetting either habitat, organisms, extractive techniques, food products, or population or some combination of these. As participants in a generally stable environment, Aleuts were causing few detectable, long-term effects that we can document today. Obviously, by their very presence, Aleuts affected their various habitats and resource organisms on which they depended. However, these effects were indeed minimal when compared to the historic period and the impact that the rifle, motorized boat, and other industrialized technology and exploitation had on that same environment.

CULTURAL PATTERNS AND INTERACTION

Considering the several thousand artifacts collected on Amchitka, the nonarchaeologist might well suppose that we have a firm understanding of ancient Aleut culture. Unfortunately this is not the case. This section begins with a résumé of what little cultural information we actually have. Although this summary applies to the Rat group, our archaeological knowledge of the Near and Andreanof groups is equally scanty if not more so. Only the eastern archipelago has received more intensive investigations (see, for example, Aigner, 1970; Denniston, 1972; McCartney, 1974; Turner and Turner, 1974). Even so, taken as a cultural whole, Aleut prehistory remains poorly known today. This is ironic in light of Dall's having initiated Alaskan archaeology a century ago by excavating along the Aleutian chain.

The state of Rat Island archaeology can be summarized as follows:

1. Only Amchitka has been adequately surveyed for sites; the nine other islands, comprising 67% of the coastline, have not been intensively searched for additional sites.

2. Of known sites, only about 20% have been tested in any fashion; no one site has been extensively excavated with systematic procedures; the largest excavations were those of Hrdlička on Amchitka (Sites 2 and 3) and Little Kiska, but these provided no cultural information besides the artifacts, a few human burials, and a small faunal sample.

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*Hett and O'Neill (1974, pp. 37-38) corroborate the limited effects of man on the Aleutian ecosystem through their study of a carbon cycle model: "... the Aleut population played a relatively minor role in maintaining or affecting the stability of the ecosystem as defined by the rate of recovery from disturbance. It should be noted that the Aleut is considered in the context of his natural state where his major effect was as a consumer. These conclusions are quite invalid when applied to civilization's present influence in the subarctic."

Rappaport (1963) notes a similar insignificant effect of native peoples in middle and South Pacific Islands: "On the reef, in the lagoon, and in the sea there continued to be relatively unmodified communities, composed of generally the same elements in generally the same relationships as those that obtained prior to man's arrival. The ecological niche or niches exploited by human populations belonging to such communities depended mainly upon the biotic elements present before the advent of man; the presence, location, and quantity of these elements were subject to little or no control by human beings" (Rappaport, 1963, pp. 166-167).

3. Only three sites have been radiocarbon dated, and all these are on Amchitka (Sites 31, 32, and 36).

4. Only one house feature has been uncovered (Site 32); other features include several hearths and burials; all features are found in Amchitka sites, and none are known from other islands.

5. Although several human skeletons have been found, these have not been studied as a series nor comparatively reported on in detail.

6. Major Amchitka collections have either gone unanalyzed (Hrdlička and Sense) or have been studied analytically with no comparative syntheses along temporal, spatial, or functional dimensions (Desautels and Cook).

7. Finally, the Rat Island native population was eliminated or removed early during the Russian colonization, and there is very little ethnohistoric literature from which to tie together historic and prehistoric cultures.

Because prehistoric remains (sites, burials, artifacts, faunal debris, etc.) from this island group are generally similar to those found elsewhere in the chain, we view Rat Islanders as taking part in the larger, archipelago-wide cultural milieu. We have adequate evidence that these past peoples adapted similarly to the Aleutian environment. For the above reasons, however, we must often speculate about specific details of the prehistoric past.

Aleutian archaeology may be accurately characterized as becoming more oriented to settlement pattern and to ecologic and systemic approaches over the past decade since these approaches have developed in contemporary archaeology generally (see, for example, Flannery, 1967; Leone, 1972; Redman, 1973). Yet the organization of Aleutian prehistory within these kinds of models is hardly an accomplished fact. Archaeologists working in many other geographic regions have made great strides with these approaches because they operate within a well-blocked-out cultural–historical frame. The major problems of time, space, and function have been addressed, but this cultural–historical foundation is largely lacking in the Aleutians, and we are hindered because of it. Unit concepts (e.g., Willey and Phillips, 1958) have gone undefined and have not been used. For various reasons, namely, poor stratigraphic control in many excavations, few radiocarbon dates, few published reports, and many unstudied museum collections, Aleutian archaeologists have operated largely in a noncomparative manner except at the artifact level. As a result of all these factors, we can offer only a sketchy and speculative synthesis of prehistory for one island group or the entire archipelago.

This section briefly reviews the nature of Rat Island collections and the kinds of interaction that occurred within this island group and between it and neighboring groups.

Rat Island Artifacts

Because the artifacts recovered under AEC-sponsored projects are now stored in the University of Alaska museum and could not be studied easily in preparation for this chapter, no synthesis of the 1968, 1969, and 1971 artifacts is presented here. Instead, the Smithsonian collections of Hrdlička and others were inspected to evaluate artifact variations within the Rat Islands. These artifacts from Amchitka, Kiska, and Little Kiska constitute the largest collections besides those of the AEC.* The Smithsonian collection has never been analyzed and published; only a few specimens appear in Hrdlička's (1945) Aleutian report. Fifty-five of the Amchitka pieces are illustrated in Figs. 9 to 15 of this chapter; all but one of these are from Sites 2 and 3. These show some of the variety of implements and weapons used in procurement and other activities plus the toolmaking skills of ancient Aleuts.

Table 9 summarizes major artifact classes as grouped by activity spheres or use contexts. These classes are taken from reports and collection notes covering all island groups, but those specifically known from the Rat Islands are marked. This listing attempts to organize artifacts of known function; artifacts of unknown function are excluded. In some cases we cannot be certain that an implement was used in only one context. Knives and scrapers, for instance, were probably used in multiple contexts on multiple materials.

It is readily apparent that almost all these typical Aleutian implements are known from the Rat group, indicating strong cultural continuity

*The U. S. Museum of Natural History, Smithsonian Institution, is the repository for a total of 2059 catalogued artifacts from the Rat Islands collected over the past century. A breakdown of this total by island is as follows: Amchitka, 1526 (74%); Little Kiska, 481; Kiska, 34; and Rat, 18. A breakdown by collector is as follows: Hrdlička, 1916 (93%); Guggenheim, 34; Dall, 25; and others, 84. Because of Hrdlička's 1930s field work, the Smithsonian has the largest Rat Island collection with the exception of the recent AEC-sponsored one.

The small Amchitka collection that Guggenheim gave to the Smithsonian has been rather picked over, and few fine pieces are included. It is typical of many collections made by World War II servicemen in that, by the time they became museum acquisitions, mostly broken bits and pieces remained. Hundreds if not thousands of artifacts left Amchitka with World War II military personnel, but very few of these were later donated to museums for safekeeping. One Amchitka exception is a collection now in the possession of Rockmont College, Denver.

over space. Examples of classes not yet found in the Rat Islands will probably be found in the future. As stressed throughout this chapter, Aleut lifeways are rather similar wherever noted in the chain, and preserved technology is accordingly similar. Differences do occur, however, at the typological or stylistic level beneath that of major classes.

Cultural Interaction Within the Rat Group

Much of the preceding discussion suggests that Rat Islanders interacted in direct proportion to their proximity to one another. Aleuts living closest together would have shared in a greater number of common cultural elements than those living on the most isolated islands. We would expect similarity to be displayed, particularly in artifact assemblages, in that style reflects shared manufacturing norms. On a single island, such as Amchitka, we would expect that two synchronously occupied villages close together would display more common cultural expressions between them than either would to a distant village. Of course, the comparison of assemblages from nearby sites occupied at different periods would indicate nothing about cultural sharing.

It is not possible to test this hypothesis of proximity—similarity on Amchitka by merely reviewing the two AEC artifact reports (Desautels et al., 1971; Cook, Dixon, and Holmes, 1972). A complete study of all the 1968, 1969, and 1971 collections would be required to detect the degree to which proximity and cultural similarity are related. Even then the existing sample may be insufficient, and additional artifact samples may be required to substantiate this postulate. Some of the materials are not comparable temporally. Most of the 1971 artifacts date to about 400 years ago, whereas the 1969 artifacts span a long period, beginning about 2500 years ago.

Furthermore it is not possible to adequately test this proximity—similarity hypothesis between islands because the only sizable non-Amchitkan collection is that from Little Kiska. A demonstration supporting this hypothesis would require additional collections from several different islands.

Cultural Interaction Between Adjacent Island Groups

Comparative Limitations. If comparisons within the Rat Islands are limited, comparisons between major island groups are little better. Limitations in making typological and stylistic comparisons include small sample sizes, noncomparable sampling techniques, lack of provenience specifications, and lack of typological analyses. These are briefly outlined before offering interim cultural generalizations.

Sample size is critical because, although Rat Island artifacts total about 10,810 (AEC, 8750; Smithsonian, 2060), collections from the Near and Andreanof groups flanking the Rat group total much less. The largest museum collection, to my knowledge, is that of the Smithsonian: Near Islands, 2010 (Attu, 410; Agattu, 1600); Andreanof Islands, 456 (Ilak, 23; Kanaga, 84; Adak, 132; Atka, 105; Amlia, 112). In addition, 936 other Near Island artifacts from Attu, Agattu, and Shemya are treated by McCartney (1971), including those published by Spaulding (1962), Jochelson (1925), and Hurt (1950). Artifacts from any one island, much less any one site, are relatively few in comparison with Amchitka and Little Kiska. Hrdlička's large Agattu collection is the single exception.

More important than mere sample size is the fact that neither Hrdlička nor military personnel responsible for other collections retained all excavated materials. In other words, the collections do not represent the artifact assemblages originally deposited at the sites. Better, complete, and unique artifacts were selected over poor, broken, and redundant ones. Worn and broken flake scrapers and knives, notched stone weights, and fragmented bone and stone implements, for example, were often left in the field. The AEC collections were systematically assembled, with attention paid to all cultural debris. These recent Amchitkan collections are difficult to compare with the older collections from the Near Islands and the Rat Islands (except for Spaulding's Agattu collection) because the analyst never knows what was actually excavated in these adjacent island groups.

Besides making incomplete collections, Hrdlička and military collectors failed to assemble provenience measurements, detailed notes about site context, or relevant maps, drawings, and photographs. We have essentially no information about midden stratigraphy and features or where the collected artifacts originate vertically or horizontally in the midden matrix. Knowing relative artifact positions would make these western island collections much more useful than they are currently.

Finally, no one has classified central or western Aleutian artifacts in either a more traditional typological manner or through cluster analysis of attributes. This condition prevails for the majority of all Aleutian sites. We are thus left with individual artifacts to compare rather than artifact clusters of demonstrated cultural significance.

(Text continues on page 107.)

Fig. 9—Typical Amchitka artifacts (U. S. Museum of Natural History, Sites 2 and 3).

Hunting implements:

a–g Chipped-stone projectile points or end blades for use in arrows, darts, harpoons, or spearheads such as h–k (basalt and similar stone). (Catalog numbers 396219, 396215, 396289, 396215, 396215, 396289, and 396289.)

h Bone arrow or dart head with conical tang and slotted tip for a stone projectile point. (Catalog No. 396130.)

i Bone spearhead with missing tip; the plug tang was inserted into a bone socket piece and probably secured with thong lashing through the basal hole; the original tip was either slotted or had an open basin for a stone projectile point. (Catalog No. 386125.)

j Bone spearhead with basal lashing lip, slotted tip for a stone projectile point, and an owner's mark incised into one face for identifying sea mammal kills; this head was probably lashed directly to a wooden shaft. (Catalog No. 396138.)

k Bone spearhead with slotted tip for a stone projectile point and finely incised line decoration; this late style head was embedded directly into a wooden shaft end and lashed around the tang notches; possible use as a fish spear instead of a sea mammal spear. (Catalog No. 387673; this specimen only from Site 20.)

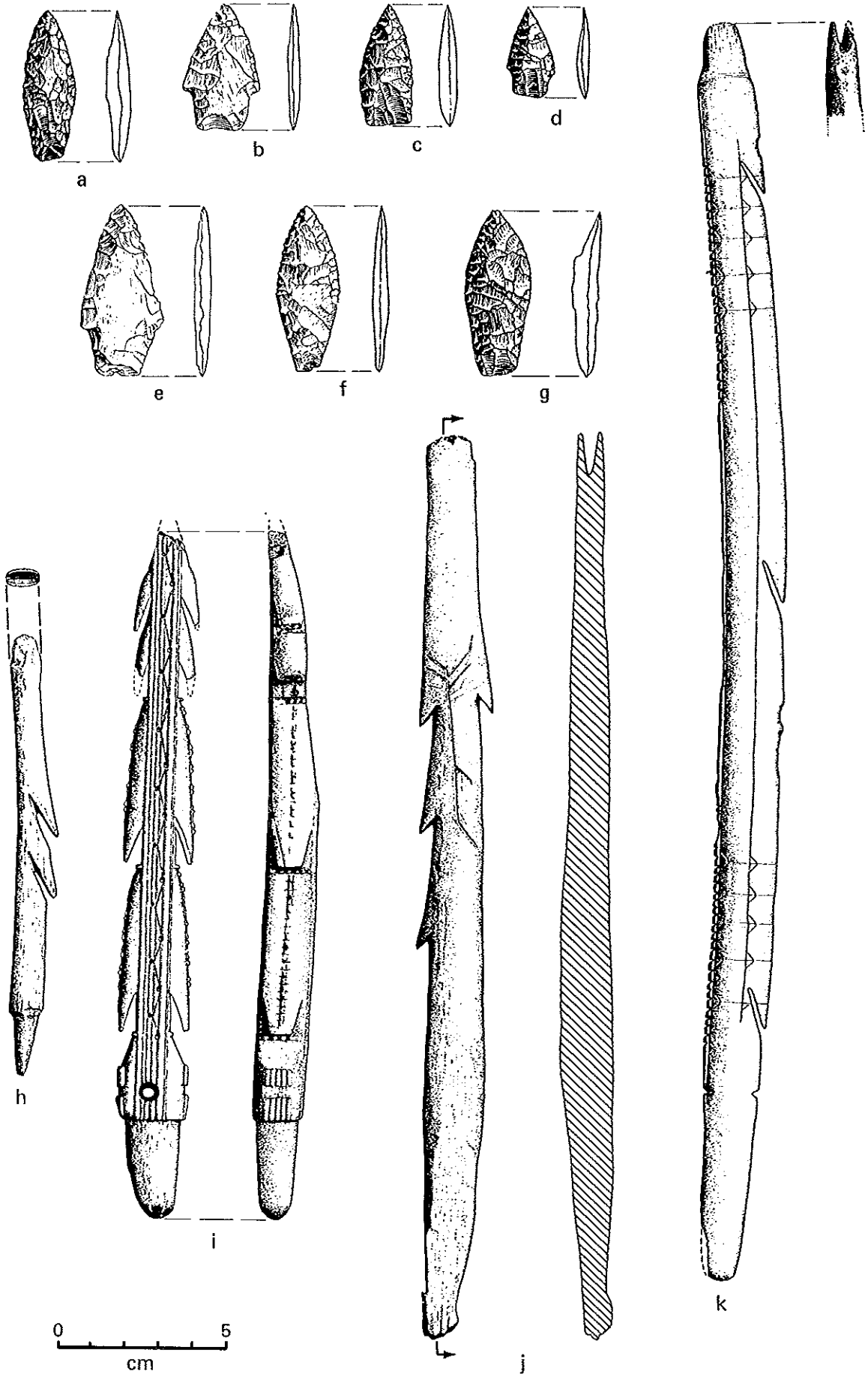
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Fig. 10—Typical Amchitka artifacts (U. S. Museum of Natural History, Sites 2 and 3).

Hunting implements:

a–e Bone dart or harpoon heads; all these heads have wedge-shaped tangs that were held secure in socket pieces such as i and j below. (Catalog numbers 396272, 396127, 396272, 396127, and 396127.)

f Bone unbarged arrow or dart point with conical tang. (Catalog No. 396142.)

g–h Bone barbed points with asymmetric tangs; possibly for use on a bird or fish leister. (Catalog numbers 396129 and 396139.)

i Bone socket piece with peg tang for insertion into a wooden shaft end or into another intermediate bone socket; two wooden inserts in the oval socket end made it possible to wedge a point tang securely between them. (Catalog No. 396287.)

j Bone socket piece with bifurcated tang; the tang fits directly into a wooden shaft end; wooden inserts were also used in the socket end. (Catalog No. 396151.)

Fishing implements:

k Bone leister side prong; for use on a bird or fish leister shaft. (Catalog No. 396092.)

l Cobble sinker or weight with full groove for line or net attachment. (Catalog No. 396191.)

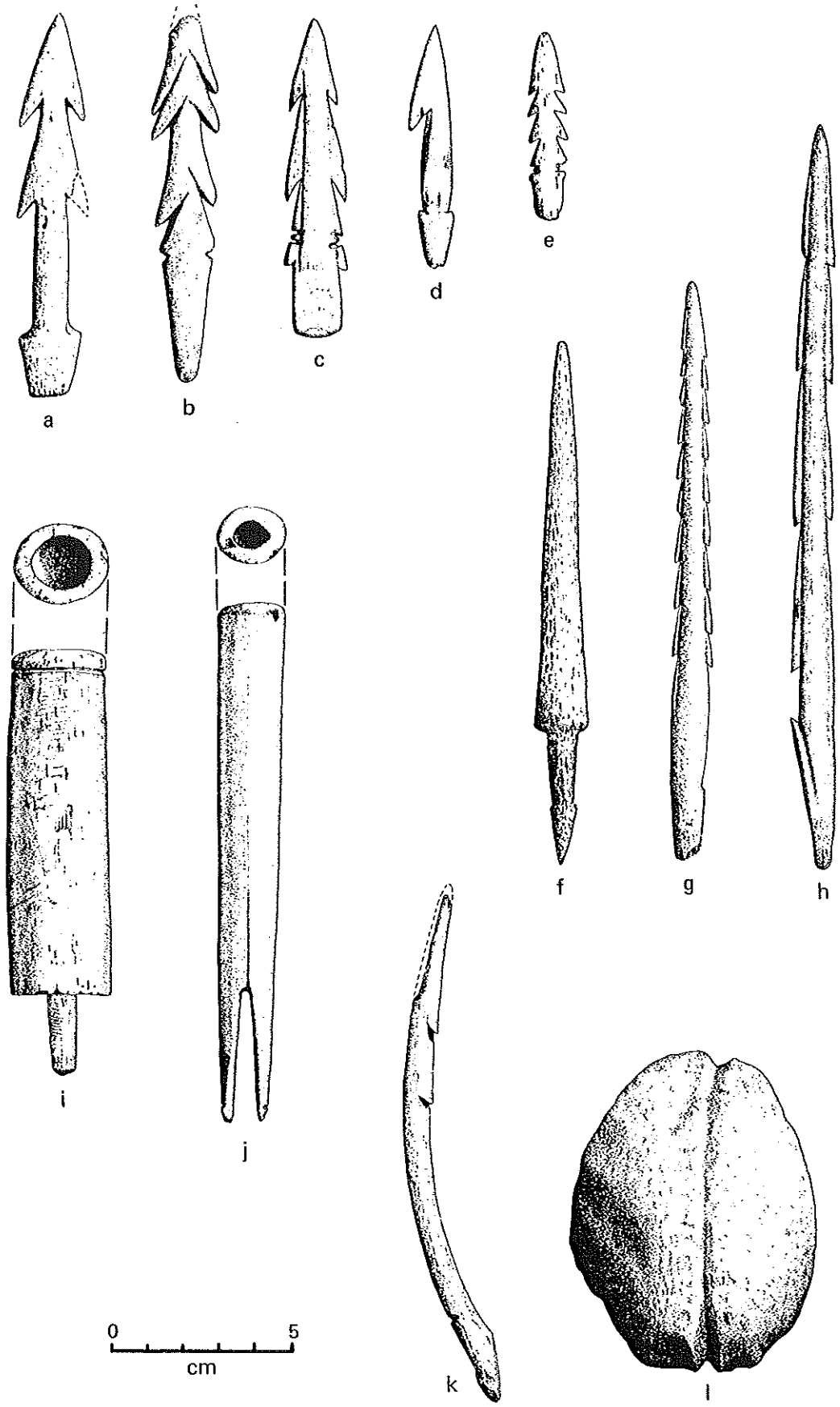
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Fig. 11—Typical Amchitka artifacts (U. S. Museum of Natural History, Sites 2 and 3).

Skin-preparation implements:

a Bone handle for a metal knife blade with step-scarf tang for attachment to a wooden-handle extension; a rusted iron-blade fragment is embedded in the end slot; the side-groove function is unknown. (Catalog No. 396145.)

b Awl of split proximal end of an albatross humerus. (Catalog No. 396088.)

c Awl of sharpened proximal end of a bird radius. (Catalog No. 396085.)

d Chipped-stone scraper blade; hafted for use in wooden handle (dark gray andesitic stone. (Catalog No. 396208.)

e–g Chipped and partially ground stone ulu blades; probably hafted for use in wooden, bone, or woven-grass handles (argillitic stone). (Catalog numbers 396218, 396334, and 396218.)

h Small ground stone ulu or knife blade; probably hafted in a wooden handle for use (argillitic stone). (Catalog No. 396218.)

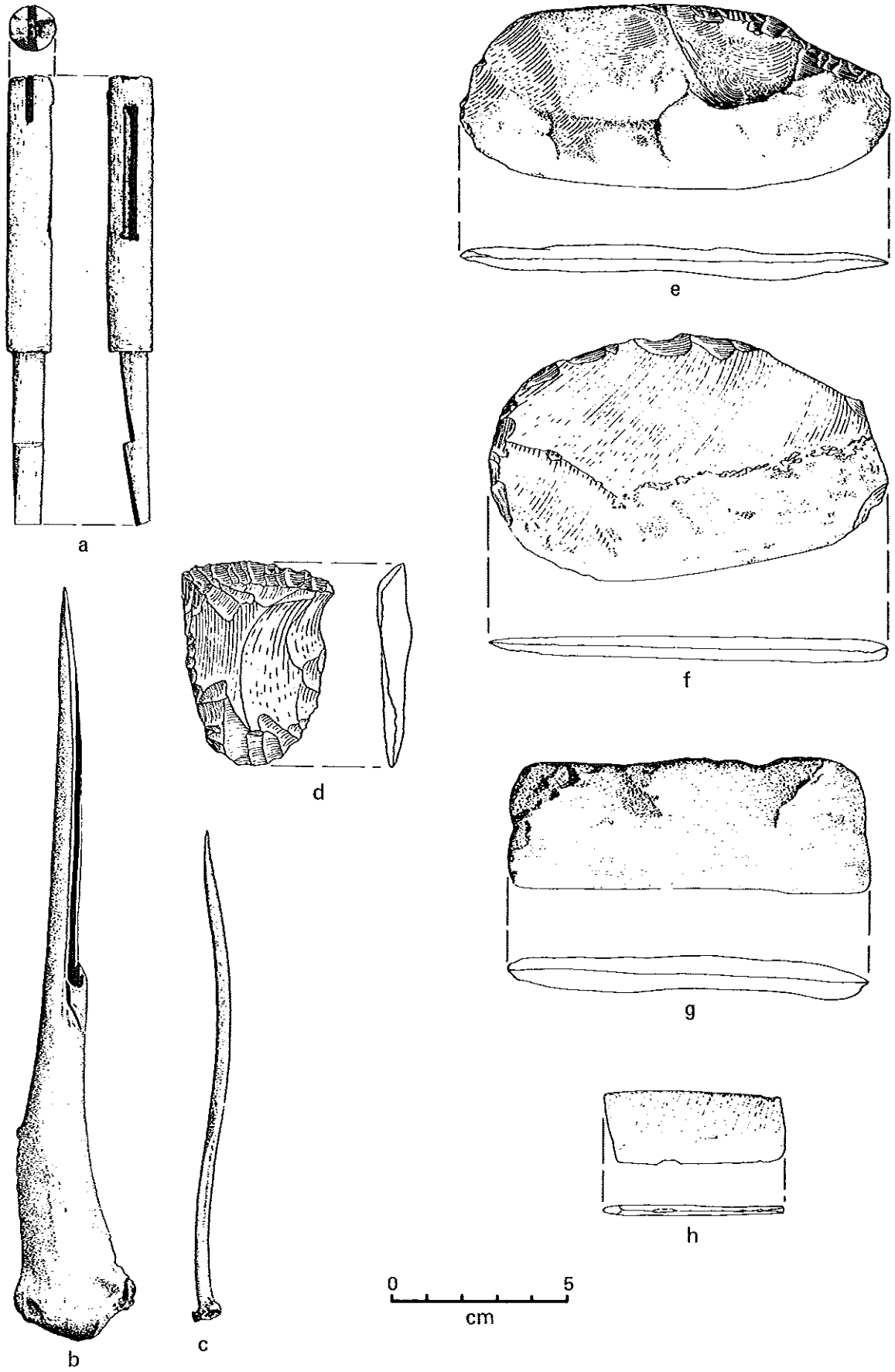
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Fig. 12—Typical Amchitka artifacts (U. S. Museum of Natural History, Sites 2 and 3).

Woodworking implements:

a Bone adze head; an adze blade such as b was lashed into the basin at the upper end, and a wooden handle was lashed onto the longer end by means of the lashing grooves. (Catalog No. 396288.)

b Chipped and partially ground stone adze blade (dark gray hard stone). (Catalog No. 396210.)

c Bone wedge with holes resulting from using the wedge as an upper bearing or holder for a bow drill. (Catalog No. 396220.)

d Small peg-like bone wedge. (Catalog No. 396219.)

e Scoria abrader. (Catalog No. 396306.)

f Chipped-stone scraper; the angled steep edge is unifacially flaked. The scraper is hafted to a wooden handle for use (basalt). (Catalog No. 396292.)

g Chipped-stone drill bit; the bit is hafted to a drill shaft for use (dark brown hard stone). (Catalog No. 396293.)

h Flake drill (gray andesitic stone). (Catalog No. 396340.)

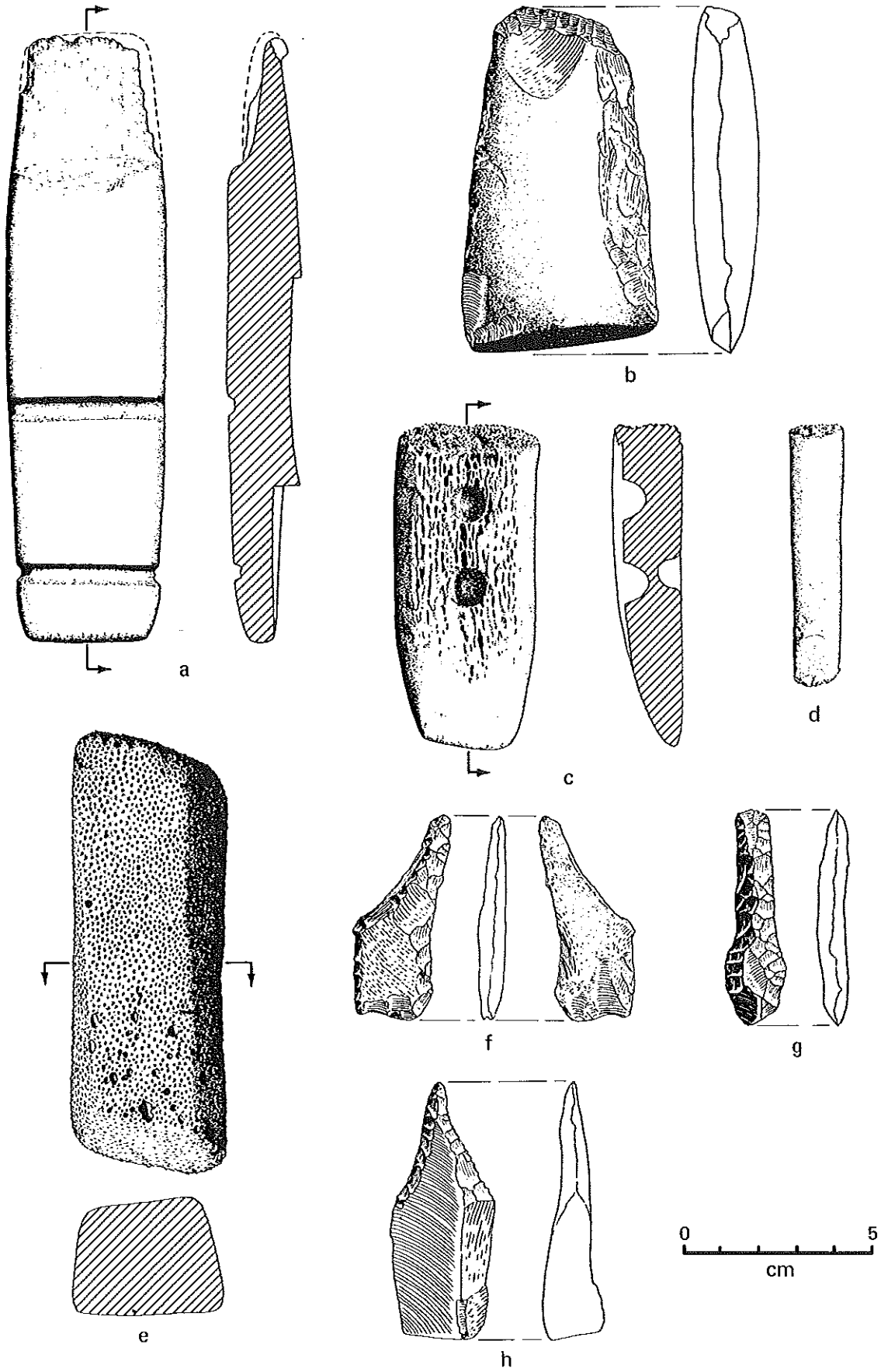
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Fig. 13—Typical Amchitka artifacts (U. S. Museum of Natural History, Sites 2 and 3).

Household implements:

a–b Bifacially chipped knife blades; used hafted or unhafted (basalt and gray andesitic stone). (Catalog numbers 396213 and 396214.)

c Bifacially chipped knife blade with tang notches for lashing to a wooden handle (basalt). (Catalog No. 396290.)

d Bifacially chipped asymmetric knife blade with one tang notch for lashing to a wooden handle (basalt). (Catalog No. 396291.)

e Bifacially chipped knife blade; probably hafted in a wooden handle before use (basalt). (Catalog No. 396290.)

f Flake knife or scraper with unifacial chipping along both cutting edges (obsidian). (Catalog No. 396296.)

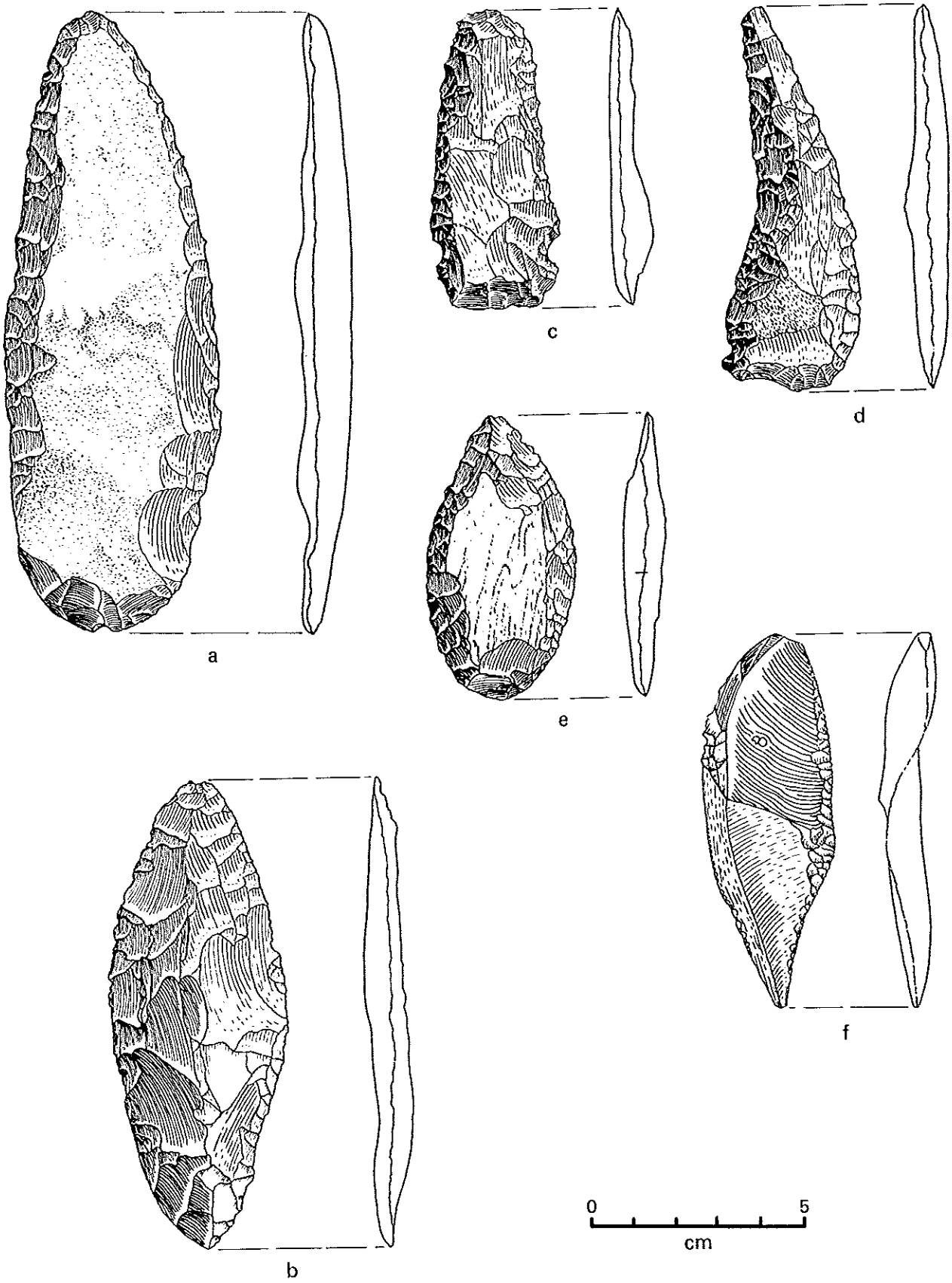
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Fig. 14—Typical Amchitka artifacts (U. S. Museum of Natural History, Sites 2 and 3).

Household implements:

a Carved stone lamp with charred oil residue. (Catalog No. 396186.)

b Combination hammerstone and grinder; both ends have been used for pounding and two side facets have been worked flat by grinding. (Catalog No. 369307.)

c Combination hammerstone and grinder; the edges and particularly the ends have served as pounding surfaces; a flat grinding facet is worn on one face. (Catalog No. 369197.)

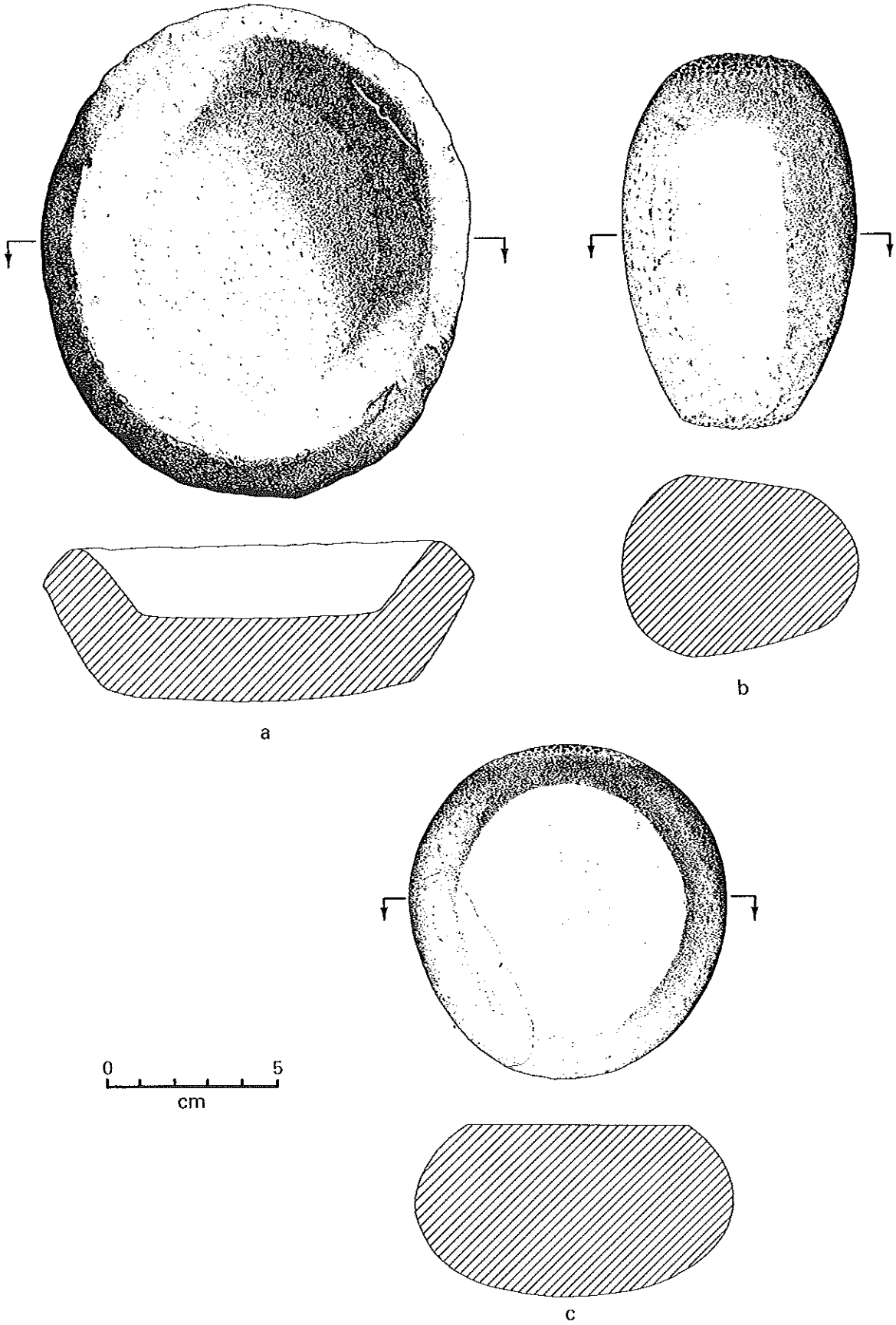
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Fig. 15—Typical Amchitka artifacts (U. S. Museum of Natural History, Sites 2 and 3).

Collecting implements:

a Ivory digger with carved handle and incised line decoration. (Catalog No. 396242.)

b Bone probe or digger with decorative end carving. (Catalog No. 396163.)

Articles of adornment/miscellaneous:

c Ivory/tooth labret. (Catalog No. 369100.)

d Ivory/tooth labret. (Catalog No. 396097.)

e Bone labret. (Catalog No. 396107.)

f Bone bead. (Catalog No. 396115.)

g Bone "gauge"; use unknown; surface polish is often found on these pieces at the ends below the pips. (Catalog No. 396112.)

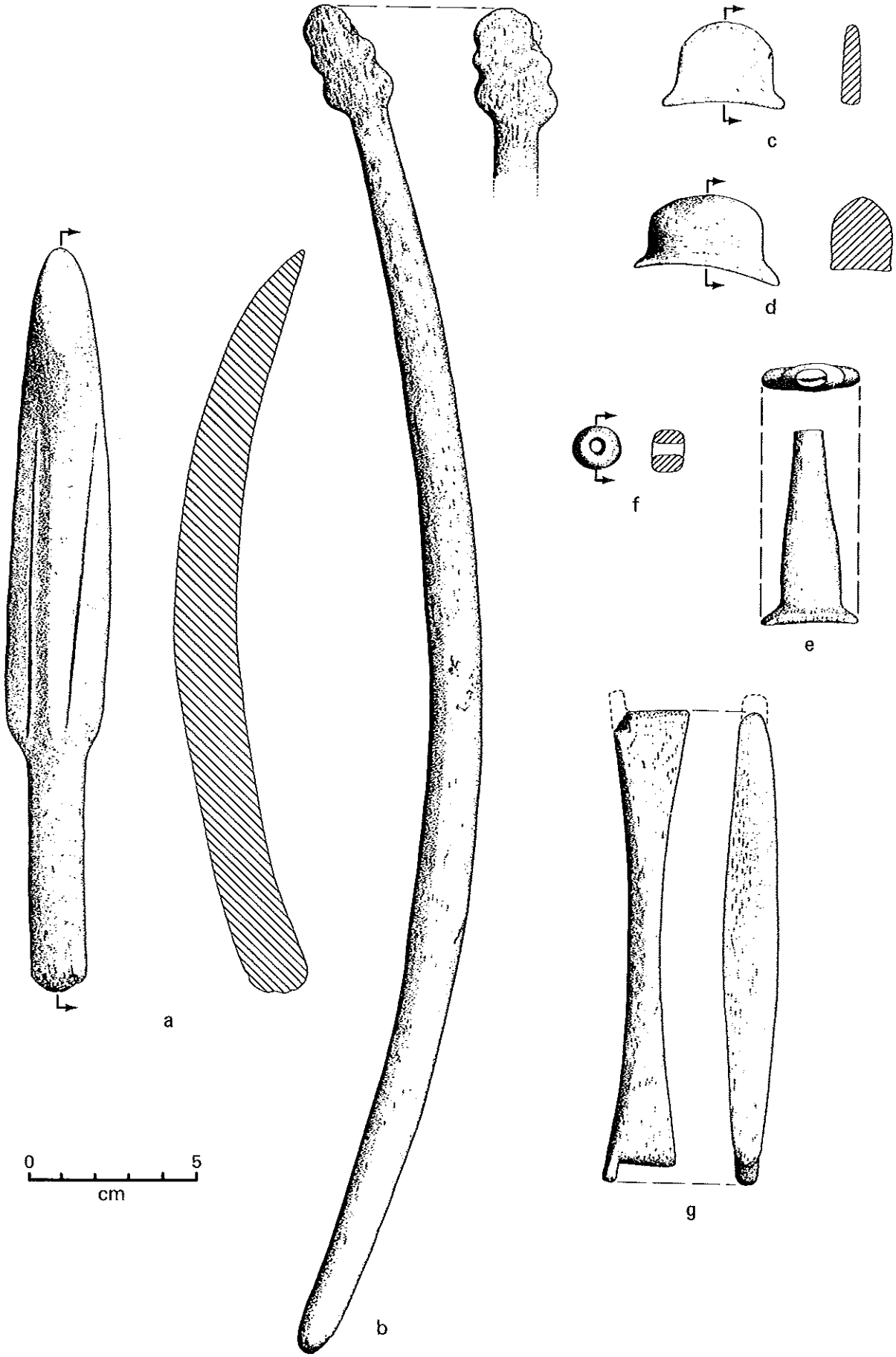
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Table 9—Aleutian Artifact Inventory

Contextual category	Artifact class	Figure
Hunting implements	Bone harpoon heads (detachable)*	10(a–e)
	Bone spear/lance heads (nondetachable)*	9(i–k)
	Bone dart heads*	
	Bone arrowheads*	9(h)
	Bone bird blunts*	
	Bone loose shafts*	
	Bone socket pieces/foreshafts*	10(i,j)
	Stone projectile points/end blades*	9(a–g)
	Wooden covers for stone end blades	
	Wooden shafts for harpoon/spears/darts*	
	Bone bladder nozzles	
	Bone and wooden clubs*	
	Bone bird gorges	
	Bola stones (?)*	
Fishing implements	Bone fishhooks*	
	Bone fish leister points/side prongs*	10(g, h, k)
	Stone weights/sinkers*	10(l)
Collecting implements	Bone diggers/probes*	15(a, b)
	Bone mattock and pick heads*	
	Net and basket containers	
Woodworking and boneworking implements	Stone maul heads*	
	Hand hammer stones*	14(b)
	Bone wedges*	12(c, d)
	Bone adze heads*	12(a)
	Stone adze blades*	12(b)
	Bone drill bearings*	12(c)
	Stone drill bits*	12(g, h)
	Stone scraper blades*	11(d), 12(f)
	Stone flake scrapers*	
	Bone knife handles*	
	Stone knife blades*	13(a–e)
	Iron knife blades*	11(a)
	Scoria/pumice abraders*	12(e)
Stoneworking implements	Whetstones*	
	Bone flaking tools	
Skin preparation implements	Bone ulu handles	
	Stone ulu blades*	11(e–h)
	Stone scraper blades*	11(d)
	Stone flake scrapers*	13(f)
	Iron knife blades*	11(a)
	Bone scrapers	
	Bone cutting/trimming tablets*	
	Bone awls/punches*	11(b, c)
	Bone needles*	
	Bone needle cases	
Household implements	Bone ulu handles	
	Stone ulu blades*	11(e–h)
	Stone knife blades*	13(a–e)
	Bone fire drill bearings*	12(c)
	Wooden fire drill base	
	Sulfur (for fire starting)	
	Hand hammer stones*	14(b)
	Ocher grinding slabs/stones*	14(c)
	Stone lamps*	14(a)
	Stone griddles	
	Stone bowls	
	Bone bowls/containers	
	Bone container sides*	
	Wooden bowls/trays	
	Bone and wooden spoons/scoops/shovels	
Articles of adornment and decoration	Bone/tooth labrets*	15(c–e)
	Bone/tooth spools*	
	Bone/tooth pins	
	Bone/tooth pendants	

Table 9—(Continued)

Contextual category	Artifact class	Figure
	Pendants made of drilled or grooved mammal teeth*	
	Bone beads*	15(f)
	Shell beads/pendants*	
	Bone chains	
	Bone/tooth animal and human figurines*	
	Bone combs	
	Bone and wooden masks	

*Known from Rat Island collections.

As with the intragroup comparisons above, artifact or cultural similarity between island groups directly expresses contact between Aleuts of these groups. Although not all contact need imply cultural transmission, stylistic similarity may be explained realistically by such transmission.

Intergroup Comparisons. I suggested several years ago (McCartney, 1971) that distinctive characteristics of Near Island material culture ultimately derived from the relative isolation of that group from the rest of the archipelago. After I completed that article, the Desautels et al. (1971) monograph appeared, and I commented that this report suggested that Amchitka was more closely related to central and eastern assemblages than to those of the far western islands (McCartney, 1971, p. 106, postscript). Since I have studied additional Rat and Andreanof artifacts, a general updating of the 1971 conclusions is in order. But the comparisons are now in two directions rather than one, as was the case with the Near Islands at the chain's end.

What can we hope to learn from artifact distribution studies? In regard to the ecologic, systemic study of marine subsistence emphasized above, we should ascertain if, in fact, all islanders adapted similarly. Even casual study shows us that indeed all these various island collections display the same artifact core as is listed, for instance, in Table 9. At the stylistic level, however, we are primarily concerned with ascertaining cultural spread over time and space. As mentioned previously, most areas of North America have a cultural—historical framework established through past decades of archaeological study. The Aleutians lack any such framework. Therefore, seeking evidence of cultural flow—population contact along this attenuated island chain requires distributional input about the spread of cultural characteristics. We have postulated that distance between islands and island groups is inversely proportional to cultural contact and spread. To establish such a relationship requires that we demonstrate some evidence of contact and cultural flow. Our medium is artifacts and other physical manifestations of cultural patterning. The physical anthropologist would test such contact by studying gene flow expressed in human skeletal series. A linguist would try to establish continuity and discontinuity on the basis of present Aleut speakers and historic language documents. Distributional artifact studies, in and of themselves, may seem a bit humdrum; yet results of these comparisons directly indicate adaptations, population movement, in situ development, trade, or other interaction and adjustment. The critical questions revolve around why these distributions are what they are. What cultural and social regularities, in other words, are being demonstrated by particular artifact clusterings in space? Although the explanatory phase will benefit greatly from accurate distributional descriptions based on large-scale comparative studies, an attempt is made in a later section to find ethnohistoric reasons for stylistic spread.

Long artifact attribute and type lists will not be included in this chapter. My previous listing of shared pan-Aleutian traits (McCartney, 1971, pp. 138-139, Table IV) stands as presented. These 32 items are indicative of artifacts found throughout the chain, and more will certainly be added in the future. The listing of central and eastern Aleutian artifacts (McCartney, 1971, p. 141, Table V) also remains generally accurate, with many Rat Island examples now added that demonstrate the western distribution of most of these 25 items to that island group. Conversely, Near Island characteristics (McCartney, 1971, p. 136, Table III) have been significantly altered. At least nine of the original 29 items are now known from the Rat Islands as well, but these may be restricted to these two groups only. We could add several artifacts whose distribution is currently limited to the Rat group. These would include iron-bladed knives (Desautels et al., 1971, p. 246, Fig. 124) and conical-tanged arrow points (Desautels et al., 1971, p. 197, Fig. 92 a and b; Cook, Dixon, and Holmes, 1972, plate 16).

As a result of further research since 1971, I now offer a subjective but considered opinion that there is far more continuity throughout the chain than discontinuity and that the Near Island group is probably not as different or distinctive from the remaining groups as previously suggested. As more is learned about artifact variation and spread from newly excavated as well as existing museum collections, it appears that every major island group will have distinctive implement styles not found elsewhere and at the same time will share artifacts with one or more other adjacent groups. Without a complete analysis of all available artifacts, one may intentionally or unintentionally stress continuity by listing shared traits or discontinuity by listing distinctive traits. A further complication is lack of time control to judge contemporaneity; the large majority of extant Aleutian artifacts are not accurately dated.

The following nine hypotheses summarize our current interpretation of artifact distribution; all demand rigorous examination in the future:

1. All island groups have been in more or less continuous contact for at least the past 2500 to 4000+ years; no group has remained isolated for a period sufficient to produce high-level artifact dissimilarity.

2. Standardization of artifact form and style is due in part to common environmental adaptation throughout the chain. Continuity over time and space is due to a relatively stable environment for approximately 4000+ years; readaptations to subsistence alternatives were not required which would be reflected in subsistence technology and artifact inventory.

3. Cultural interaction and population contact was heightened by geographic restrictions on travel; homogeneity resulted from east—west travel only along the chain with no interior to occupy via river systems as in mainland Alaska.

4. Artifacts appear to have been spread independently of one another; no large clustering appears to occupy the same space simultaneously. This conclusion may, however, be based on incomplete knowledge of actual cluster spread. A small complex of late prehistoric artifacts previously described (McCartney, 1971, p. 96) may exemplify implement styles spreading to varying degrees through the chain. Whether artifacts spread singly or in clusters, the critical questions are what functional, adaptive, or other cultural processes were responsible.

5. Material specificity is an important factor in artifact commonality. For technologic reasons, one material may be better suited for a particular artifact than some other. This is not unique to the Aleutians, but the particular combination of materials to choose from may be. Examples of material—tool associations are as follows: slate or argillite (soft, fine grain), ulu blades; basalt (hard, brittle), knife and scraper blades and projectile points; welded tuffs (soft, vesicular), carved bowls and lamps; and scoria and pumice (soft to hard, vesicular), abraders. Only rarely is one material substituted for another, which causes a given material's properties to be disregarded. Much less frequently, form rather than material dictates persistent use. Drilled sea-mammal teeth with no other alteration are commonly used for pendants or beads, or bird-wing bones are usually sharpened at one end to make awls and punches.

6. Artifactual distribution carries no assumed implications about spread of physical type (Paleo-Aleuts or Neo-Aleuts) or language dialects (eastern, central, or western). The entire chain, plus the adjoining Alaska Peninsula, is a geographic continuum along which race, language, and culture assorted themselves independently since their modes of transmission are distinct (McCartney, 1974).

7. On the basis of proximity, the Rat Islanders had more contact with adjacent Near and Andreanof (including Delarof) people than with any other group. Because the Delarof Islands and Buldir Island are intermediate between the Andreanof and Near groups, respectively, and because these islands probably either supported no resident villages (Buldir) or only a few (Delarofs), these islands would likely be peripheral hunting, fishing, and collecting areas for the remaining Rat Islanders. Recent Delarof estimates show a combined colony bird total of 250,000 and a sea lion total of 6,600 (Sekora, 1973); these compare favorably with abundance figures for Buldir and the remaining Rat Islands.

8. Because the Aleutian chain extends from the mainland far into the North Pacific, the western islands, including the Rat group, will tend to show less cultural interaction with mainland Alaska than the closer eastern islands. A firm demonstration of this awaits additional study of central and western Aleutian artifact collections.

9. Finally, trade or exchange was not conducted at the pan-Aleutian level. Rather, what little evidence we have suggests trade predominantly within island groups (compare Lantis, 1970, p. 274, for supporting ethnographic data). Part of the problem lies in establishing sources of land-bound materials that, because of their scarcity, would lend themselves to trade. Obsidian is an excellent choice. Because it is hard, brittle, and has conchoidal fracture, it is an excellent material for projectile points or knife and scraper blades, but obsidian was not widely traded throughout the

chain. Of all the Near Island specimens examined, none are of obsidian (McCartney, 1971, p. 136, Table III). The Rat group collections (AEC and Smithsonian) reveal only two pieces, one of which is illustrated in Fig. 13f of this chapter (Turner, 1970, p. 121; Desautels et al., 1971, pp. 78 and 109; Cook, Dixon, and Holmes, 1972, p. 23). I have located only one obsidian artifact in the Smithsonian Andreanof collections. In the eastern Fox Islands, however, where at least three or four obsidian sources are reported (Umnak, Unimak, Unalaska, and Akutan; Elliott, 1886, p. 148; Hrdlička, 1945, pp. 98-99), obsidian is not at all rare. It makes up, for instance, about 15% of the 8000-year-old Anangula core and blade complex (McCartney and Laughlin, 1964), 5 to 48% of Chaluka (Umnak) artifacts (Denniston, 1966, p. 91, Fig. 3), 4.5% of Akun waste flakes (Turner and Turner, 1974, p. 47, Table 3), and 5.4% of Izembek flakes (tip of the Alaska Peninsula; McCartney, 1974, p. 72). The highest use of obsidian reported is at the Ashishik Point site (northeastern Umnak), which is very close to the obsidian source on that same island end (Denniston, 1972, pp. 94-95 and 296, Fig. 17). Obsidian here ranged between 40 and 90% in different levels. These indications of distribution suggest that obsidian was quarried only in the Fox Islands and that there was hardly large-scale trafficking of this material throughout the chain. The two Rat pieces must have passed from east to west by undirected exchange.

The Rat Islanders exploited one regional resource apparently found in few other localities. This is pre-eighteenth-century foreign iron, and it, too, failed to be traded widely to other areas. Desautels et al. (1971, pp. 243-248) found 12 iron-bladed knives at Sites 10, 14, 35, and 36, and Cook, Dixon, and Holmes (1972, p. 21, plate 24) found two pieces at Site 32. Hrdlička's Smithsonian collections include seven iron-bladed knives or iron-stained bone handles (Amchitka, four, including the one shown in Fig. 11a; Little Kiska, two; and Kiska, one). Because none of these were associated with Russian- or American-period trade goods and clearly are not just surface finds, we may safely take them to be precontact in age. The fact that all the blades are hafted in typical Aleut style bone handles rather than having originally manufactured handles suggests that the iron alone was acquired from an Asiatic source and made into knives once in the hands of Aleuts. The ultimate source of iron prehistorically was China or Japan; it was obtained by the Aleuts from boats wrecked on Aleutian shores. There is little support for Jochelson's (1933, p. 22) hypothesis of Chukchi—Eskimo—Aleut distribution. Several references to early iron and copper suggest fairly wide distribution at the early contact period. Steller reported iron knives in the Shumagins in 1741, shipwrecks were noted on Kodiak, Atka, and in the western islands, and iron exchange between Aleuts and Asiatics or Europeans is referred to on Avatanak (east of Unalaska) and Attu (Coxe, 1787, p. 50; Jochelson, 1933, pp. 21-23; Hrdlička, 1945, pp. 100-101; deLaguna, 1956, pp. 62-63). Iron from Kodiak or the Alaska Peninsula shores was traded to the eastern Fox Islands (Hrdlička, 1945, p. 142).

Archaeologically we do not find prehistoric evidence of wide metal use in the chain. Of all the prehistoric collections I have studied or have knowledge of, I have never found metal fragments or bone knife handles with iron or copper oxidation stain except in the Rat group. The Smithsonian has one bone knife handle from Amaknak (Fox Islands) that is similar to, but not exactly like, those found in the Rat Islands, but the piece has no metal stain in the blade slot. Presumably relatively rare shipwrecks during the late prehistoric era supplied the iron for the Rat Islanders since no terrestrial or meteoric sources are known in the Aleutian chain. Shipwrecks would be expected to occur with greater frequency the more recent the period.

Obsidian and iron, then, are examples of two scarce but useful commodities that might have been exchanged widely. Of course, iron may have been even more limited and insufficiently abundant for trade. The fact that long-distance trade networks did not develop may have been due to the fact that material such as obsidian and iron was not required for successful toolmaking and survival. They were luxuries to be used if available. They seem to substantiate the hypothesis that ideas of style spread widely but materials spread only regionally.

Other precious materials traded include dentalium, amber, mineral pigments, and porphyry (Veniaminov, 1840, Vol. II, pp. 94-95; Lantis, 1970, p. 275).

Explanation of Artifact Similarity. It is appropriate to suggest possible mechanisms responsible for the spread of artifact styles. Although we have stressed Aleut seasonal movement as an adaptive mechanism, little has been said thus far about social interaction and movement. Given that interaction is expressed archaeologically in shared artifact styles, then how did short-term social interaction facilitate the sharing of normative patterns? Two major ways of interacting are immediately apparent. One is that resulting in finished artifacts being exchanged between dif-

ferent villages, islands, or island groups. Second, movement of people rather than items will spread styles even more effectively than exchange.

Trade and festivals are two previously mentioned modes of social interaction between Aleuts of different villages. In fact, festivals were likely the most important occasions for social as well as material exchange. Gifts, or more realistically investments of presents demanding reciprocity, were given during the winter festivals or feasts (Veniaminof, 1840, Vol. II, p. 91). Such artifact scattering contributed toward homogenization of styles within an island group at least. Short-range trade of weapons, masks, clothing, skins, etc., also occurred between villages in other trading situations (Coxe, 1787, p. 197; Veniaminof, 1840, Vol. II, pp. 110-111). As pointed out above, long-range trade throughout the chain is not borne out by archaeological evidence or by ethnohistoric accounts.

Perhaps more important than the movement of items was the movement of people, either temporarily or permanently, from one residential alliance to another. There is abundant ethnohistoric information about both males and females changing their residence willingly or unwillingly. For instance, men moved for a year or two to their wife's village at marriage to perform bride service. Matrilineal clans appear to have established kin, and clan exogamy would likely have a man marrying his mother's brother's daughter, a member of another matrician. Or, if he did not marry his cousin, a man would likely marry another nonclan woman from another village to expand political bonds to that village. Besides, in small villages of related families, it might be difficult to find the proper spouse within the village at marrying time. Because residence after marriage was at the original village of the husband (patrilocality), the wife would be moving into a new community. Boys were preferably instructed during adolescence by their maternal uncles (avunculate), and this would usually occur at the mother's original village prior to marriage. When we add warfare captives or slaves to the above, we obviously find significant social movement (for details of kinship, marriage, education, and warfare, see Veniaminof, 1840, Vol. II, pp. 73-108; Lantis, 1970, pp. 205-271).

Because people will express learned styles when manufacturing implements and other material goods, reshuffling Aleuts from village to village and even from island group to island group resulted in spreading stylistic behavior. However, since Aleut men are believed to be the makers of more durable artifacts (bone, tooth, stone, and wood) than those made by women (grass, skin, gut, hair, etc.), our archaeological collections primarily express spread of male cultural behavior.

CONCLUSIONS

This chapter relates to Aleutian archaeology of the past, present, and future. Archaeology over the past century has largely been eastern-oriented, artifact-centered, nonclassificatory, and noncomparative. It quite logically has treated origins and development as central issues. Integration of ethnohistoric and archaeological data has profitably stressed temporal continuity out of the distant past. But, as one part of Alaska most intensively occupied and dominated by Russian and later American trading companies, the Aleutians have never been studied commensurate with their historic importance.

This chapter centers on the Near and Rat Islands, especially on Amchitka. Archaeological data from that island provide a much needed western counterpoint to eastern-island information to reveal what is culturally representative of the entire chain. Artifacts have been given only secondary consideration here because most of them have been adequately treated in previous publications. Another reason is because archaeologists today are looking beyond artifacts at less tangible, but no less real, cultural phenomena. By stressing the spatial dimension, one immediately becomes engrossed with such interrelated cultural aspects as settlement patterns, subsistence, demography, social organization, trade, and religion as well as technology. We are pressing for cultural dynamics that operated within the Rat Islands to understand the relative importance of determinants as described above.

Future Aleutian archaeology will progress the furthest by addressing hypotheses such as those set forth in this chapter. Amassing more artifacts will not, in and of itself, answer the sorts of human behavior questions raised here. Salvaging prehistoric remains from endangerment by man or from natural erosion is important, but it will be more fruitful to an understanding of Aleutian prehistory if our excavations also aim at higher level questions, as, for instance, those dealing with adaptation, interaction, and development.

Future archaeological research will continue the interdisciplinary approach exemplified by the AEC ecologic studies on Amchitka. The kinds of questions now raised cannot be adequately answered without input from other scientists of the physical and biological environment and integration of their information.

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History, 1741-1967

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Amchitka has long been subject to man's influence. When discovered by the Russians in 1741, the Aleutians had 10,000 to 20,000 inhabitants and Amchitka itself perhaps 100. Hard treatment caused their number to fall drastically, and by 1849 Amchitka was abandoned. No one has lived there on a permanent basis since, but old living sites are still visible around the edges of the island.

Pressure by Russian and American hunters led to the near extermination of sea otters, conservation measures not having been kept up after the 1867 purchase; the 1911 Fur Seal Treaty, however, served also to protect sea otters, and they have recovered well. In 1913 the Aleutians were set aside as what is now called the Aleutian Islands National Wildlife Refuge.

In 1921 blue foxes were introduced onto Amchitka for support of Aleuts from Atka. As a result the Aleutian Canada Goose was extirpated from the island. The foxes themselves were finally eradicated from the island by 1960 by an extensive poisoning program.

During World War II Amchitka became the forward fighter-bomber base in the campaign against Japanese-held Attu and Kiska. About 5000 troops were present on the island then, and facilities were later added to house an authorized troop strength of about 16,000. Many structures, roads, three airstrips, and much miscellaneous debris remain from the war years.

In 1965, 1969, and 1971, nuclear shots were fired underground at Amchitka by the U. S. Department of Defense and the U. S. Atomic Energy Commission. During the first of these, there was a small bioenvironmental program, and, during the last two, a large one, the results of which are reported in other chapters of this book.

No one knows when man first set foot on Amchitka. It is believed that Paleo-Aleuts came to Amchitka from the east at least 2500 years ago as part of their slow clockwise advance around the shores of the Bering Sea. Thereafter for centuries these people lived on these islands and called them home, drawing their living from the rich seas about. Their origins faded into myth. Their arts of life changed little over the centuries. They exploited the resources of the area as far as their numbers and their skills let them, leaving to this day signs of their presence in numerous living sites around the edges of this and other islands marked by lush green growth and by sprinklings of shell and bone fragments on the beaches below some of these sites as the sea cuts into the cliffs supporting them.

THE RUSSIAN DISCOVERY

It is even uncertain when Amchitka was first seen by western man and thus entered into the light of written history. The Russian Sokolov (1851, quoted in Golder, 1922, Vol. I, p. 199) believed that Amchitka was the island sighted by the crew of Bering's ship the *St. Peter* on Sept. 25, 1741 (Old Style*), and named by them St. Markiana. Golder disagreed; he believed it was Kiska that was sighted that day. But it does not matter; if Amchitka was not seen in 1741, it was within the next two decades.

Bering's ship came to an end on Bering Island, of the Komandorskie Islands, after months of beating westward against hostile winds. Bering himself died a month and a day later, and the surviving members of the expedition spent the winter in horrible circumstances. They ate what they could find (foxes, sea otters, seals, and sea cows), and, when those who survived recovered their strength, they broke up the first *St. Peter* and built another smaller ship and went home. Only 45 of the original 76 men on the *St. Peter* survived scurvy and the hardships of winter to return at last to Petropavlovsk in Avacha Bay, Kamchatka, in August 1742 (Golder, 1922, pp. 235, 281-282).

Among the things the returning crew brought back with them were some of the skins of the foxes, fur seals, and sea otters they had subsisted

*Russian dates of that period were by the Julian calendar. September 25 is equivalent to October 6 by the Gregorian calendar now in use.

on during the winter. This raised much excitement. The Russian spread across Siberia had been a tumultuous rush by small groups of men looking for sources of furs not yet exhausted by overhunt and overkill. So impetuous was this rush that it had taken only 58 years, from 1581 to 1639, to advance from the Urals to the Pacific at Okhotsk, a distance of nearly 5000 km. And here now was promise of more furs to the east. They were across water to be sure, but those unknown or uncomprehended risks were more than balanced by the promise of riches for the taking.

It fell to a local entrepreneur, Basov, to outfit the first commercial venture east in 1743 and then again in 1745, 1747, and 1749. After that the record becomes very confused as to who went when, in what ships, and if they returned with how many furs. In 1823 Vasilii Berkh tried to reconstruct the history but was only partially successful. Makarova (1975, pp. 37-78, 117-139, 209-216), who has access to what remains of Berkh's sources and to others in the U.S.S.R. Central State Archives of Ancient Acts, reports that there were 22 expeditions to the east between 1743 and 1755, 48 more by 1780, and 22 more by 1800, by which time exploitation was regularized by the Tsar giving a monopoly to the Russian–American Company.

The records are vague about individual islands, leaving it uncertain which adventurer was first on Amchitka. Basov's trips were to the Komandorskie Islands only. In 1745 Nevodchikov wintered on Attu and Agattu, which are to the west of Amchitka. Probably Amchitka was discovered by Bashmakov, either on his 1753–1755 trip on the *Ieremiia* (Jeremiah) or on his 1756–1758 trip in the *Petr i Pavel* (St. Peter and St. Paul). On the first of these trips, he was wrecked on Adak, which is to the east of Amchitka, after having discovered eight islands. On the second of these trips, it is noted that he stopped at "the fifth from the Near Islands" (Makarova, 1975, p. 51). This may have been Amchitka itself. The earliest specific reference to Amchitka I have found is Makarova's note (1975, pp. 61, 211) that Vorob'ev's ship, the *Ioann Ustiuzhskii,* touched at Amchitka and others of the Rat Islands on a trip from 1760 to 1763.

RUSSIAN EXPLOITATION

The Russian promyshlenniki (hunters) found the Aleutian Islands inhabited by a people they came to call Aleuts, perhaps 15,000 of them. The Aleuts were people well adapted to the islands they lived among but not to encounter with these strangers from the west. They were a stocky well-built people with facial tatoos and wearing lip labrets and bones through their noses. They were inured to what we call hardships, often going barefoot and usually eating their fish raw. All the early observers remark on the Aleuts' skill with baidarkas (what we now call kayaks). No European not trained from youth could handle a baidarka like an Aleut; in later years after the Aleuts were thoroughly subdued, this skill made the Aleuts the most valued of the Russian–American Company's native assistants.

Early contacts were far from smooth and amicable. There is evidence that the Aleuts had a tradition of hospitality to strangers (Veniaminov, 1840, Vol. II, p. 57; Lantis, 1970, pp. 191-192), but the crude Russian promyshlennik did not appreciate this aspect of the savage before him. To the promyshlennik the Aleut was an expendable hunter he could use to extend his own efforts in harvesting the riches all about. The promyshlenniki drove themselves; they drove these new servants even harder. There are numerous well-documented stories of abuse of the natives, such as the story of Soloviev tying a group of men together and firing his rifle at them to see how many the bullet would go through before stopping; it stopped in the ninth man (Veniaminov, 1840, Vol. II, p. 189; Bancroft, 1886, fn. pp. 151-152).* The natives retaliated, the Russians called it murder, and the result was near genocide.

A large fraction of the Aleut population disappeared in the first hundred years of Russian occupation. Estimates of their original numbers vary; Lantis (1970, pp. 172-179) thinks 12,000, Veniaminov (1840, Vol. II, p. 177) thought 12,000 to 15,000, Quimby (1944, p.3) says 16,000, Laughlin (1967, p. 427) suggests over 16,000, and Bank (1958, p. 113) thinks 20,000. When systematic and accurate censuses began in 1830, there were about 7000 Aleuts and Koniags,† and, after the epidemics‡ of the late 1830s, about 4000

*The reader is cautioned against excessive reliance on Bancroft. Ivan Petroff's translations and research for Bancroft formed the evidential basis of Bancroft's history, and Petroff wrote some of it. He was not always reliable and was, in fact, later proved capable of deliberate falsification. Although no one has done a point-by-point check, his record and reputation throw a shadow over the trustworthiness of Bancroft's book and over Petroff's other works on Alaska as well, including his contribution to the 1880 census (Petroff, 1884). The last solid word on Petroff's career is Pierce (1968).

†The Koniags were really Kodiak Eskimos, but the Russians considered them Aleuts and counted them thus in censuses.

‡Veniaminov (1840, Vol. II, pp. 178, 197-199) mentions "an epidemic of coughs with pain in the chest" in 1830 and 1831 and smallpox from 1829 to 1838.

(Table 1). As the mention of epidemics indicates, it was not only direct killing that reduced their numbers. The earlier promyshlenniki took hostages of children or women and sent the men out to hunt with a quota of furs to be met to recover their families. Later, men were conscripted to move along with the hunters and work for them with no assurance and little likelihood of ever returning. The intervention of the Russian government did decrease the severity of this treatment but left forced labor as a regular practice. One must remember that during this period serfdom still existed in Mother Russia; that institution was never brought to Russian America. However, there remained such incidents as the time in 1800 when Baranov sent a fleet of 300 men in baidarkas back to Kodiak after having established Fort St. Michael near present-day Sitka. En route at Peril Straits 200 of them died from eating poisonous mussels (Bancroft, 1886, p. 390; Chevigny, 1942, p. 171). As an old Russian saying puts it, "God is high above and the Tsar far away."

There is no need to detail the development of Russian America here. The western Aleutians were quickly passed by. The principal settlements were Kodiak and then Novoarkhangelsk (Sitka). Order was brought to Russian America, first by monopoly given to the Company in 1799 and then by the practice of assigning naval officers to 5-year terms as governors of the Company.

A number of scientific and supply expeditions were sent out. The last two sent by the Siberian route were those of Krenitsyn (1764–1771), which was singularly unsuccessful because of repeated shipwrecks, and of Billings (1785–1793), who had previously served under the famous Englishman Captain Cook. Billings made one trip north down the Kolyma River to the Arctic Ocean in 1787 and two trips to Alaska from Pacific ports sailing in 1788 and 1791 and reaching as far east as Prince William Sound. Technically his information had little value because it repeated ground that Cook had covered in 1778 (and published), but Billings' reports did make known to the Russian government the abuses of the Aleut natives being perpetrated by the promyshlenniki. The first completely seaborne expedition was that of Krusenstern and Lisianskii (1803–1806). Their ships were also the first Russian ships to go around the world. This expedition is most notable for the help that Lisianskii, in the ship *Neva*, was able to give to Baranov in recovering Sitka from the hostile Tlingits after the massacre of 1802. Thereafter numerous names occur, Golovnin, Hagemeister, Kotzebue, and Lazaref, few of whom paid any attention to the western Aleutians.

The Church came to Alaska in 1794, at first ineffectively, but eventually she supplied the only Orthodox saint ever to come out of North America (St. Herman, 1757–1837, canonized in 1970) and the great Ivan Veniaminov. Veniaminov was at Unalaska from 1824 to 1834 and at Sitka until 1838. A powerful man physically, a gifted linguist, and a keen observer as well as a strong man of God, he is one of our primary sources of objective knowledge of the Aleut and his ways, albeit as altered by 80 years of Russian dominance. His abilities eventually made him Innokentii, Metropolitan of Moscow and head of his church (Bensin, 1967; Hulley, 1970, pp. 166-167).

Gradually the population of the western Aleutians decreased. I can find population figures for Attu and Atka over the longest period of time but only occasional mention of other places (Table 2). Fluctuations in population are due in part to the fact that the Russian administration moved people around freely. In 1821 the Atka District* was reorganized, and the people of the west concentrated in fewer centers. Atka got a permanent Russian settlement of about 50 Russian hunters and 60 Aleuts and with a church housing the Administration (!) and the priest. The Amchitkans and other Rat Islanders were brought eastward, some to Adak and some to Korovin Bay on the north side of Atka. A snow avalanche at the latter place buried the village and killed its inhabitants. The Adak group of Amchitkans was later moved to Atka where descendants of the tribe were still said to have been living at the beginning of this century, so at least went the oral tradition in 1952 (Bergsland, 1959, pp. 13-14, 68-69). In a conflicting account, Dall, writing closer to the event in 1877, reported that the last permanent settlement on Amchitka was abandoned in 1849 (Dall, 1877, p. 44). Thereafter, after over 2500 years of human occupation, Amchitka had no permanent residents. The village sites remain, and today we see them as areas of lush greenness with high tangles of the grass *Elymus* and prominent stalks of cow parsnip, *Heracleum*.

One might wonder how it is that Atka rather than Adak or Amchitka became the administrative center of the western Aleutians. Jones (1960, p. 5) thinks that "the Russians with their sailing ships did not care for [Amchitka] because of its very poor harbor and reefy coast. This view seems to be supported by the fact of the survival here of the largest remnants of the sea otter populations." Indeed the navigational guide of 1886 says that

*Consisting of all the western Aleutian Islands, the Komandorskie Islands, and, for a while, the Kurile Islands.

Table 1—Population of Russian America and Alaska

Year*	Total	Aleuts†	Russians‡	Creoles§
1741		12,000		
1799	8,200		225	
1805			470	
1806		5,234		
1817			421	
1818	9,101	3,252	375	280¶
1819	9,019		391	244
1821		4,880	526	130
1822	8,286	5,334	488	553
1824	9,636		488	548
1827	10,561		734	1,295
1830	10,327¶	6,864	531	916
1831	10,453**	6,917	572	949
1832	10,493	6,949	587	935
1833	10,600**	6,951	627	991
1834	10,678¶,**	6,946	677	1,040
1835	10,867	6,980	699	1,079
1836	10,989	6,991	711	1,111
1837	11,022	6,990	738	1,118
1838	10,313	6,259	706	1,295
1839	8,070	4,303	823	1,318
1840	7,574	4,007	699	1,191
1841	7,580	4,163	717	1,351
1842	7,470	4,112	699	1,405
1843	7,726**	4,264	647	1,405
1844	7,899**	4,338	653	1,593
1845	7,924**	4,214	633	1,483¶
1846	7,783	4,207	560	1,491
1847	8,702**	4,264	513	1,599
1848	8,702¶,**	4,320	469	1,588
1849	8,892	4,322	469	1,562
1850	9,091	4,084	485	1,636
1851	9,273	4,041	505	1,703
1852	9,452¶	4,187	567	1,693
1853	9,578**	4,298	592	1,687
1854	9,514¶	4,259	547	1,751
1856	9,725	4,127	658	1,902
1857	9,788**	4,541	640	1,903
1858	10,065¶,**	4,553	754	1,838
1859	9,992¶,**	4,454	615	1,910
1860	10,540**	4,592	595	1,909
1862	10,156¶	4,752	577	1,892
1863	10,124¶,**	4,712	632¶	1,989¶

Year	Total	Aleutian Islands Census District	Aleuts	White men	Creoles
1867				812	
1870	28,747			483	1,421
1880	33,426	2,451	2,145	430	1,756
1890	32,052	2,361		4,298	
1900	63,592			30,493	
1910	64,356	1,083		36,400	
1920	55,036	1,080	2,942	27,883	
1929	59,278	1,116		28,640	
1939	72,524	1,298	5,598	39,170	
1950	128,643	5,600	3,892	92,808	
1960	226,167	6,011		174,546	
1970	302,173	8,057			

*Sources: 1741–1880: Fedorova (1973, pp. 161, 203-204, 275-279). Obvious errors in arithmetic have been corrected. Others appear to exist and are marked ¶. Totals sometimes disagree with Tikhmenev (1863), as quoted by Petroff (1884); these are marked **.

1880: Petroff (1884, p. 33).

1880–1970: Decennial reports of the U. S. Bureau of the Census.

†Russian counts of Aleuts included Koniags as well. U. S. counts of Aleuts were not always made, and, when they were made, varying criteria of who was an Aleut were used.

‡The column labeled Russians included others before 1870 and includes all whites after 1870.

§In Russian usage a Creole was a person of mixed Russian and native blood.

¶At these points Fedorova or her source made an arithmetic error that cannot be corrected with the information available to me.

**At these points Fedorova's totals disagree with Tikhmenev's totals.

Table 2—Population of Native Villages in the Western Aleutians

Year*	Attu	Atka
1754–1757	60†	
1757–1758	50†	
1774	27†	
1825		60
1835	97	130
1860		220
1867	210	
1872	155	227
1880	107	236
1890	101	132
1920		56
1929	29	103
1939	44	89
1942	39–45	
1945	18‡	70
1950	0	85
1960	0	119
1970	0	88

*Sources: Fedorova (1973); Petroff (1884); decennial reports of the U. S. Bureau of the Census.

†Only heads of families counted.

‡Returned to Atka, not Attu.

"Kirilovskaia Bay* [is] the only place on the island where you can stay at anchor. This anchorage is somewhat sheltered from seaward by a reef off its middle, which requires caution in entering; there are some reefs on either side of it. It is dangerous to remain here in autumn or winter, when northerly gales are prevalent . . . . However when it was visited by Mr. Dall in 1873, he found nowhere more than 3 fathoms of water, and only the smallest class of vessels could enter it. The schooner Yukon anchored in Constantine Harbor . . . ." (Findlay, 1886, p. 682).

After 1849 we can for a while only follow the history of Amchitka by following the history of all the Aleutians. Governor followed governor of the Russian–American Company. Between depleted stocks of sea otters and greater conscientiousness for the welfare of the company employees, profits went down. Conservation measures, progressive for the times, were put into effect, starting with Rezanov's orders in 1805 restricting the killing of fur seals (Bancroft, 1886, p. 446). In the 1820s and 1830s a series of measures were added to protect the most valuable sea mammals, such as interdiction of hunting in fixed areas for one or two years and prohibition of firearms during the protected season (Fedorova, 1973, p. 189). In 1840 Governor Etholen extended the fallow periods to ten years (Bancroft, 1886, p. 582). By the end of the Russian period, the Atka Aleuts were allowed to take only 300 sea otters per year (Bergsland, 1959, p. 75).

The problems of the Russian government in holding a distant profitless territory in the face of vigorous expansion across the continent by the British and Americans and its general international posture, including its need to consolidate its influence in Asia along the Chinese border, led to the decision to give up Russian America. These problems are illustrated by the facts that the Russian–American Company actually played down the discovery of gold in 1848 lest it lose its monopoly, and then, when gold was discovered in Canada along the Stikine River in 1862, the Company asked for an armed cruiser to protect their possessions from being overrun by American and Canadian prospectors, but they never got that help (Gsovski, 1950, p. 29; Okun, 1951, pp. 245-249).

U. S. TERRITORY

In short, in 1867 the Imperial Russian government agreed to sell the territory to the United States. The purchase was not without argument. It was a year before the House of Representatives would appropriate the money needed to complete the transaction, but it was carried through, and Russian America became Alaska (Shiels, 1967).

After the purchase Alaska was nearly forgotten, and effective administration was only slowly extended to it. The only further actions by Congress were to establish Alaska as a customs district and to direct the Secretary of the Treasury to advertise for bids for the lease of the fur seal fisheries. With only 430 whites in the territory, there was little pressure to provide for local government. An army garrison was left in Sitka; but, when it was withdrawn in 1877 to help put down an uprising of the Nez Perce Indians in Idaho, there was no shadow of governmental authority left in Alaska. Indeed, in 1879 the inhabitants of Sitka had to call on a British naval vessel to restore order (Gruening, 1968, pp. 135-136). By 1884, however, after the throes of the Reconstruction following the Civil War were past, Congress constituted Alaska a "civil and judicial district," and the laws of the state of Oregon were made applicable to it.

A very important aspect of U. S. ownership of Alaska was that it encouraged adventuresome men

*What we now call Cyril Cove, not Kirilov Bay, according to Jones (L. M. Gard, private communication, 1974).

to go there to see what they could find. They found more than furs and fish. There were numerous small and large finds of gold from the seventies on, and the return of the *Portland* in 1897 with a ton of gold from the Klondike made Alaska news throughout North America.

With some restrictions the fur seal fishery on the Pribilofs was leased in 1870 to the Alaska Commercial Company, and, when their lease expired 20 years later, the lease went to the North American Commercial Company. The taking of sea otters was nominally restricted to natives, but this rule was circumvented by enterprising white hunters marrying the comelier native women (Petroff, 1884, p. 18). Various traders competed for these skins, the Alaska Commercial Company being the most successful one. Bancroft (1886, p. 746) notes that "in 1885 they gathered nine-tenths of the world's supply of sea otter skins." Four years later, however, the Alaska Commercial Company was roundly denounced for closing its Attu store, leaving the Aleuts there without provisions or access to outside goods (Hinckley, 1972, p. 197). Presumably the long supply route combined with the scarcity of sea otters made it uneconomical to keep that trading post open; Petroff (1884, p. 22) indicates that even by 1880 the Attu people were beginning to turn to blue fox because of this scarcity.

Indeed, so far as the public record shows, the western Aleutians might not have existed at all. The only people remaining west of Umnak were at Attu and Atka. Unalaska, far to the east, with its good harbor continued to be visited by whalers until the collapse of that industry in the 1880s and by ships en route to northwestern Alaska. The very first U. S. court sessions to be held in the Aleutians were at Unalaska in 1901 (Wickersham, 1938, p. 322).

By the end of the century it appeared that the sea otters were nearly extinct and the fur seals in imminent danger of extinction. The conservation measures of the Russians had never entirely disappeared; for instance, the Pribilof Aleuts now refused to kill females (Jordan and Clark, 1898, p. 27). In addition to killing seals on land, another form of killing known as pelagic sealing had arisen. This had always been carried on by the Indians of Oregon and Washington, who were accustomed to going out in their canoes to take the animals in the course of their normal winter migration. The number of animals so taken was merely nominal then, but, after 1879, when schooners were introduced to transfer the canoes to their field of operations and care for them there, the industry began to make significant inroads on the herd. The rise of pelagic sealing thereafter was rapid. This form of sealing was both inefficient in that not all the seals that were shot could be recovered and indiscriminate in that females could not be distinguished and were taken as well as males (Jordan and Clark, 1898, pp. 142-164).

Pelagic sealing was international and could not be controlled by our country alone. Since such sealing was largely a Canadian industry, in 1893 the United States entered into arbitration with Great Britain on the matter. Subsequent negotiations were extended to Japan and Russia as well, resulting finally in the Convention for the Preservation and Protection of Fur Seals of July 7, 1911 (Martin, 1946, pp. 200-232; Abegglen, Chap. 20, this volume). Thenceforth pelagic sealing was entirely forbidden. Fur seals were to be killed only on the islands where they came ashore to breed and have their young, the Pribilof Islands of Alaska, the Komandorskie Islands of Russia, and Robben* Island then of Japan. Canada and Japan, in return for forbidding pelagic sealing by their nationals, were to receive 15% of the harvest. Seemingly as an afterthought, that treaty also has 1 section out of 17 that says:

> Each of the High Contracting Parties agrees that it will not permit its citizens or subjects or their vessels to kill, capture or pursue beyond the distance of three miles of its territories sea otters in any part of the waters mentioned in Article I of this Convention.

Thus sea otters too received international protection. It almost seems that the negotiators thought that the sea otter population was either already gone or too small to be viable, and this section was added just in case there was some chance they might recover. The Fur Seal Treaty remained in force until 1941, when it was abrogated by Japan; but, as detailed elsewhere (Abegglen, Chap. 20, this volume), it has been outstandingly successful in preserving and bringing back populations both of fur seals and of sea otters.

REFUGE STATUS

Following up on that treaty, on Mar. 3, 1913, President Taft, by Executive Order 1733, set aside all the Aleutian Islands† "as a preserve and

*Robben Island is now Russian and is known as Ostrov Tyulenii (Seal Island). It is little more than a reef, 600 m long and 10 to 35 m wide, lying off Sakhalin in the Sea of Okhotsk at latitude 48°30′N, longitude 148°38′E.

†Subsequent Executive orders have removed some of the islands and specific tracts from the Refuge. For the current status, see Bureau of Sport Fisheries and Wildlife (1974).

breeding ground for native birds, for the propagation of reindeer and fur bearing animals, and for the encouragement and development of fisheries." The Executive Order itself is given in full in Appendix A of this chapter. Control over the Aleutian Islands Reservation was placed with the Department of Agriculture and the Department of Commerce and Labor. This put the Bureau of the Biological Survey in charge of all terrestrial species of animals and birds and the Bureau of Fisheries in charge of all aquatic species, including fish and sea mammals.

The Biological Survey had been established by the Secretary of Agriculture on July 1, 1885, as part of the Division of Entomology. It became a separate bureau under the Agriculture Appropriation Act of 1905. The Bureau of Fisheries had been established as the U. S. Fish Commission by Joint Resolution of Congress on Feb. 9, 1871. It became a bureau of the new Department of Commerce and Labor on July 1, 1903, and remained with Commerce when Labor split off on Mar. 4, 1913. These two bureaus were transferred to the Department of the Interior on July 1, 1939, were consolidated as the Fish and Wildlife Service on June 30, 1940, and were renamed the U. S. Fish and Wildlife Service in 1956. The two component parts were renamed the Bureau of Sport Fisheries and Wildlife and the Bureau of Commercial Fisheries. On Oct. 3, 1970, the latter became the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration of the Department of Commerce. The Bureau of Sport Fisheries and Wildlife, renamed again the U. S. Fish and Wildlife Service on July 1, 1974, remains in the Department of the Interior (U. S. Government Manual, 1974–1975).

The Aleutian Islands Reservation was transferred to the Department of the Interior in 1939 together with the two bureaus that had control over it and renamed the Aleutian Islands National Wildlife Refuge on July 25, 1940. This was a change in name only and did not affect the continuity of management of the Refuge.

FOX FARMING

Aboriginally the blue fox occurred as a dominant form of the Arctic fox, *Alopex lagopus*, in the Near and Komandorskie Islands; farther north along the Bering Sea and Arctic Ocean coasts of mainland Alaska, few foxes show this maltese coloration. The early Russian explorers found these animals abundant in the Komandorskie and some of the Near Islands. The blue foxes later ranched in Prince William Sound and southeastern Alaska were transferred there from this area. Similarly the early explorers found a dark-color phase of the red fox, *Vulpes fulva*, on the Alaskan peninsula and the eastern Aleutians. However, many of the central and western Aleutians had never seen a fox until the fox-farming splurge of the 1920s (Murie, 1959, pp. 287-295).

The very next year after the establishment of the Aleutian Islands Reservation, permits began to be issued for the use of individual islands for fox farming. The early permits (1914 to 1920) were unconditional and granted the permittee exclusive use of an island. Later permits carried requirements of stocking and annual reports of operations, but this proved in practice to be impractical, and there was a great deal of irregularity in submitting these reports (Murie et al., 1937, p. 74).

On May 23, 1916, a permit for Amchitka was issued to Peter Horozoff of Atka. There is no indication of the permit being used, and the permit was subsequently canceled. On Oct. 9, 1920, a permit was issued to "Native Residents of Atka" naming G. Stepatin, I. Petikoff, P. Horozoff, L. Sposnikoff, and P. Somekensky. This permit continued in force until June 22, 1929, when it was canceled, and Permit No. 189 was issued to the Atka Village Community [National Archives, File RG22, Box 652; Gray (?), 1937]. Renewal of this permit was finally denied in 1947.

In 1921 seven blue foxes were released on Amchitka. The method of conducting a fox farm in those days was to place a minimum breeding stock on an island and let natural increase take place. Very little care was needed. An island provided its own fence and protection, except for poachers, and the foxes depended on natural food for subsistence. No consideration was given to the conservation of any other resource. In fact, the presence of birds as a source of food was one of the main considerations in the fox-farm industry; it was well known that the best bird islands were the most productive fox islands.

By 1925 the number of foxes on Amchitka had increased to the point where they could be harvested, and 144 were trapped. In subsequent years over 4000 were taken off the island (Table 3). The last harvest was in the winter of 1946 and 1947; for this harvest we have an anecdotal description:

> In 1946 we trapped blue foxes on Amchitka. We took the North Star to Adak [from Atka] and reached Amchitka on an FS [an Army freight ship]. Of the ten men, two trapped on the east side, two on the south side, four on the west side, and Philip and I on the north side. I went with Philip because I knew him better than anyone else there. I got 50 foxes and Philip 39. I spent two months with him, December and January. At the end of January he and I returned. All

Table 3—History of Fox Farming on Amchitka

Year*	Number introduced	Number trapped	Value
1921	7		
1922–1924		No report	
1925		144	$ 7,200
1926		172	7,200
1927		No report	
1928		516	35,000
1929		564	35,000
1930		Not trapped	
1931		965	37,000
1932		660	18,150
1933		Not trapped	
1934		555	23,310
1935		Not trapped	
1936		500	20,000
1937		Unknown	
1938		Unknown	
1939		Unknown	
1940		Unknown	
1941		Unknown	
1942		Unknown	
1943		Not trapped	
1944		Not trapped	
1945		Not trapped	
1946		Unknown	
1947		441	?

*Sources: 1921–1936: Murie (1937).
1943–1945: Inferred from the evacuation of the Aleuts.
1947: Bergsland (1959, pp. 127-128).

the trappers returned. In April we all returned to the village from there. We passed four days on Adak and then went to Atka. We had killed 441 foxes altogether. (Paraphrased from a word-for-word translation by Bergsland, 1959, pp. 127-128.)

Trapping was a time-consuming business, and transportation between islands was thoroughly unreliable. Some sort of shelter had to be built on any island used for fox farming. In 1924, 11 barabaras (half-buried sod huts) were built as hunting camps on Amchitka and in 1925 3 more. The Site 20 mentioned by McCartney in Chap. 5, this volume, is the remains of one of these. In addition, a small village, consisting of five cabins, a boathouse, and a church, was built at the head of Constantine Harbor. The village was destroyed in the Aleutian campaign of World War II. All that now remains is a number of pits and a graveyard (Fig. 1), in which the only still legible headstone is for Anna Zaochney, 1884–1930. This is the Site 21 referred to by McCartney.

The story of fox farming deserves a monograph of its own. It is another case of a dream that started magnificently and then petered out with changes of fashion and oversupply of product. From annual reports of the Alaska Game Commission* come the data given in Table 4 on the growth and decay of the Alaskan blue fox fur industry. In 1923, the first date they report, furs sold for over $100 apiece. The price reached nearly this level again in 1929, but during the depression years the price dropped to $30 and after the war fell further to nearly $10 a skin. Production stayed high during the 1930s, but it was a moribund industry, and the war killed it off.

During the 1930s the Biological Survey developed the pattern of an annual summer trip into the Aleutians on the motor ship *Brown Bear*. On most of the islands the state of the bird population was the principal business, but on Amchitka the emphasis was on sea otters because that was where one of the principal remaining groups of them was to be found. Their existence was kept an unofficial secret; the service did not wish to advertise their presence since poaching was already going on.

It also became evident during this period that something was happening to the bird life of the islands. O. J. Murie led two expeditions to the Aleutians in 1936 and 1937, his purpose being "to investigate the faunal relationships on these islands with a view to obtaining necessary data on which to base satisfactory administration." In his trip report Murie says (Murie et al., 1937, p. 70): "There seems to have grown a general vague feeling that a fox island is 'good for only so long.' Probably in many cases this coincides with the length of time the bird supply lasts." At the end of his report he made recommendations as to which islands should be left fox islands and which should be returned to the status of bird islands. As to

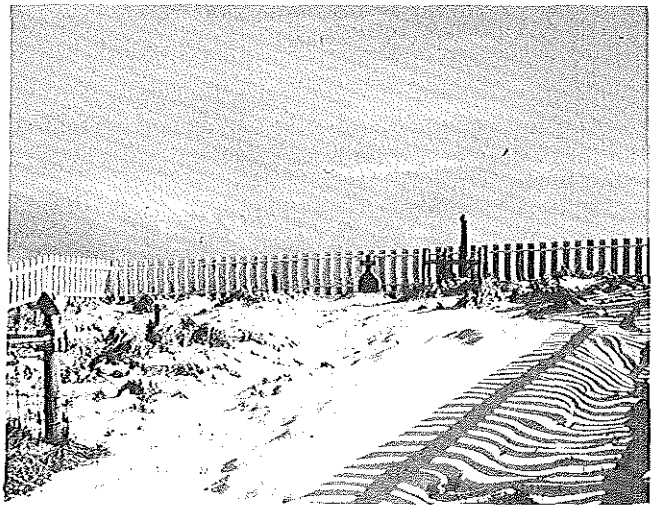

Fig. 1—Aleut graveyard remaining from 1930s village (fence erected in 1968).

*Established Apr. 14, 1925.

Table 4—History of Blue Fox Farming in Alaska

Year*	Number trapped	Average price†	Total income (in thousands of dollars)
1923	1,718	$101.50	174
1924	2,427	74.56	181
1925	5,493	49.83	274
1926	8,776	45.70	401
1927	11,021	61.48	678
1928	7,854	68.72	540
1929	8,520	99.10	844
1930	7,855	62.04	498
1931	6,922	28.14	195
1932	9,942	20.58	205
1933	9,960	30.35	302
1934	12,137	33.82	410
1935	10,281	24.36	250
1936	10,045	30.33	305
1937	11,433	29.50	337
1938	11,403	26.50	302
1939	10,444	22.38	234
1940	8,844	19.25	223
1941	6,804	26.64	181
1942	5,079	15.54	79
1943	1,783	34.00	61
1944	1,495	22.59	34
1945	1,806	24.81	44
1946			
1947	929	11.00	10
1948	430		
1949	210		
1950	200		
1951	100		
1952	70		
1953	10		

*Source: Annual reports of the Alaska Game Commission.

†I cannot account for the fact that these average prices sometimes differ markedly from those to be inferred from Table 3.

Amchitka the report said (Murie et al., 1937, p. 196):

> ... the ideal use of this island would be for wildlife, such as waterfowl and sea otters. However this island plays an important part in the life of the Atka natives and under present conditions we could hardly withdraw the island from fox raising.
>
> However, the following solution is suggested. First, it is barely possible that the importance of fox raising may be lessened in the future due to events at present unforeseen. In that case Amchitka could be put to its most fitting use as outlined above. Or, the natives may be induced and assisted to practice more controlled and intensive fox farming on Atka Island itself so that Amchitka Island will not be needed. It should be recalled that at present the Atka natives have Atka, Amlia, and Amchitka, all large islands. We feel that it is well, in some manner, to be alert for an opportunity to release Amchitka without working undue hardship on the native Atka community.

That opportunity came with the collapse of the fox-farming industry.

Later Murie (1959) returned to the theme of the drastic reduction of the bird population, especially on Agattu. He quoted Clark (1910) as saying that the Hutchins Goose (now called the Aleutian Canada Goose, *Branta canadensis leucopareia*) was in 1906 "the most abundant bird on Agattu, where it breeds by the thousands." In 1937 his party managed to find less than half a dozen nesting pairs there.

Foxes did not affect all species of birds as drastically. Murie (1959, p. 297) says:

> The importance of birds in the blue fox diet is evident ... they furnish 57.8 percent of the food, though the percentage varies on different islands, depending on availability. Land birds are relatively unimportant. They are hard to capture and do not gather in large groups. But the concentrated colonies of petrel, auklets, and related species furnish rich hunting grounds.

Today the Aleutian Canada Goose is on the Secretary of the Interior's list of threatened species (Bureau of Sport Fisheries and Wildlife, 1973, p. 288) and apart from game farms apparently survives only on Buldir Island. We may wonder, how did the Biological Survey come to commit the ecological blunder of introducing foxes onto these islands? Three reasons present themselves. Executive Order 1733, which set up the Aleutian Islands Reservation, specified "... the propagation of reindeer and fur bearing animals" as one function of the Reservation. H. Douglas Gray (private communication), retired Alaskan Wildlife Agent, told me that in 1921 the Biological Survey was staffed in this part of the world with old trappers and other fur-oriented people. They were interested in what the land could produce and naturally turned to this "highest and best use." Probably too they wanted to help the economically depressed Aleut people, with whom they could not help but sympathize.

Before World War II the Aleutian Islands Reservation was administered from Kodiak. In October 1948 the refuge received its own manager, Robert D. Jones, Jr., to be stationed at Cold Bay and furnished with a dory to get about in. Jones had come to the Aleutians during the war, spending a little over a year on Amchitka itself.

The goal of eliminating foxes from Amchitka first appears on the record in March 1939 in Gray's "Proposed Plans for the Administration of the Aleutian Islands Wildlife Refuge," which said, "Amchitka Island has been taken out of fox farming production." Then the war put these plans aside. In 1948 Jones took them up again. How to do it? Control was not enough; complete elimi-

nation would be the only satisfactory answer. In 1950 Jones experimented with strychnine-loaded pellets of seal blubber left along established fox trails. That summer it did not work, but, in the harsher conditions of the following winter, the pellets were eaten and were effective. Rat poison (1080) was also set out, and, although the rat population of the island has never been more than reduced, their 1080-laden carcasses killed off the feral dogs and cats left by departing soldiers. The poison-pellet campaign continued and was enlarged, supplemented by the shooting of such foxes as were seen. By 1960 tracks of a single fox were found around an old mess hall not far from Constantine Harbor. Signs of four to six others were found elsewhere on the island but nowhere any signs of litters or dens. These, it turned out, were the last foxes on Amchitka. After 40 years they were gone (Jones, 1960; Berns, 1960).

WORLD WAR II

On June 3 and 4, 1942, planes from a Japanese carrier force struck Dutch Harbor on Unalaska. On June 7 Japanese troops landed on Kiska and Attu. It was part of a plan to draw support away from the impending Battle of Midway. In that respect it failed; Admiral Yamamoto lost all four of the carriers he had committed to the Midway engagement, and the tide of battle was turned in the Pacific. On the northern front, however, Japan was ahead. War had come to Alaska, and henceforth service in Alaska warranted the Asiatic—Pacific Campaign Medal and ribbon.

On Kiska there had been a 10-man Navy weather observation team. All were captured, although one man held out for 50 days, eating grass, worms, and shellfish. These men lived out the war as prisoners of war in Japan; they were put to work in forced-labor prisoner gangs in shipyards and steelworks. All survived to return home after the war (Garfield, 1969, pp. 80-81, 310).

Attu village had been there since aboriginal times and was thus one of the oldest villages in the chain as well as the most distant from the mainland. Accounts differ as to how many Aleuts were on Attu, various accounts putting it at anything from 39 to 45.* Fifteen of them were children. There was also the schoolteacher and his wife, Charles Foster Jones and Etta Jones. [Golodoff (1966), an Attu Aleut, remembered them as Gene and Jane Foster.] Jones died in the aftermath of the occupation; it is not clear whether he was shot trying to escape or committed suicide rather than surrender (Garfield, 1969, pp. 81, 310; *New York Times,* 6/21/43, p. 3; Bergsland, 1959, p. 126). Mrs. Jones was separated from the others, sent to a prisoner-of-war camp at Zentsuji, Japan, and returned to the United States in October 1945 (*New York Times,* 6/21/43, p. 3; 10/19/45, p. 3). In September 1942 the Japanese evacuated the Attu Aleuts to Otaru, Hokkaido. (The *New York Times* erroneously reported them as having been taken to Sakhalin, but in 1943 their sources of information from Japan were poor.) The Attu people were put to work digging pottery clay.

After the war the survivors were flown to Okinawa and then to Manila, from which they went by ship to San Francisco, by train to Seattle, and by ship to Adak. Golodoff says that they wanted to return to Attu, but that "we were not enough people so the Government wouldn't let us go to Attu. The Government told us to live with the Atka people." The reason that the Bureau of Indian Affairs gave was that Attu was too distant to supply, and the villagers were sure to need a subsidy and other assistance. The Attuans went to Atka, arriving there on Dec. 11, 1945, 18 of them: 4 men, 3 women, and 10 children, the oldest 15, in five families plus a baby boy born to Mrs. Alfred Prokopioff about the time they left Japan (*New York Times,* 10/19/45). The rest of them had starved on the scanty and unfamiliar diet the Japanese had given them.

In the meantime, in June 1942 the Americans evacuated all remaining Aleuts west of Unimak, including those on the Pribilofs. Atka itself was evacuated on June 13—14, just ahead of a Japanese air attack from Kiska. The Aleuts were taken to various places in southeastern Alaska: the Pribilof Islanders to Funter Bay on the north end of Admiralty Island near Juneau, the Atka people to Killisnoo near Angoon on Admiralty Island, the Nikolski people to Wards Cove near Ketchikan, and others to Bernet Bay near Sitka. Here they remained for three years, until June 1945, suffering somewhat from the different environment and resulting respiratory diseases and from the cultural shock. Duncan (1945) ends his article on their prospective return, "But how are you going to keep 'em out on the Chain after they've seen Juneau? Indian Service men have discovered a little wavering, especially among the younger Aleuts. 'We'll go back to the island now,' some of them are saying, 'and see how we like it. If we don't like it there, maybe somehow we can get back here

**New York Times* (6/21/43): 42 Aleuts and 2 whites.
Duncan (1945): 45 Aleuts and 2 whites.
New York Times (10/19/45): 40 Aleuts and 2 whites.
Berreman (1955, p. 57): 42 (not clear if whites included).
Golodoff (1966): 40 Aleuts and 2 white.
Garfield (1969, p. 79): 39 Aleuts and 2 whites.

again.' " More seriously, Berreman (1955, pp. 52-53) says of Nikolski that the wartime removal, the postwar return to find their village a shambles, slow and inadequate resolution of their losses, and general frustration at not being able to satisfy the wants acquired during the removal were important new factors in the continuing disintegration of the old Aleut ways and social integration.

These evacuations left the Aleutians an empty and open field for the prosecution of the military campaign. It was to prove a messy, wet, inefficient operation. The Americans concentrated on harassing the Japanese-held positions with as many bombing raids as weather and supplies would permit and developed a series of ever more forward bases to facilitate that effort and to serve as bases for finally dislodging them. The Japanese concentrated on holding, supplying, and reinforcing the positions they held; they started a few desultory movements forward, but these were never carried through. For both sides the Aleutian front was a war poorly supplied and equipped.

Conditions made the war dangerous in more ways than just being shot at. Today Reeve Aleutian Airways flies the chain on a regular basis; you can count on delivery safely to your destination with seldom more than a few hours' or a day's delay due to fog or winds. During World War II there were few of the aids used today: only beacons and radio direction finders, and those were scarce. There was "a complete lack of radio ranges, lighting facilities, and other navigational aids west of Umnak" (Craven and Cate, 1950, p. 397). Aircraft flew visually where often there was little visibility, and ships went where there were no charts more recent than those from Russian times. Many an airplane crew was lost for no reason other than that they could not find their way back or down.

In June 1942, just after the Americans discovered the presence of the Japanese on Kiska, the submarine S-27 was sent out to find out if the Japanese had yet occupied Amchitka. The S-27 went onto a reef, and the crew had to abandon ship, setting up camp in the church in the unoccupied village at the head of the Constantine Harbor. Six days later a patrolling PBY plane found them there, and the next day, June 26, they were evacuated back to Dutch Harbor. There had been no Japanese on Amchitka.

Bombing missions could be run from Dutch Harbor or Umnak, but it was a long run and costly in men and machines. A more forward base was needed. The Army Air Corps nominated Tanaga; the Navy nominated Adak. The Joint Chiefs of Staff had to adjudicate and chose Adak because the fine harbor there made it a natural for staging later amphibious operations (Conn, Engelman, and Fairchild, 1964, p. 270; Morison, 1968, pp. 12-13; Craven and Cate, 1950, p. 374). Scouts were put ashore on August 28 to check for the presence of the enemy; there was no sign of the enemy, and the main force of 4556 men went ashore on the 30th. Within 10 days an airstrip had been built by putting a dike around a shallow lagoon and closing off the tide from it. The strip was hard-packed sand and was later covered with steel matting. Today's airfield on Adak is concrete, at the same place, and it still has to be kept dry by pumping the ditches alongside.

On the 10th of the next month, a small party reoccupied Atka. Atka had been used at various times before for seaplane operations, and a land strip was now built there.

In between these islands and Kiska lay two other large islands, Tanaga and Amchitka, with land flat and low enough to be considered seriously as possible sites for airstrips. The official army history indicates that the initial plan was to move onto Tanaga (Conn et al., 1964, pp. 270-276). Reconnaissance parties had been sent to both islands at the end of September, the one to Amchitka being made by 34 scouts on September 23. The History of the Alaskan Air Command says of this reconnaissance: "In the report made by Col. Verbeck, it would seem impossible to construct a suitable runway of any type on the island. With the exception of the recommendation that a landing field could not be built on Amchitka, Colonel Verbeck's report was of great value in the preparation and planning of construction"! (History of the Alaskan Air Command, 1952). A plan was drawn up to move onto Tanaga on November 1, but reviews carried all the way up to General Marshall eventually brought back the decision to use Amchitka, the more forward island (Conn et al., 1964, p. 275).

Preceded by an aerial strike to find out if any Japanese troops were on the island and to destroy the village on Constantine Harbor, including the church, so that there would be no hiding place, a new survey was made on December 17—19. It was led by Colonel Talley, who had made his reputation in the speedy job of airstrip building on Adak. His reports were instrumental in confirming the change of the proposed base from Tanaga to Amchitka. He predicted two to three weeks would be needed for a fighter strip and three to four months for a main airfield (Conn et al., 1964, p. 275; Craven and Cate, 1950, p. 374). His party found signs that Japanese had been there—a boat with no water in it from snow that had fallen two nights before and unweathered rifle cleaning patches along a trail. A story told during the AEC occupation of Amchitka was that the airstrip was

built according to Japanese survey stakes, but Talley (private communication, 1976) himself says that what they found was several test pits showing soil cross sections.

The Japanese had, in fact, made two abortive sorties toward occupying Amchitka. One in October 1942 turned back when their intelligence service warned Admiral Hosagaya, falsely as we know and he did not, that a strong U. S. Navy task force was in the vicinity. The other in late November was deterred by heavy air raids (Garfield, 1969, pp. 148-149).

On Jan. 12, 1943, 1945 men, under the command of Brigadier General Lloyd E. Jones,* went ashore at the head of Constantine Harbor (Figs. 2 and 3). It was in the tail end of a storm, and the worst of the winter was still ahead, probably as miserable weather for a landing as U. S. troops have ever had to make. Their first priority task was to make a landing strip, and this they did in 5 weeks' time; so on February 16 a P-40 squadron was able to come in and land. Aleutian weather is such that often even in the worst of clouds and fog there is a hundred feet or so of somewhat clearer air down near the water. A graben crosses Amchitka, dipping gently under the water at both ends to form Constantine Harbor and Makarius Bay. The new Amchitka fighter strip (Fox Runway) took advantage of these climatic and geomorphological peculiarities by going right from the water's edge gently uphill to the southwest (Fig. 4). This water-level strip saved many a pilot's life. The Navy also had a PBY patrol squadron on the island that used a ramp into the sea at the foot of Fox Runway.

After Fox Runway was complete, work was started on a bomber runway (Baker Runway). In mid-June 1943 a third cross runway (Charlie Runway) was started. In early 1944, after the Aleutian campaign itself was over, construction began to enlarge Baker Runway to support B-29's in bombing attacks on the Japanese homeland. The runway construction was completed, but the B-29's never arrived: Rapid advances in the Central and South Pacific and poor weather in the Aleutians made an Amchitka base less desirable than bases in the Mariana Islands and in China (Craven and Cate, 1950, pp. 396, 400-401; History of the Alaskan Air Command, 1952). [B-29's finally made it to Amchitka 4 years later when two of them landed there after making observations of the eclipse of May 8–9, 1948. This was the first time that aircraft were ever used for this purpose (Kinney, 1949).]

*For whom Jones Lake is named (see Geological Survey map in the pocket at the back of this volume).

Fig. 2—Troops landing at the head of Constantine Harbor, Jan. 13, 1943. (U. S. Army photograph SC 171235-B.)

Fig. 3—Scene of 1943 landing in May 1974.

Fox Runway is no longer useful. It was concreted in the 1944 construction program, but, sometime before the eventual pullout in 1950, trenches were cut across it since it was no longer usable. Winter storms and the 1957 tsunami have built a beach ridge across its foot; and the Rat Island earthquake of Feb. 3, 1965, caused some of the fill land in the foreground of Fig. 4 to settle and block its drainage to the harbor (Fig. 5). Baker Runway was renovated and improved during AEC occupancy of the island and is a good runway. A beacon and landing lights remain, but these are only operational when there is a party of people on the island. Charlie Runway has not been maintained. It was used once during the AEC occupancy when crosswinds did not permit use of Baker Runway, but the landing was so rough that it was never repeated.

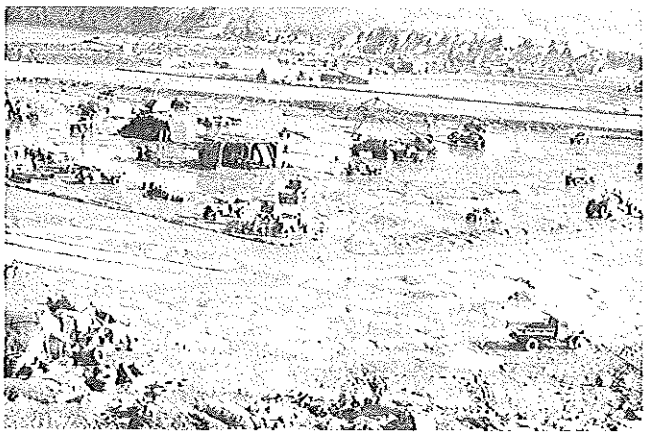

Fig. 4—Foot of Fox Runway, Mar. 4, 1943. Motor pool is in foreground, P-40's on taxiway in rear, and derelict B-24 in water beyond strip. (U. S. Army photograph SC 571335.)

Fig. 5—Foot of Fox Runway, May 1974. Note subsidence of fill land from the 1965 Rat Islands earthquake.

The American presence on Amchitka was discovered by the Japanese on Jan. 23, 1943. Bombers immediately started hitting the runway under construction, but these attacks were kept up only a month. The very geography is against an attacker acting from Kiska. Bird Cape, at the northwest end of Amchitka, is only 50 miles from Kiska; a small camp and radar site was set up there which, weather permitting, was able to warn those at the airstrip 30 miles to the east of approaching airplanes.

Occupation of Amchitka, although producing no immediate spectacular results, did help make the Japanese hold on the Aleutians hopeless. Systematic supply of their garrisons became hazardous, requiring a powerful task force to drive a convoy of ships through the air and naval blockade. Just such an attempt was foiled by the Navy on March 26, and the Japanese doom was sealed.

Kiska was the chief target of planes from Amchitka; any intermittent letup in the cloud cover permitted a bombing run on a target only 80 miles away. Weather also played its part in making Kiska the main target in another way. Bombers sent to Attu frequently found that island closed in and unloaded on Kiska on the return trip; so in April only 30 sorties were actually made against Attu. These did other important work, however; the aerial pictures they took constituted almost the sole source of intelligence about Japanese troop strength (Craven and Cate, 1950, pp. 376, 379).

The overriding purpose of the American military forces was to dislodge the Japanese from the islands they held. On May 11, 1943, a force of 14,826 men under Major General Albert E. Brown landed on an Attu defended by about 2500 men under Colonel Yasuyo Yamasaki. It was expected to be a short action, but, in fact, it lasted until May 29, when only 28 Japanese remained alive to become prisoners. The American forces suffered 3829 casualties, including 549 dead, 1148 wounded, 1200 with severe injuries from the cold, 614 with disease (including exposure), and 318 other casualties. Many mistakes were made, especially in not taking good advice about the conditions to be expected in the Aleutians. We are told that the services profited greatly from this experience (Garfield, 1969, pp. 208-258).

On May 11, of 168 Air Force planes in the forward area, 86, or 51%, were on Amchitka (Craven and Cate, 1950, p. 381).

Kiska remained in Japanese hands. A force of 18,006 men, including 4983 Canadians, landed there on Aug. 18, 1943. As it turned out, the Japanese had been able to evacuate their forces on July 28, and the U. S. and Canadian troops encountered only mines and booby traps left by the departing Japanese. There were 208 casualties, 28 dead, 50 wounded, and 130 with trench foot (Garfield, 1969, p. 288).

The expulsion of the enemy left the North Pacific forces without an immediate mission. One possible one was using the Aleutians to attack northern Japan or the Kuriles. The Kuriles had been Russian since the seventeenth century but had been taken by the Japanese as part of the spoils of the Russo–Japanese War of 1904 and 1905. They had come to be considered part of the Japanese homeland, and Shimushu and Paramushiru, the first and second of the Kuriles (from Kamchatka), had been developed into major bases of the Imperial Japanese Navy. (Since World War II the Kuriles have become Russian again.) During the time between the retaking of Attu and the landing on Kiska, the Army Air Corps used the Aleutians

to stage the first strikes against the Japanese homeland since the Doolittle raid of April 1942 (Thirty Seconds over Tokyo). A raid on July 18, 1943, found the Japanese on Shimushu and Paramushiru unprepared; a second on August 11 found them ready and waiting, and two out of nine planes failed to return home. On September 11, 10 out of 19 planes failed to return, although 7 of them got to Petropavlovsk to be interned. The next year the tempo increased, and, including photographic reconnaissances, there were over 100 sorties over the Kuriles from the Aleutians. Airstrips were prepared on Amchitka, Adak, and Shemya in 1944 for a possible full-scale operation against Paramushiru, but the tide of war elsewhere caused that to be unnecessary, and the airfield expense has to be written down as one of those things called for in the prodigality of global warfare. In the end the mission of the troops remaining in the Aleutians was to tie down an even greater number of troops and planes in the Kuriles.

Amchitka was the forward fighter-bomber base for the Aleutian campaign, but it was also the end of the line. The early garrison lived in tents, at first with mud floors (Figs. 4 and 6). Wet feet and cold C rations were the order of the day. There were no recreations except what the men could invent, and the normal outdoor athletics of healthy young men were hardly attractive in cold mud. There was just endless waiting.

Thus, when word got out that there was archaeological loot to be had, digging reached almost epidemic proportions. Lieutenant Paul Guggenheim, a doctor who had been a student helper with Hrdlička on Amchitka in 1937, wrote the commanding general asking permission to reconnoitre the island and excavate archaeological sites. This was granted, but there was no effective way to control casual collectors; General Jones thought it inadvisable to use rigid military control in the absence of orders from Washington. In a misguided effort to encourage a scientific approach, several official memoranda were issued from force headquarters, one of which is reproduced in Appendix B. These memoranda served to create interest rather than to control it, and all easily available sites were thoroughly pillaged. Many fine collections of artifacts were made, unfortunately without the proper concern for provenance; a few of these have ended up in the Smithsonian and other museums. One might say in hindsight that this digging should not have been permitted, but the realistic view is that, under the very trying circumstances of life on Amchitka, this recreation was a sanity saver (Guggenheim, 1945).

One looks now at Amchitka, especially in the southeastern section around the harbor and the three runways, and the signs of man's past presence on the island seem almost overwhelming (Fig. 7). One wonders just how many men were there to warrant all that construction. As we have already seen, the initial landing on Jan. 12, 1943, consisted of nearly 2000 men. Air Force records show that their strength was 3040 on June 5, 1943, and 3027 on June 30, 1945 (History of the Alaskan Air Command, 1952). Navy records are less precise and merely indicate 1200 men in 1943 (Anonymous, 1947, p. 182). Army records I have not seen. Records of the Corps of Engineers indicate that by 1945 there were facilities for an authorized troop capacity of 16,134 men, and their total construction costs had come to over $34 million. The same records indicate that there were then 1873 Pacific huts usable, each with a capacity of 8 men (Corps of Engineers, 1945). Thus it appears that during the actual campaign there were about 5000

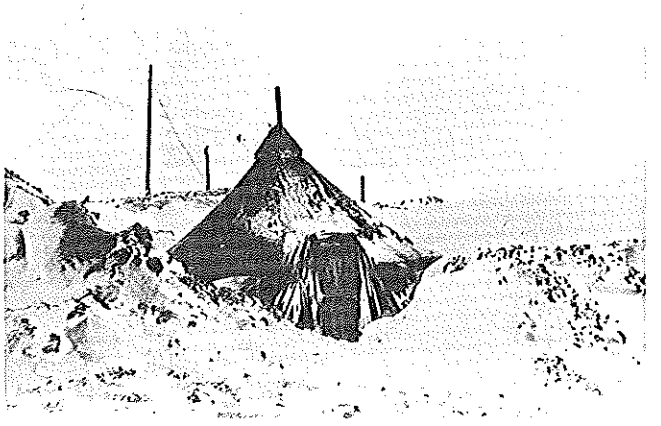

Fig. 6—Troop tent, winter 1944–1945. (Photograph courtesy of R. F. Shary, Anchorage.)

Fig. 7—Roads and buildings left from World War II. (Photograph courtesy of E. D. Campbell, Energy Research and Development Administration.)

men and that this number may have nearly tripled later in the war.

The early primitive tent quarters and steel-mat runways were improved as time went by. In 1944, runways were paved and more permanent quarters were built. Most of these are of the semicylindrical shape commonly called Quonset huts. The true Quonset hut has metal ribs and skins; most of the huts on Amchitka were of the same shape but were made of a masonite-like material and are properly called Pacific huts; they were developed by a Colonel James Lang as a steel-saving proposition. KD (Knock-Down) huts of wood were also used. In general, these huts were dug into the peat, the peat removed forming berms around the sides and ends as additional protection against the wind and wet (Fig. 8). They were built by hand labor from material brought across frozen ground during the winter by crawler-type vehicles, accounting for the fact that there are no roads to many of them, only foot trails. In later years the garrison also built many boardwalks along commonly traveled routes which are now in the process of rotting away and being covered over by encroaching vegetation.

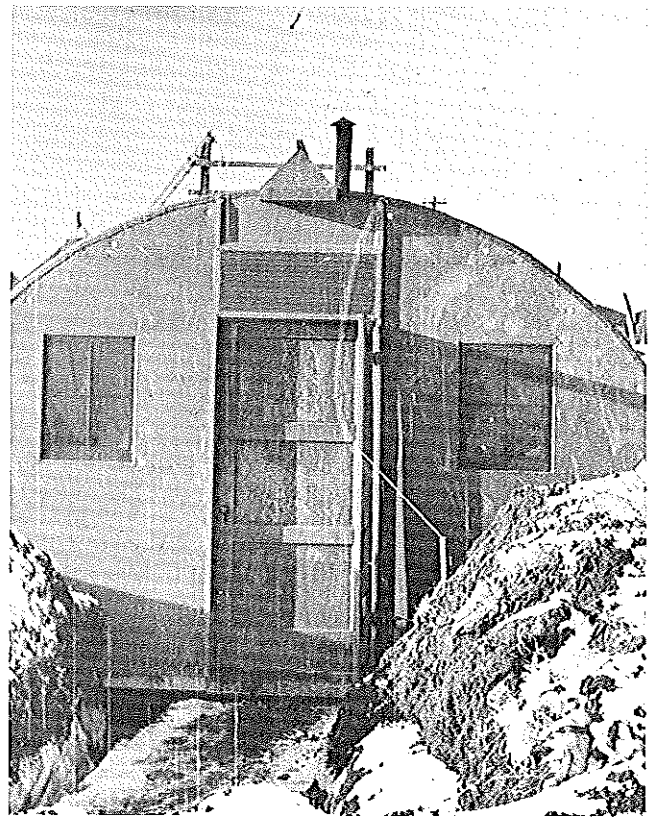

Fig. 8—Pacific hut protected by peat berms, winter 1944–1945. (Photograph courtesy of R. F. Shary, Anchorage.)

THE POSTWAR YEARS

Some troops stayed in the western Aleutians for a while after the war. Amchitka itself was evacuated by August 1950 (Jones, 1960, p. 9). Attu was empty by March 1949, although at some time since the Coast Guard has put 35 men there to run a loran station. Atka was placed in caretaker status in January 1944. Kiska was not held for long after it was found that the Japanese had abandoned it, perhaps because there is much unexploded ordnance on it. Shemya was evacuated in 1951 but was later used as a refueling stop by Northwest Airlines on the Anchorage–Tokyo route and now again has an Air Force station on it. Adak has been occupied continuously and indeed has gained importance when the Navy headquarters was removed from Kodiak in 1971 and the refuge headquarters to Adak from Cold Bay in 1972. Adak now has the distinction of being the station farthest west in the United States where military dependents are allowed.

In 1951 a proposed new project involved Amchitka, foreshadowing its recent use by the Department of Defense (DOD) and the U. S. Atomic Energy Commission (AEC) as a site for nuclear explosions. Project Windstorm was a response to a military need for information about the cratering potential of nuclear explosions. The DOD wished to fire two 20-kt explosions, one surface burst and one shallowly buried. For this they required a site having "a minimum thickness of 150 feet of incoherent detrital material in which the seismic velocities would be essentially uniform" (Piper, 1952). For some reason it was thought this could be found on Amchitka. Two drilling parties were sent to the island, and in early 1951 they drilled 34 test holes at various positions to the northwest of where Cannikin was fired in 1971 (Chap. 1, Fig. 11). No such conditions were found, and the exploratory drilling was stopped on May 10, 1951. The scope of the project was reduced to the 1.2-kt level and became the Jangle Surface and Jangle Underground shots fired in November 1951 at the Nevada Test Site.

In the early 1950s much of what is now old, rotten, and weatherbeaten was still in very good shape. This, of course, was also true in other former fields of war, and there too a great deal of material remained, surplus to the military but potentially valuable to someone. Some time after the war, probably about 1951, salvage rights were put out to bid. The original bid invitations brought no response; so the Navy, which was acting as the executive agent for the military in this matter, entered into negotiation with Bankers Life and Casualty Company of Illinois. After prolonged negotiations, a figure of $318,000 was agreed on

for all the salvage rights on 13 islands of the Aleutian chain (Anonymous, 1961). This firm intended to do the job with Japanese labor, but the unions objected; so they were forced to abandon this idea and sublet the rights (Robert Atwood, private communication, 1973). The first salvage operation was by Aleutco, a Seattle firm whose name suggests that it was formed ad hoc for this particular job. Aleutco took only items of large value that could be easily transported, things on wheels so to speak: trucks, generators, compressors, and installed real property, such as motors. A second salvage was conducted in 1953 by General Metals of Tacoma. They salvaged metals, particularly copper and lead (R. D. Jones, private communication, 1973). These were "high-grading" operations; for instance, the copper of telephone wires was often taken by felling the poles, but this was only done in the southeastern part of Amchitka where there was much of it. The salvage rights have since either been bought back by the government, as in 1955 when Shemya was to be made a refueling stop for Northwest Airlines, or simply expired, as seems to have happened to Amchitka.

During the years 1954 to 1957, a Distant Early Warning radar network (the so-called DEW line) was built across northern Alaska and Canada. A DEW line extension was run into the Aleutians starting in 1957. The communications portion of the DEW line was called the White Alice system. (Since then the White Alice system first became a separate entity serving also the isolated bush towns of Alaska, and now large portions of it are melded into the statewide telephone service run by RCA Communications.) In connection with White Alice operations and the DEW line extension, Western Electric crews were on Amchitka from 1959 to 1961. Their mission was to run a relay station using a 30-ft antenna dish to bridge the 400-mile gap between Adak and Shemya during the time those stations had only 60-ft dishes. These and other main DEW line stations now use 120-ft dishes and have ample power and sensitivity to bridge such gaps. The actual White Alice site is in an area not damaged in World War II; it is a little over a kilometer northwest of where Cannikin was later to be fired (Chap. 1, Fig. 11), coincidentally fairly close to the 1951 proposed site for Project Windstorm. From this short time activity comes the name of the White Alice Creek that drains the Cannikin site and figures elsewhere in this book.

POSTWAR REFUGE MANAGEMENT

Amchitka and the western Aleutians were still part of the Aleutian Islands National Wildlife Refuge, these other activities being tolerated under the original provision of Executive Order 1733 that "the establishment of this reservation shall not interfere with the use of the islands for lighthouse, military, or naval purposes. . . ." The Department of the Interior resumed management over most of the refuge territory in 1948 with the appointment of Jones as Refuge Manager. Reading his reports from 1950 on, we see a series of activities that continued year after year. Some of them were pure housekeeping matters, such as permits issued, poachers caught, and trips made. There are also extensive lists of birds seen and identified with their times of arrival and nesting. There are details on rats trapped on Amchitka (Brechbill, Chap. 12, this volume). There are lists of plants. But the dominant themes, especially for Amchitka, are the sea otter and the Aleutian Canada Goose.

In 1958 the refuge was described as follows:

> The Aleutian Islands National Wildlife Refuge was established in 1913 to insure protection of the native birds and fur bearers, to provide for the propagation of reindeer, and to encourage and develop the fisheries. As we now know, the propagation of reindeer is often inimical to populations of nesting birds, and to the range itself if the animals are not carefully managed. That and the Aleut people's lack of interest in reindeer has dictated a "go slow" policy in reindeer propagation. Because of remoteness and the existence of severe weather conditions, development of the fishery has proceeded slowly. Even today the inshore fishery of all but the eastern end of the Refuge is rarely utilized. The Japanese high seas fishing fleet is currently engaged in the development of the off-shore fishery. It is mainly in the field of native bird protection and the management of fur bearers that Refuge administration has moved. The redevelopment of a sizeable population of sea otters has been the most significant step in the history of the Refuge. When in 1913 the Refuge came into being a sea otter was a rare specimen, but there are now more than 20,000 of the curious little animals within the Refuge boundaries.

(In spite of the comment about reindeer, caribou, a closely related species, were introduced to Adak in 1958 and 1959. They are kept under close control by hunting; indeed, G. Vernon Byrd, the present Assistant Refuge Manager, while in the Navy on Adak had as part of his duties as Base Conservation Officer assisting the Fish and Wildlife Service in the management of this game herd.) The sea otters of the western Aleutians, and especially Amchitka, were extensively studied, resulting in a Ph. D. thesis by Lensink (1962) and a monograph by Kenyon (1969). Kenyon describes at length the experiments that have led to recent apparently successful transplants of sea otters from Amchitka and elsewhere where the population is now stable into parts of their former range where they had been completely extirpated by hunting (Abegglen, Chap. 20, this volume).

I have already indicated the plight of the Aleutian Canada Goose and how the introduction of foxes to most of the Aleutians all but wiped them out. Jones' reports give a picture of a dedicated long-term effort to reverse this sad history. Foxes were extirpated from Amchitka by 1960 and from Agattu by 1968,* the latter island being the one that Murie (1959) had believed was once the very best island for the geese. Jones suspected from Murie's reports that these geese had survived in small numbers on Buldir and verified this in 1961. In 1963, 18 goslings were removed from Buldir and sent to a game farm in Colorado. Sixteen of these survived and formed the nucleus of a captive population now at the Patuxent game farm in Maryland. Thus Jones (not single handedly, of course, but as the driving force) had done away with the primary enemy of the geese on two islands, had found a surviving nucleus of them, and had arranged for them to be cared for and to multiply in numbers. It only remained to reintroduce the geese to these islands, when the DOD and later the AEC took over Amchitka for other purposes and frustrated the long-term plan.

Actually it has not been quite as bad as all that. In the spring of 1971, the Fish and Wildlife Service did bring back Aleutian Canada geese to Amchitka using AEC support to transport them. They did not bring them back in an effort to transplant, however, so much as in an experiment on transplanting methods. The proven system for transplanting migratory birds consists of bringing a group of adults into a place and holding them in cages. The adults rear young, and these young, who are imprinted with this place, are released. This standard method requires a crew to provide continuous care for several years, usually about 3. What was tried in 1971 was to see what could be done on a much shorter time scale. Seventy-five geese were brought in and released shortly before the nesting season. Very few live birds were seen after the release, and the few dead birds seen had either been killed by eagles or eaten by them after death from other causes. There was no evidence of production of young birds or the return of the geese in the following years. Thus this experiment proved unsuccessful. The Patuxent game farm has yet other Aleutian Canada geese, and in 1974 the Fish and Wildlife Service reintroduced them to Agattu and in 1976 started to return them to Amchitka.

There has been a slow change in management purposes for the refuge over the years. At the beginning in 1913 it was reindeer, fur bearers, and fisheries. In 1958 it was not reindeer but sea otters, birds, and, to a much smaller extent, fisheries. The most recent statement of purposes is in a recent Wilderness Study Report (Sekora, 1973):

> 1. To maintain at minimum recovery levels all native species normally associated with the environments found on the Refuges—more specifically, to protect and preserve populations of colonial nesting birds, marine mammals, and other wildlife indigenous to the Aleutian Islands and their adjacent waters.
>
> 2. To assure the survival in a natural state of each of this Nation's plant and animal species—more specifically to restore the Aleutian Canada goose and sea otter populations to former ranges and levels of abundance.
>
> 3. To contain all lands or networks of lands of national significance whose benefits to the public can best be achieved by the distinctive competence of the National Wildlife Refuge System—more specifically to preserve watersheds which contribute materially to the production of salmon stocks.
>
> 4. To seek out, identify, designate, preserve, and appropriately use sites and objects on refuges that are recognized to have esthetic, historic, geologic, archeologic or scientific values.
>
> 5. To raise to optimum levels the kinds, range, amount, and quality of wildlife and wildlands—oriented recreation—more specifically, to manage game populations [caribou] on Adak Island as a harvestable resource.
>
> 6. To establish and preserve in a natural state selected areas for reference observation, scientific study, and/or specialized public use, and in which the major ecological communities in the system are represented.

Statehood came to Alaska in 1959 after a long and difficult struggle. The Territory of Alaska had never had much control over its natural resources, and indeed this had been one of the sore points that led to the demand for statehood. In the Aleutian Islands National Wildlife Refuge, statehood has meant some sharing of responsibility by the Department of the Interior with the newly established Alaska Department of Fish and Game. (The old Alaska Game Commission ceased to exist.) Today one must have a state fishing license to fish for salmon or Dolly Varden on Amchitka. More important was the control and management of the sea otter. Technically the State acquired jurisdiction over sea otters at sea, between the lower tide line and the 3-mile (5-km) limit of U. S. sovereignty, and the Department of the Interior kept jurisdiction over sea otters on land. This was a fine and artificial line that did not meet the practicalities of the situation. In practice, the State has managed the sea otter resource, issuing permits for their taking for such purposes as research, transplanting them into other parts of their former range, and harvesting their furs for sale where their density of numbers permitted. All this, of course,

*So reported Jones, but he was mistaken. A crew bringing geese to Agattu in the spring of 1974 found over a hundred foxes still there.

has been rendered moot by passage of the Marine Mammal Protection Act of 1972, which has returned responsibility for all sea mammals to the Department of the Interior and has resulted in a moratorium on taking them for any purpose (Abegglen, Chap. 20, this volume).

TSUNAMIS

Before finally turning to the events that led to nuclear testing on Amchitka, mention should be made of another external influence on the island, one provided by nature, not man. It is well known that the Aleutians are a region of the world that is very active seismically (Gard, Chap. 2, this volume). Earthquakes sometimes give rise to tsunamis or seismic sea waves (often miscalled "tidal waves"). Cox and Pararas-Carayannis (1969) list tsunamis that have been felt in Alaska so far as the historical record reveals them. Presumably tsunamis have been felt in the western Aleutians for as long as those islands have existed, but they do not appear in the record until 1944, after which there are 15 entries (Table 5). These were all recent enough that measurements at standard tidal stations exist on them; four of them had amplitudes of a meter or greater at Attu or Adak. For three of them observations at Amchitka itself are available.

The 1957 tsunami, which arose from a source near Unimak in the eastern Aleutians, is mentioned by Jones in his Narrative Report of 1957:

> . . . . A tidal wave reaching 13 ft above high tide followed the most severe of the earthquakes, washing debris onto the lower part of the islands and creating additional damage at Adak. At Adak agitation of the water sources for trout hatchery apparently released the accumulated products of decomposition and temporarily polluted water flowing in the troughs. Ten to eleven thousand fingerlings were lost before the situation was restored. While the Refuge Manager was on the Island in mid May the settling basin and piping system were completely cleaned of sediment as an effort to prevent or ameliorate a recurrence. Most of the cabins and other facilities remaining from the fox farming days were demolished by this tidal wave.

Jones' report concerns Adak; Everett (Chap. 8, this volume) gives some evidence of the effects of this tsunami on Amchitka.

At the time of the 1960 Chilean earthquake and resultant tsunami, Jones was on Amchitka. He reports:

> A curious event, one that made us uneasy took place on the 23rd and 24th of May [later than the time indicated in Table 5 because of the travel time from South America]. At noon of the former we noted a visible tidal current flowing into the Harbor. Thoughts of a damaging tidal wave leapt to mind and we watched with anxious eyes, expecting a bore to develop. The current oscillated in and out and we thought it prudent to haul the dory higher on the Island. This we did and continued to watch with apprehension the silent ebb and flow. Clearly the sea was in a state of unrest due to some seismic disturbance. Later we learned of a damaging earthquake at that time on the coast of Chile in South America (Jones, 1960, p. 20).

The Great Alaskan or Good Friday earthquake of Mar. 27, 1964, produced a tsunami that was very destructive in the epicentral region and along the Pacific coast as far as California, but, because of the directionality of the source, the resulting tsunami was little felt in the Aleutians.

No one was on Amchitka on Feb. 4, 1965, when the magnitude 7¾ Rat Island earthquake took place with its epicenter just 20 miles south of Amchitka. This was during the period leading up to Long Shot (below), and so a party was sent to see what damage had been caused on the island. Gard (1965, p. 4) reports that a water wave had washed up on the beaches, "no higher than about 6 feet above high tide," and that the fill land along the foot of Fox Runway had settled (Fig. 4), but no major damage was done.

ACTIVITIES LEADING UP TO THE AEC USE OF AMCHITKA

The western Aleutians must have cropped up numerous times in the postwar years as possible sites for projects requiring isolation from masses of people. I have in my files, for instance, a short memo written in 1960, during the days of great optimism in the Plowshare program,* that discusses the feasibility of using nuclear explosives to dig a harbor at Shemya. It was just a paper exercise, one among many such that were not taken seriously and not followed up on.

Early Site-Selection Efforts

The period of the early 1960s was one of many searches for test sites. During these years limitations began to become evident in the use of the existing Nevada Test Site (NTS). After the unofficial moratorium on nuclear testing was broken by the U.S.S.R. on Sept. 1, 1961, the NTS had been used almost exclusively for underground tests. The city of Las Vegas, 60 miles from Yucca Flat, was beginning to acquire high-rise structures along the "strip." High-rise buildings tend to be sensitive, one might almost say near-resonant, to the ground shocks from the larger nuclear explosions. The initial step in adjusting to this growing problem was to enlarge the test site to the northwest to

*Plowshare was the AEC program of study of nonmilitary uses of nuclear explosions.

Table 5—Tsunamis in the Western Aleutians*

Date (GMT)	Earthquake source	Magnitude	Runup height (m) at Attu	Adak	Unalaska	
Dec. 7, 1944	Japan	8.0	0.3	0.1		
Mar. 4, 1952	Japan	8.3	0.1	0.2	0.1	
Nov. 5, 1952	Kamchatka	8¼	1.5	1.1	0.6	
Nov. 26, 1953	Japan	8.0	0.2			
Mar. 30, 1956	Kamchatka	NA	0.3	0.1	0.1	
Mar. 9, 1957	Unimak	8.3	0.6	4.0	0.7	
Nov. 7, 1958	S. Kurile	8.7	0.2	<0.1		
Nov. 13, 1958	S. Kurile	7.3	0.2	<0.1		An aftershock?
May 4, 1959	N. Kurile	8	0.2			
May 22, 1960	Chile	8.5	>1.8	1.5	0.8	
Dec. 20, 1962	Fox Island	6.5		0.1?		Uncertain if real.
Mar. 27, 1964	Prince William Sound	8.4	0.4	0.3	0.4	
Feb. 3, 1965†	Rat Island	7.75	3.2	NA	0.2	
Mar. 29, 1965	Rat Island	7.3	0.2			An aftershock.
Oct. 17, 1966	Peru	7.5	0.1	0.1		

*Source: Cox and Pararas-Carayannis (1969).
†Time was 0521, February 4, GMT, which was 1821, February 3, local time (BST).

include Pahute Mesa, which raised the distance to Las Vegas to over 100 miles. In subsequent years the use of Pahute Mesa has permitted tests of somewhat larger than a megaton at the NTS.

These limitations led in 1964 to an extensive search for an alternative to the NTS. This search was confined to areas in the 48 contiguous states west of the Cordilleran front and turned out to be a mere paper study; no visits to possible sites were permitted, and the 1964 alternate test site efforts died away without ever being formally canceled.

Long Shot

In late 1963 planning started in secret for what is now known as Long Shot. At that time there were unanswered questions about the ability of the U. S. detection system and the worldwide seismic community to detect and distinguish nuclear explosions, especially if one happened to be fired in the Kuriles or in Kamchatka, naturally seismic areas next to the sea. Could an explosion in such a place be distinguished from natural seismic shocks? To what extent would the Aleutian trench, a major exception to the usual seismic assumption of a horizontally uniform earth, speed up or delay a signal and cause its epicenter to be mislocated? It was proposed to shoot an underground nuclear test in that region unannounced and see how the seismic community would do (Test Command, Defense Atomic Support Agency, 1967).

However, the AEC's statutory responsibility for test safety included even those tests carried out by the Department of Defense, and the AEC had to be brought into the planning. The then manager of the AEC's Nevada Operations Office, James Reeves, insisted that it is just not possible in American society to carry out such a test without knowledge of its preparation leaking out. So the secrecy was dropped and with it the feature of an unannounced seismic event, but the test went ahead on the issue of determining travel times from sources near oceanic trenches. Thus was born Long Shot. Jones (1965, p. 35) confirms the misgivings about being able to keep such a test secret, saying, "In March 1964 we learned of a major, highly classified project soon to begin on Amchitka, and assumed we were again in the presence of the Bomb . . . . In the spring a series of heavily loaded military aircraft flights proceeded to Amchitka, and the nature of the cargo (which became common knowledge along the route) confirmed our assumption." The cargo included a Canadian-made drilling rig whose presence became known when the U. S. customs held up its passage through Anchorage some hours for lack of proper papers.

During the summer of 1964, six test holes were drilled about the eventual Long Shot site to confirm the Geological Survey's analysis that there was no local faulting. Preparation for even a simple test is not short, and on Oct. 29, 1965, Long Shot was finally detonated. It was an 80-kt shot 720 m (2350 ft) deep 2 km southwest of Cyril Cove (Chap. 1, Fig. 11).

From the refuge viewpoint, Long Shot was an unexplained interference with the long-term plans for Amchitka by men insensitive to refuge values. Kenyon (1966), in his internal report on the shot, speaks several times about the "progressive destruc-

tion of refuge values that are added by each new invading activity." He mentions meeting men on the project who had no idea before coming that the island was part of a National Wildlife Refuge. Normally a happy man, he was dismayed that he and Spencer, the Associate Supervisor of Alaska Refuges, had to "join, as temporary employees, the staff of the Laboratory of Radiation Biology of the University of Washington in order to make post-blast examination of refuge wildlife resources at Amchitka."

What Long Shot and the two later nuclear shots did to these wildlife resources is discussed in Chap. 26 of this volume. Suffice it to say here that the blast-caused effects of Long Shot were almost nil, but there resulted a small (and still continuing) tritium leak into drilling mud pits next to the Long Shot pad (see Seymour and Nelson, Chap. 24, this volume). The island was evacuated in December 1965, with little effort having been made to clean up the island.

Search for a Supplemental Test Site

In mid-1966 the search for another test site was revived, this time impelled by the need for a place to test a series of devices leading up to the warhead for the U. S. Anti-Intercontinental Ballistic Missile (AICBM) system, which would include yields considerably greater than what experience since 1963 had indicated could be tolerated at the NTS's Pahute Mesa. (The NTS limitation continued to be high-rise structures in Las Vegas, whose numbers and heights were steadily increasing.) The investigation proceeded informally from June until Nov. 18, 1966, at which time a new Site Selection Committee was formally set up. The search had by then narrowed down to an area in central Nevada north-northeast of the NTS and to Amchitka Island in the Aleutian chain, with the western end of the north slope of the Brooks Range in Alaska considered an "insurance" alternative in the event the other sites did not meet programmatic requirements.

Much of the early thinking of this Site Selection Committee was devoted to central Nevada. Eventually a general location in Hot Creek Valley was chosen; particular sites within it were suggested by the Geological Survey; exploratory holes were drilled; and, after the long process of preparation, on Jan. 19, 1968, a calibration shot called Faultless was fired. It was an intermediate yield shot (200 to 1000 kt) at a depth of 975 m (3200 ft). No further work has been done at the Central Nevada Supplemental Test Site. The site is not suitable for shots as large as were required to test the AICBM warhead.

Amchitka

Between Nov. 30 and Dec. 16, 1966, a U. S. Geological Survey team made a geological reconnaissance and aeromagnetic survey of most of the southeastern half of Amchitka. Their immediate purpose was to select five sites for deep exploratory drill holes. They picked five, plus one alternate location, and reported their findings to the Site Selection Committee on Mar. 2, 1967. (Unimaginatively, these six sites were called Sites A, B, C, D, E, and F.) A generalization of their geological findings during this reconnaissance together with data gathered earlier is given in Carr, Gard, and Quinlivan (1967).

The following criteria were used by the Site Selection Committee in its 1966–1967 site-selection activities: The rock needed to be competent enough for mining at shot depth and impermeable enough to avoid the risk of groundwater contamination, all at a depth sufficient for containment of radioactivity. (Amchitka's isolation would help if containment were to fail.) There should be adequate separation of individual sites on the island; sites were to be 4 miles apart, 3000 ft from either coast, and at least 3 miles from Baker Runway. Logistical factors favoring Amchitka were year-round access by sea or air, an existing road network, a harbor, airstrips, and a land mass large enough that people at a Control Point at the northwest end of the island would be far enough from any prospective firing site to protect them from the effects of ground shock. As to environmental concerns, it was recognized that Amchitka is in the Aleutian Islands National Wildlife Refuge and that operations would have to be carried out with minimum disturbance to the natural environment and wildlife.

It would seem that there ought to be a formal Memorandum of Understanding on record between the AEC and the Department of the Interior on the use of the island, but a search for one has not turned it up. Apparently the AEC's original entry onto the island was based on an informal agreement made in late 1966 between AEC Chairman Seaborg and Secretary of the Interior Udall.

ORGANIZATION OF BIOLOGICAL STUDIES ON AMCHITKA

In 1966 Battelle Columbus Laboratories (BCL) was managing a program of ecological studies in Panama for the AEC and the Atlantic–Pacific Interoceanic Canal Commission associated with the possibility of digging a new canal. They were asked to organize studies at Amchitka as well. Their ideas and plans were discussed with the Fish and Wildlife

Service, first in March 1967 and periodically thereafter. Actual on-island biological studies started in the fall of 1967. These investigations were designed to predict, evaluate, and document the effects on the biota and the environment from the proposed nuclear tests, to recommend measures for minimizing adverse effects, and to predict and evaluate the potential hazards to man that might result from the accidental release of radionuclides to the environment and their subsequent transport to humans via marine food chains.

These broad objectives had to be brought down to the level of specific concerns and particular projects. The first list of specific concerns, agreed to with the Fish and Wildlife Service in 1967, is as follows:

1. Effects on the sea otter population.
2. Transport of radionuclides to man via marine processes.
3. Transport of radionuclides to man via migratory birds.
4. Disturbance of terrestrial habitats.
5. Disturbance of freshwater habitats.

The broad objectives and the specific concerns within them changed somewhat as time went on; for instance, the concern about sea otters changed from an early study of their ability to withstand shock waves in the water to a study of their population distribution and behavior. Also, the early emphasis on radionuclide transport changed to an emphasis on possible physical effects on the environment.

Competent investigators had to be recruited. Some of these came from within the Battelle staff; others were enlisted from the academic community and government laboratories. Later a few investigators entered the program under direct contract with the AEC. Most of the contributors to this book are drawn from this group of investigators.

The Fish and Wildlife Service of the Department of the Interior assigned four men to the Amchitka activities: two refuge-management biologists who were rotated to keep one man on the island at all times to monitor construction activities and otherwise to look out for Interior's interests and two research-oriented men to monitor and participate in the research being carried on. (These latter men, Merrell and Abegglen, are also among the authors of chapters in this volume.)

In April 1967 the Department of the Interior and the AEC agreed that demobilization at the conclusion of the program would include cleanup, removal of all movable material brought onto the island, and demolition of buildings built for the project except for what the Department of the Interior would need for its continuing refuge responsibilities. In general, the island was to be returned insofar as possible to its condition in 1967 before construction activities started. The debris left from Long Shot was to be cleaned up, but not World War II debris or buildings, except in specific instances along roads: it was believed that many of these wartime remains were so covered with subsequent growth that their removal would entail more damage than benefit.

The story of activities on the island during its use by the AEC is left for later chapters of this book. All people evacuated the island on Sept. 8, 1973, after demobilization and cleanup, and AEC rights of use and control over Amchitka were relinquished on Sept. 18, 1973. Two continuing stipulations remain from the AEC occupancy of the island. The Department of the Interior has been asked to prohibit excavation, drilling, and removal of materials near the surface zeroes of the three nuclear tests that have been executed there, Long Shot, Milrow, and Cannikin. Also, the AEC has asked for visitation rights and use of residual facilities and equipment remaining on Amchitka for scientific parties examining possible long-term consequences of those tests. So far there have been three such return parties, in May and August 1974 and in August 1975 (Kirkwood, 1974; 1975; Nelson, 1975).

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APPENDIX A: THE EXECUTIVE ORDER THAT ESTABLISHED THE ALEUTIANS AS A RESERVATION AND NOW AS A NATIONAL WILDLIFE REFUGE*

Executive Order

It is hereby ordered that all islands of the Aleutian chain, Alaska, including Unimak and Sannak Islands on the east, and extending to and including Attu Island on the west, be and the same are hereby reserved and set apart as a preserve and breeding ground for native birds, for the propagation of reindeer and fur bearing animals, and for the encouragement and development of the fisheries. Jurisdiction over the wild birds and game and the propagation of reindeer and fur bearing animals is hereby placed with the Department of Agriculture, and jurisdiction over the fisheries, seals, sea otter, cetaceans and other aquatic species, is placed with the Department of Commerce and Labor.

It is unlawful for any person to kill any otter, mink, marten, sable or fur seal, or other fur bearing animal within the limits of Alaska Territory, except under such regulations as may be prescribed by the Secretary of Commerce and Labor; and it is unlawful for any person to kill any game animals or birds in Alaska or ship such animals or birds out of Alaska except under the provisions of law and under such regulations as may be prescribed by the Secretary of Agriculture.

Within the limits of this reservation it is unlawful for any person to hunt, trap, capture, wilfully disturb, or kill any bird of any kind whatever, or take the eggs of any such bird, except under such rules and regulations as may be prescribed by the Secretary of Agriculture.

Warning is expressly given to all persons not to commit any of the acts herein enumerated and which are prohibited by law.

The establishment of this reservation shall not interfere with the use of the islands for lighthouse, military, or naval purposes, or with the extension of the work of the Bureau of Education on Unalaska and Atka Islands.

This reservation to be known as the Aleutian Islands Reservation.

WM H TAFT

THE WHITE HOUSE,
March 3rd, 1913.

[No. 1733.]

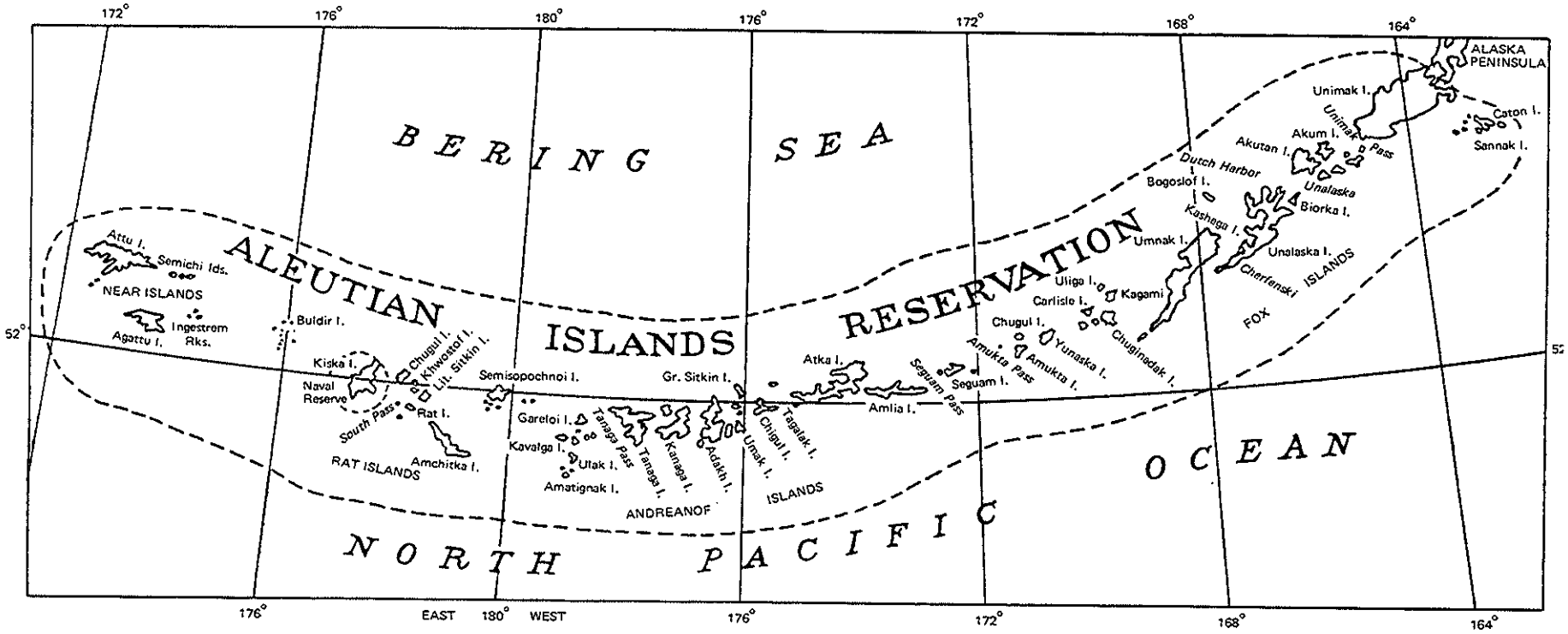
*This Executive order has been retyped verbatim from the original copy.

ALEUTIAN ISLANDS RESERVATION

For Protection of Native Birds the Propagation of Reindeer and Fur Bearing Animals and the Development of Fisheries

ALASKA

Embracing the Islands of the Aleutian chain as segregated by broken line and designated "Aleutian Islands Reservation."



DEPARTMENT OF THE INTERIOR
GENERAL LAND OFFICE
Fred Dennett Commissioner

APPENDIX B: THE WARTIME MEMORANDUM TO TROOPS ON AMCHITKA THAT CALLED ATTENTION TO ARCHAEOLOGICAL SITES ON THE ISLAND*

R E S T R I C T E D

HEADQUARTERS U. S. TROOPS
APO 986, U. S. Army

MEMORANDUM) 16 June 1943

No.. . . . .35)

ARCHEOLOGICAL OPPORTUNITIES, THIS STATION

1. It is the desire of this Headquarters, both from the scientific and recreational standpoints, to encourage the collection and preservation of archeological specimens.

2. The Aleutian Islands contain the buried remains of ancient races, important in the peopling of the New World. The soldiers of this garrison have an unparalleled opportunity to collect and preserve these specimens and thus to contribute materially to Science. The United States Government's Smithsonian Institute is interested in the remains found on this island. For a number of years The Smithsonian Institute sent an expedition to the Aleutian Islands. An officer of this Post, FLT Paul Guggenheim, 444th Signal Battalion, was a member of an expedition in 1937.

3. In order to develop our opportunities to the fullest, it is requested that individuals and organizations, wherever they find specimens (bones and tools, etc.) that are suspected to be of archeological interest, preserve the specimens and notify Lt. Guggenheim through Dispatch 16-R1. The specimen should be turned over to Lt. Guggenheim and all the information that can be given concerning the place found, etc., so that more specimens may be located. Specimens will be sent to The Smithsonian Institute and credit will be given to the discoverer. Any person who now has knowledge of the place where specimens may be found should give the information to Lt. Guggenheim.

4. It is desired that Organization Commanders and all other officers explain the possibilities of this endeavor to their men. With interest and enthusiasm on the part of the officers, much interest will be developed. The recreational advantages are great.

5. Excavations for specimens must be made in a scientific manner so as not to disturb or break up specimens in the ground. In the near future, this Headquarters will publish information as to the scientific manner in which to work a site containing specimens, so that men under the supervision of an officer may themselves engage in excavating work. Until that time, sites that are known to contain specimens should not be disturbed unless required for military reasons; but information as to location of the site should be given to Lt. Guggenheim (Dispatch 16-R1). This Headquarters will authorize sites for excavation which will not be disturbed by personnel other than those specifically authorized. Signs will be respected by all personnel.

By command of Brigadier General JONES:

Arthur A. Lundin
ARTHUR A. LUNDIN,
Major, F. A.,
Adjutant.

/jgl
DISTRIBUTION "A"

R E S T R I C T E D

*This memorandum has been retyped verbatim from the original copy.

7

Previous Scientific Investigations, 1867-1967

R. G. Fuller*
Battelle Columbus Laboratories,
Las Vegas, Nevada

During the first century after the United States acquired Alaska, progress in the scientific exploration of the western Aleutians was erratic. The islands were distant from the Alaskan mainland, and the Aleutian climate was a deterrent to exploration. Despite these obstacles, many investigators were drawn to the remote islands. Between 1867 and 1967 much was learned about the natural history of the western Aleutians and about the primitive peoples who inhabited the islands from prehistoric times. This body of knowledge was a useful base for planning the bioenvironmental studies reported in this volume.

During the first 126 years following the discovery of the Aleutians by Vitus Bering in 1741, some useful information about the geography, human inhabitants, flora and fauna, and general character of the western Aleutians† was collected and recorded by various explorers, by the Russian fur hunters, and by Russian administrators and missionaries who accompanied the hunters and traders during their exploitation of the natives and the natural resources of the islands. But, however valuable these observations may have been, most information was collected only incidentally to the primary missions of conquest, commercial exploitation, and religious conversion that engaged the observers.

Sherwood (1967) reviews the more important investigations of this period, for which he says he "... used the standard sources in English and in German, and in English and German translations from the Russian." I am not surprised that the Aleutians are scarcely mentioned in this review. Most exploring and collecting expeditions bypassed the western Aleutians, concentrating on the mainland, the Alaskan peninsula, and the eastern islands. The Russian center of power for trade and administration, after the first few years of free-for-all exploitation, was located first on Kodiak Island and later at Sitka on Baranof Island. The scattered islands to the west must have been even more forbidding and difficult of access to the early explorers than they were to later investigators.

The discussion that follows will focus on those investigations of a more strictly scientific nature which began after Alaska was purchased by the United States in 1867. I have chosen to treat the advances in chronological order rather than by scientific discipline. Many of the investigators who have added to our knowledge of the Aleutians were generalists whose interests ranged widely. It therefore seems more logical to discuss their contributions in the order in which they were made,* instead of separating them among different areas of interest. The history of geographic exploration is outside the scope of this chapter; for a good general survey that covers such exploration in the North Pacific Ocean—Bering Sea region up to the early 1960s, see Friis (1967).

The progress of scientific discovery in the western Aleutians after 1867 was erratic and for good reasons. Two themes are common to the accounts of most investigators: (1) the obstacles imposed by adverse weather and (2) the difficulties of getting logistic support and transportation among the remote islands.

Armstrong (Chap. 4, this volume) discusses the Aleutian climate, and the subject needs only brief mention here. Problems that weather posed for field investigators on the foggy windswept islands are easily imagined: it was difficult, and sometimes impossible, to preserve supplies and specimen collections against the dampness; favorable conditions for observing wildlife were rare, and the severe storms that often swept the islands sometimes stopped field work entirely.

*Present address: Oracle, Arizona.

†The Andreanof, Delarof, Rat, and Near Island groups.

*This plan is adhered to except for the treatment of Russian research in oceanography and marine biology. That subject is discussed briefly in a section at the end of this chapter.

Transport was the other big obstacle. Attu Island, at the western end of the chain, is over 900 km (about 550 miles) from Atka. This section of the Aleutians comprises some 40 islands and islets, many of which lack safe harborage for support vessels. The usual base from which to explore the chain was Unalaska, some 500 km (350 miles) east of Atka, and until recently no regularly scheduled transport was available among the islands.* Early investigators were forced to provide their own vessels or to depend on the support of trading ships, government vessels, or any other ships of opportunity that happened to sail through the area.

Commercial and government vessels had their assigned missions, which understandably took precedence over rendering assistance to visiting scientists. Few exploring parties were fortunate enough to work from their own support ships; so a catch-as-catch-can mode of travel was normal. Inevitably, investigators experienced frustrating delays, were often unable to visit important target islands, or had their visits cut short by the early departure of a support ship. So it is not surprising that scientific studies in the western Aleutians seem to have proceeded unevenly with long periods when advances were slight. The investigators worked against formidable odds, and what is remarkable is that they succeeded as well as they did against those odds.

DALL

The American naturalist William Healey Dall had a distinguished scientific career in Alaska, a résumé of which is presented by Sherwood (1965). His work in the far northwest began in 1865 when, at the age of 19, he joined the Scientific Corps of the Russian American Telegraph Expedition. I have found no evidence that this assignment took him into the western Aleutians,† but it did establish his reputation as a reliable and productive field naturalist and awakened in him a lifelong interest in Alaska. When he joined the staff of the Coast Survey in 1870, he embarked on a course that enabled him to make extensive natural-history collections and to pursue ethnological and archaeological investigations in the Aleutians.

Sherwood (1965) says of Dall: "The collections he made in his leisure time were extensive. He sent seven boxes of dry shells, echinoderms, and fossils to Professor [Louis] Agassiz* at the Museum of Comparative Zoology [Harvard University]. Plant specimens were mailed direct to the eminent American botanist, Asa Gray. In one year alone, Dall forwarded twenty-seven boxes and kegs of general zoological and ethnological materials to the Smithsonian." Hultén (1960) credits Dall with making ". . . fairly good collections. . ." of plants, which were deposited in the National Herbarium and in Gray Herbarium at Harvard.

Dall (1877a) reported the results of his archaeological and ethnological studies and the conclusions he drew from them in the first volume of *Contributions to North American Ethnology*. One of his three papers in the volume is "On Succession in the Shell-Heaps of the Aleutian Islands." In the introduction to this paper, he explains the circumstances under which he was able to investigate the archaeological remains of the islands: "The notes of which this paper is the result were made while engaged in a hydrographic and geographical reconnaissance of the Aleutian Islands, under the auspices of the United States Coast Survey. They were made at enforced intervals of leisure, occasioned by weather which would not permit the ordinary surveying operations of the party to be carried on, ..." Considering the limited opportunities Dall had to pursue this effort, it is noteworthy that he was able to collect as much information as he did.

Dall's report on the shell heaps (mounds of debris that constitute the principal repositories of material remains of the prehistoric inhabitants of the western Aleutians) is prefaced by a brief description of the topography of the islands and the flora and fauna of the islands and adjacent seas. He lists the islands, from Unalaska westward, on which shell mounds were observed or reported to exist (a total of eight). Of these, Amchitka Island is discussed at greatest length, and he stresses the abundance of shell heaps on that island, which he took to be evidence of a large resident human population in earlier times.

Dall describes in some detail the methods he used in excavating the heaps, methods that were remarkably sound as judged by modern standards. Turner (1970) mentioned the fact that Dall in his ". . . excavations at Constantine Harbor employed the principle of stratigraphy—preceding by 50

*Even today commercial air transport is available on a scheduled basis to only a few of the western islands (Adak, Shemya, and Attu) whereas ship transport is available from Adak to Atka.

†In 1865 Dall crossed the Bering Sea on the expedition vessel *Nightingale* with stops at St. Lawrence Island and at two ports on the Siberian coast. The captain of the *Nightingale* was Charles M. Scammon, who a few years later achieved some scientific recognition with publication of *The Marine Mammals of the North-Western Coast of North America* (Scammon, 1874).

*Dall had studied earlier with Professor Agassiz.

years its use by the archaeologist N. C. Nelson."* Dall reported that excavations were carried out on Attu, Amchitka, Adak, and Atka. As an example of the ground plan of a typical shell heap, he includes a sketch of one examined at the head of Constantine Harbor, Amchitka Island (probably RAT3 as reported by Desautels et al., 1970).

The conclusions Dall reached as a consequence of his archaeological investigations in the Aleutians will be discussed only briefly here. What is notable is that some of his judgments, though by no means all of them, have been supported by the much more extensive subsequent studies. Among his generalizations, probably the most important are:

> I. That the islands were populated at a very distant period.
>
> II. That the population entered the chain from the eastward.
>
> III. That they were, when they first settled on the islands, in a very different condition from that in which they were found by the first civilized travelers . . . .
>
> VI. That a gradual progression from the low Innuit stage to the present Aleut condition,† without serious interruption, is plainly indicated by the materials of, and utensils in, the shell-heaps of the islands . . . .
>
> VIII. That the stratification of the shell-heaps show a tolerably uniform division into three stages, characterized by the food which formed their staple of subsistence and by the weapons for obtaining, and utensils for preparing this food, as found in the separate strata; these stages being
>
> I. The Littoral Period, represented by the Echinus Layer.
>
> II. The Fishing Period, represented by the Fishbone Layer.
>
> III. The Hunting Period, represented by the Mammalian Layer.

Finally, Dall concludes, "On the whole, I am inclined to think that three thousand years is a moderate estimate for the time required to form these mounds of refuse."

Later workers have challenged Dall's neat division of Aleutian prehistory into the "Littoral," "Fishing," and "Hunting" periods as well as some of his interpretations of cultural evolution among the prehistoric peoples of the chain (Jochelson, 1925; Hrdlička, 1945; Laughlin, 1951; Spaulding, 1953). On balance Dall appears to have reached some sound conclusions regarding the prehistory of the Aleuts, a notable achievement when we consider the hardships and limitations under which he worked.

*Ceram (1971) reports that as early as 1781 Thomas Jefferson described the use of this valuable technique in his excavation of prehistoric earthern burial mounds in Virginia.

†Dall here no doubt refers to the conditions of the Aleuts at the time of first contact with so-called civilized man.

In discussing articles of personal ornamentation found in the shell heaps, Dall notes that the early peoples made beads of amber, among other materials. He adds, "This substance occurs sparingly in the lignitic deposits of Tanaga, Unalashka (sic), Atka, and Amchitka, and was reckoned of the greatest value by the Aleuts." His reference to "lignitic deposits" calls to mind the later discovery of partially carbonized tree remains on Amchitka (Powers et al., 1960; Humphrey and Branstetter, 1973; Barr, Ellis, and Helle, 1973).

Dall (1877b) attempted to determine the relationship between the Aleuts and the aborigines of mainland Alaska, with whom he had been in contact during his early Alaskan field work. He recognized the affinities between Aleuts and Eskimos, on the bases of language, geographic distribution, and a common dependence on maritime resources for subsistence. He listed 20 divisions of Eskimos or Innuit, drawing on his personal observations of those groups occupying the coast of western Alaska and on reports by others on more-distant divisions. The Aleuts were treated in less detail since he had less information to draw on. He recognized two principal geographic divisions: the Eastern or Unalashkans (sic) and the Western or Atkans. He estimated the total Aleut population in 1871 to be about 2450 persons, of whom less than 500 lived in the western islands.

A review in detail of Dall's contributions to knowledge of the geography and natural history of the western Aleutians is beyond the scope of this chapter; they appear to have been substantial by any standard. Bartsch, Rehder, and Shields (1947) give an account of Dall's entire career and a bibliography of his voluminous publications. These authors, staff members of the U. S. National Museum, write:

> At the close of the 1874 season Dall was recalled to the Washington office [of the Coast Survey, later the Coast and Geodetic Survey] to assemble all the known data of use to navigation in Alaskan waters. The information thus assembled was published in the 'Pacific Coast Pilot of Alaska,' the foundation upon which all subsequent Alaskan studies by the Coast and Geodetic Survey were based. . . . . During his period of office at the United States Coast and Geodetic Survey his spare hours were devoted to the arranging of the immense collections that he had made in Alaskan waters as well as the material that had accumulated at the Smithsonian Institution. His journals reveal that no opportunity was missed to collect on land or with dredge in the sea during his work in the north. Our knowledge of the fauna of that region is still largely based on Dall's collecting.*

*Although this last assertion (made less than 30 years ago!) may be something of an overstatement today, it suggests the esteem in which Dall's work was held by his peers three-quarters of a century after he began his Alaskan field studies.

Dall's primary fields of inquiry were malacology and paleontology, but he was a true naturalist, and his observations and collections ranged far beyond his own areas of special interest into every aspect of natural history. As a result, specialists in many diverse fields benefited from the collections he made. For example, much of our early knowledge of the marine fauna of the western Aleutians rested on the collections made there by Dall during his Coast Survey cruises.

BEAN

Tarleton H. Bean of the U. S. National Museum participated in at least a portion of the 1880 summer cruise of the U. S. Coast Survey vessel *Yukon* commanded by W. H. Dall. The following year he published what appears to be the first attempt to enumerate the fishes of Alaska and adjacent marine waters (Bean, 1881). Bean's list contained 116 species, of which only 16 were collected from the western Aleutians; it represented all the Alaska collections then held by the U. S. National Museum plus a few species that had been reported from Alaska waters by other investigators.* In an Appendix are listed an additional 99 species of fish that ". . . are known to occur in waters bordering upon the limits of Alaska, and will doubtless be found by future investigations."

A review of the Alaskan species enumerated by Bean shows that nearly all those reported from the western islands were collected by Dall. Amchitka was among the collection locations cited for 10 of the 16 species from the western Aleutians.

TURNER

Lucien McShan Turner, a naturalist, served in Alaska as a meteorological observer with the U. S. Army Signal Corps from 1874 to 1881. In May 1874 he arrived at St. Michael, on Norton Sound, where he was stationed until July 1877. After his return to the States and a brief separation from the Signal Service, he returned to Alaska in May 1878 and began his tour of duty in the Aleutians, an assignment that took him to the western islands of the chain. Turner established and operated a meteorological station on Atka from May through August 1879 and one on Attu from July 1880 through mid-May 1881. His official duties as a weather observer occupied much of his time, but he, nevertheless, managed to make observations and substantial collections of Aleutian birds (his special area of interest), fishes, and mammals and to record some interesting ethnological notes on the Aleuts of the western islands. Turner never maintained a station on Amchitka, but he apparently managed to spend the latter part of May and the early part of June 1881 on that island while he was en route from Attu to Unalaska via schooner.* While there he added considerably to his observations of the natural history of the islands. After Turner returned to the States, he worked up his Alaskan material for publication.

Turner (1886) devoted most of his report to the birds and fishes of Alaska, often supplementing the results of his own investigations with those of others in such a way that it is not always possible to identify the source of the information. Among the fishes he reports as occurring in the western Aleutian region are 11 species not listed from that area by Bean (1881).

Turner appears to have been the first investigator to publish an annotated list of the birds of Alaska. His listing includes over 50 species from the western Aleutian Islands. Over 20 of these species are specifically noted as having been observed on Amchitka. Turner also commented on the adverse effects of native foxes on the breeding populations of Aleutian Canada geese on those islands where foxes occur naturally. His observations thus appear to have anticipated the disappearance of breeding populations of geese from islands to which foxes were introduced in the 1920s.

Turner tried to make plant collections during his stay in the Aleutians, but his attempts were largely thwarted by the weather. He reports that, ". . . of all great difficulties the most troublesome was to preserve the plants after I had collected them. The constant moisture of the climate has frequently ruined my entire collection of a summer's work." Hultén (1960) notes that Turner left "medium sized collections" in the National Herbarium and Gray Herbarium. However, Hultén is critical of Turner's contribution to the knowledge of Aleutian flora. He points out that, since Turner was not a botanist, his observations regarding the distribution of plants in the Aleutians are not wholly reliable.

EVERMANN AND GOLDSBOROUGH

In 1903 a special commission appointed by the U. S. Commissioner of Fisheries carried out an

*Bean says of his listing: "The species named are almost wholly shore species, or such as are found in comparatively shallow water; the deep-water fishes of Alaska are still undiscovered. . . ."

*This can be inferred from references to Amchitka observations mentioned in his published report.

investigation of the salmon fisheries of Alaska and, in the course of the study, added considerably to knowledge of the fish fauna of the North Pacific Ocean and the Bering Sea. Evermann and Goldsborough (1907) incorporated this information into a new catalog of "The Fishes of Alaska."* The listing includes more than twice as many Alaskan species as Bean (1881) reported, but the authors rely to a considerable extent on the reports of Bean (1881) and Turner (1886) for data on the western Aleutian fauna. The catalog includes at least seven species from that area that are not in the earlier listings. These are attributed mainly to collections made during the cruises of the U. S. Fisheries vessel *Albatross* in the 1890s and during the salmon investigations of 1903.

CLARK

A. H. Clark of the U. S. National Museum participated in a long northern cruise of the U. S. Fisheries steamer *Albatross* in 1906. The cruise started from San Francisco, Calif., in April, proceeded north along the coast to the Alaskan peninsula, west through the Aleutian Islands, to the Okhotsk Sea, to Japan, to the Hawaiian Islands, and back to San Francisco in December. The *Albatross* passed close to Amchitka without stopping, but brief stops were made at Atka, Agattu, and Attu [see Gilbert and Burke (later in this chapter) for a reference to the fisheries results of the cruise].

Clark (1907) published an account of 18 new species and 1 new genus of birds from eastern Asia and the Aleutian Islands which included a new subspecies of *Lagopus ruprestris* (Rock Ptarmigan)† from Adak Island, presumably collected during the 1906 cruise of the *Albatross,* although this is not stated. Clark (1911) gives a complete listing of the birds collected or seen during the cruise. Of the 172 species and subspecies listed, 43 are noted as occurring in the western Aleutians (Atka, Agattu, Attu, Semichi, and Kiska are specifically mentioned). Most of them are birds associated with the pelagic and seashore habitats, and most are to be found among the species now known from Amchitka Island (see White, Williamson, and Emison, Chap. 11, this volume).

*The title is not entirely accurate; the 288 species listed include 22 species not found north of Dixon's Entrance. Technically these would not be considered Alaskan species.

†*Lagopus mutus* of current nomenclature (Murie, 1959).

GILBERT AND BURKE

The U. S. Fisheries vessel *Albatross* carried out exploratory fisheries investigations in the northwestern Pacific in the summer of 1906. Gilbert and Burke (1912) reported on the results of this cruise. They note:

> On the outward voyage the vessel passed the Aleutian chain, touching at Unalaska, Atka, Agattu, and Attu Islands . . . . Shore collecting was carried on in these localities, and some 37 hauls of intermediate net or dredge were made along the route, several of these hauls being highly successful. Rich ground, which would repay thorough investigation, was found on Petrel Bank (north and east of Semisopochnoi Island), [and] in the vicinity of Attu and Agattu Islands . . . .

These authors concluded that the *Albatross* reconnaissance produced no evidence of a sharply defined marine faunal break anywhere along the Aleutian chain or, in fact, between the Aleutian and Commander Islands. They did note differences between the marine fauna off Kamchatka vs. that around the Commander Islands, which they attribute to the barrier effect of the deep channel between the two areas.

Of the 123 species listed from the 1906 *Albatross* collections, 34 are described as new species (8 new genera are also recognized). Sixty of the species listed are noted as occurring in the western Aleutians if the Petrel Bank collections are included. Among these are 17 of the species described as new.

JOCHELSON

Russian scientific interest in the Aleutians did not terminate with the sale of Alaska to the United States in 1867. Russian scientists continued to inquire into possible geological, floristic, and faunistic relationships among the western Aleutians, the Commander Islands, the adjacent Siberian mainland (especially the Kamchatka peninsula) and the Kurile Islands. The origin and the prehistoric antecedents of the Aleuts also constituted a problem of great interest to the Russians, understandably so because they were the first Europeans to meet and observe the Aleutian aborigines.

The Kamchatka Expedition (sometimes referred to as the Aleut–Kamchatka Expedition) was initiated in 1907 by a Russian banker, F. P. Riaboushinsky, and was later carried out under the auspices of the Imperial Russian Geographical Society. The expedition included 20 scientific staff members and was organized under several divisions representing the disciplines of anthropology, botany, zoology, geology, and meteorology. The

anthropology* division, headed by Waldemar Jochelson, contributed most to our knowledge of the western Aleutians.

Jochelson and his wife, a medical doctor who assisted him in the field work, reached the Aleutians by way of New York, Washington, D. C., San Francisco, and Seattle. En route, official permits were obtained, supplies were purchased and packed for shipment, and Aleutian Island collections in the United States were studied. Transportation for Jochelson's party from Seattle to Unalaska, to various other Aleutian Islands, to the Pribilofs, and, finally to Kamchatka was provided by the Alaska Commercial Company, various U. S. Government agencies, and a Russian military transport. Jochelson and his party apparently had the wholehearted cooperation of almost everyone they encountered, but the uncertainties of travel arrangements and the exigencies of Aleutian weather hampered their field studies and extended the time they spent in the islands well beyond what they had originally scheduled.

Jochelson (1925) writes, ". . . according to the estimate of our original plans, only one year was to be devoted to the Aleut problem. Actually, the field-work in the Aleutians stretched over a period of 19 months,† while the journey from Petrograd to Unalaska and the preparatory work occupied 3 months more." He also reports: "In all, we excavated at 13 ancient village sites, investigated 57 pits of various size, 3 burial caves, and 3 other caves . . . . Of the 47 days devoted to excavation, only 8 were dry and calm; the remainder of the time we worked in rainy and stormy weather . . . ."

Jochelson apparently made no excavations on Amchitka, but he did work on Atka and on Attu, westernmost of the Aleutian Islands. He collected much ethnographic data and an extensive Aleut vocabulary, including Aleut terms for many of the important plants and animals which the natives used. He also recorded meteorological observations (maximum and minimum temperatures), and Hultén (1960) credits the expedition with making a small collection of plants, later deposited in Leningrad.

The full report of the findings of the Anthropological Division was published in 1925 under the auspices of the Carnegie Institution of Washington. Jochelson (1925) reports that the original manuscript, written in Russian, was ready for the printer in 1916. Publication was delayed by World War I and the Russian Revolution. Ultimately, Jochelson brought his manuscript to America, and, after making further comparative studies of Eskimo–Aleut collections in this country, he rewrote it in English. The history, ethnology, and physical anthropology of the Aleuts are discussed in Jochelson (1933).

In his 1925 report, Jochelson discusses at some length the conclusions reached earlier by Dall, who had excavated on some of the same western islands as Jochelson (Attu and Atka). In particular, he takes exception to Dall's division of Aleut culture history into three periods (Littoral, Fishing, and Hunting) and to Dall's contention that the first peoples reaching the islands possessed only a rudimentary culture, lacking fire, stone implements, and many other traits known to the Aleuts at first contact with Europeans.

On the other hand, Jochelson agrees fully with Dall on the important point that the Aleutians were peopled from the east, i.e., from the continent of North America. And, although he is cautious in attempting to fix a date for the first habitation of the islands, his judgment is not greatly different from that of Dall. Jochelson concludes: "All the foregoing considerations fail to give us a definite measure of time which could be expressed in figures; nevertheless they show clearly that the Aleut came to the islands many centuries ago . . . ." His ". . . many centuries . . ." can easily accommodate the 3000 years cited by Dall as a reasonable estimate for the time required to form the shell heaps he excavated.

BENT ET AL.

A. C. Bent, R. H. Beck, F. B. McKechnie, and A. Wetmore participated in a brief natural-history survey of some of the western Aleutian Islands in 1911, and Bent (1912) reported the observations of avifauna made during the expedition. Bent's paper indicates that the original plans called for chartering a special vessel and for spending ". . . the entire summer in making a thorough biological survey of the whole Aleutian chain . . . ." So much for plans; this scheme was subsequently abandoned, and the party finally accepted transportation aboard the U. S. Treasury Department revenue cutter *Tahoma*. Consequently the investigators settled for a greatly reduced field program; Bent (1912) writes, with obvious disappointment, ". . . we started (from Unalaska) on the western trip among the Aleutian Islands on June 10, with orders for the *Tahoma* to return to Unalaska on July 1. This gave us less than three weeks to explore over 800 miles of difficult islands, an undertaking for which three months would have

*Also sometimes referred to by Jochelson (1925) as the ethnological division.

†January 1909 to July 1910.

been hardly enough." The expedition members landed briefly on Atka, Adak, Tanaga, Kiska, and Attu but were unable to explore any of these islands thoroughly. Most of their efforts seem to have been concerned with observations of avifauna and collection of bird specimens. However, Hultén (1960) notes that Wetmore also made plant collections at Atka, Kiska, Attu, and Tanaga; these collections were later deposited in the U. S. National Herbarium.

Bent (1912) reports: "Good series of all the land birds were collected on nearly all of the islands visited; particularly fine series of the various subspecies of ptarmigan were taken, . . . among which a new subspecies was discovered inhabiting Tanaga Island, *Lagopus ruprestris sanfordi;** two species, hitherto unrecorded from North America, were collected, ..." Of the 62 species and subspecies listed by Bent, 35 are specifically identified with western islands.

TATEWAKI AND KOBAYASHI

The Japanese botanist Misao Tatewaki, accompanied by an assistant, visited the middle and western Aleutians briefly in the early summer of 1929, at which time they collected plants on Attu, Amchitka, and Atka. In 1931 Yoshio Kobayashi spent 3 months among the Aleutian and Commander Islands collecting on Attu, Amchitka, Atka, Umnak, Unalaska, and Bering Islands. Kobayashi's visit was made possible by the support of a Japanese newspaper company; it is a matter of some curiosity that such a company took an interest in the flora of the Aleutian Islands at that time.†

Tatewaki and Kobayashi (1934) jointly published the results of their botanical explorations in the islands. In addition to their catalog of the terrestrial plant species, they also attempted to characterize the plant associations of the islands, starting with the marine plants of the "Sublittoral Belt," which they define as being "a few metres in depth at the low tide." These authors identify several marine algal associations that have been recognized in more recent studies of the inshore marine flora of the islands and also note the common terrestrial associations. The catalog of Aleutian flora by Tatewaki and Kobayashi (1934), coupled with publications regarding special plant groups based on their collections (Akiyama, 1933; Satake, 1932; Okamura, 1933), constituted the most complete description of the plants of the Aleutian chain available before the publication of the monograph by Hultén (see below). Over 300 species of terrestrial plants are listed, and, of these, 106 were reported as having been collected on Amchitka, although not necessarily on that island alone.

HULTÉN AND EYERDAM

The first comprehensive treatise on the vascular flora of the Aleutians was published in 1937 by the Swedish botanist Eric Hultén. A revised and enlarged second edition of this work was published in 1960. In the preface to the first edition, Hultén explained why he felt it necessary to carry out his extensive collecting trip through the islands in 1932. In 1930, after publishing a work on the flora of Kamchatka, Hultén undertook a study of the phytogeography of the Bering Sea region. He soon concluded that the flora of the Aleutian Islands ". . . was so little known that practically nothing could be said with any certainty concerning the occurrence and distribution of the plants of the islands. This was particularly true of the western part of the chain . . . ."

Having recognized the need for more information on the Aleutian flora, Hultén set out to obtain it. He collected in the islands in the summer of 1932 in company with an American associate, W. J. Eyerdam. The expedition was supported financially by Swedish scientific groups, including the Swedish Academy of Science. Working out of Unalaska as a base, Hultén and Eyerdam made two collecting trips through the islands, one aboard a trading ship belonging to the Alaska Commercial Company and the other in the U. S. revenue cutter *Haida.*

Hultén (1960) gives a serial account of plant collections made in the Aleutians through 1951. His listing covers a period of over 170 years (1779 to 1951). For that period Hultén lists 27 instances of collections made in the western Aleutians, including his own. His samplings in the western islands were made at Atka, Adak, Rat, Attu, Alaid, Agattu, Kiska, Kanaga, and Amchitka Islands. Collections on Amchitka were made at two locations, ". . . one close to 'Square Bluff' of the marine chart, the other in the middle of the northern shore . . . ." At least 9 of the 27 western

*L. *mutus* in current nomenclature.

†An American official who saw Japanese at Amchitka and on other islands in the summer of 1931 conjectured much later that the visitors may have been spies, although their ostensible purpose was to maintain emergency caches of fuel and supplies in support of a "Tokyo–San Francisco Good Will Flight," the route of which was over the Aleutians (Dufresne, 1966). There is no indication as to whether the botanist Kobayashi was one of the three Japanese Dufresne saw at a distance in Constantine Harbor in 1931.

Aleutian collections mentioned in his serial list involve Amchitka.

In preparing the second edition of his work on Aleutian flora, Hultén not only used his own extensive collections but also had access to the holdings of the more important herbaria of the world, including several in the United States. Hultén presented a complete list of the vascular plants then known to occur in the Aleutians as well as his analysis of the phytogeography of the chain and the affinities of the island flora with those of the adjacent Asian and North American mainlands. Subsequent collections have shown that Hultén's list was not complete and that his assumptions regarding distribution of species among the islands were not always entirely correct. Shacklette et al. (1969), who made collections on Amchitka in 1966 to 1968, list 2 species of vascular plants previously unreported from the Aleutians and 47 species heretofore unreported from Amchitka. Shacklette et al. also list a number of lower plant species not previously reported from the islands.

In general, Hultén's conclusions regarding the major features of the Aleutian flora are still considered valid despite the subsequent accumulation of some new information regarding species distribution. He pointed out that the island flora, particularly that of the western section of the chain, has much stronger affinities with Kamchatkan flora than with that of the North American mainland. He also noted the depauperate character of the Aleutian flora and emphasized the relative instability of plant associations in the Aleutians as compared to their counterparts on Kamchatka.

The Hultén–Eyerdam expedition also produced one of the earliest published reports indicating the recovery of the once-threatened sea otter population in the western Aleutians. Eyerdam (1933) notes: "In July 1932, while engaged in botanical explorations on various islands of the Aleutian chain, I spent two weeks on Atka Island, and there learned that sea otters are becoming quite common in the Western Aleutians." Eyerdam went on to suggest that it would be desirable for ". . . our government to capture a couple of dozen pairs to transplant at the Pribilofs or at some favorable locality where they can be guaranteed full protection."

HUTCHISON

A British botanist, Isobel Wylie Hutchison, made a brief plant collecting tour through the Aleutians in the summer of 1936 while traveling aboard the U. S. Coast Guard cutter *Chelan*. In the western islands she collected at Atka, Amchitka, Kiska, and Attu. Her collections, which included about 50 species from Amchitka (Hutchison, 1942), were deposited in the British Museum. An account of her collecting experiences in the Aleutians and a list of the collections are given in Hutchison (1937).

MURIE ET AL.

The first coordinated biological study of the entire Aleutian chain was conducted by the U. S. Bureau of Biological Survey during three consecutive summers, 1936 to 1938. The 1936 expedition, led by Olaus J. Murie, included Cecil S. Williams, also of the Survey, and Homer W. Jewell and H. Douglas Gray of the Alaska Game Commission. The 1937 party, also headed by Murie, included Victor B. Scheffer and John B. Steenis of the Survey and, again, Douglas Gray. Scheffer headed the 1938 expedition, concentrating mainly on the nearshore marine life of the islands; information is lacking as to whether any other scientists accompanied him.

All three expeditions were carried out with the support of the M. V. *Brown Bear*,* which enabled the parties to make the most comprehensive biological reconnaissance of the islands thus far carried out. Murie (1959) says, "During these two seasons (1936–1937) we visited every Aleutian Island of any size, as well as many islands south of the Alaska Peninsula and several points on the Peninsula, ..." The three expeditions gave some attention to essentially every aspect of the biota of the islands. However, when the official report was ultimately published by the U. S. Fish and Wildlife Service (Murie, 1959), it was entitled "Fauna of the Aleutian Islands and Alaska Peninsula." Plant life got meager notice in the report, discussion being limited to two and a half pages on marine algae.† Hultén (1960) reports that plant collections were made by the *Brown Bear* scientists, and he presumably included the results of these in the second edition of his monograph on the Aleutian flora.

The objective of the *Brown Bear* expeditions was to obtain data needed by the Bureau of Biological Survey for management of the Aleutian Islands Reservation (later the Aleutian Islands

*The M. V. *Brown Bear* was later used to conduct the oceanographic surveys of the Chukchi Sea in 1959 and 1960 in connection with the AEC-supported study of the Cape Thompson Region (Wilimovsky and Wolfe, 1966).

†One marine vascular plant, eel grass (*Zostera* sp.), is mentioned as occurring near Umnak Island ". . . but was not seen farther west." (Scheffer in Murie, 1959).

National Wildlife Refuge).* As Murie writes in the 1959 report: "In 1920, the United States Bureau of Biological Survey was given the responsibility for enforcement of the Alaska fur laws and administration of the *blue-fox industry* (emphasis added) in the Aleutians. As time went on, it became apparent that proper supervision of this important wildlife refuge would necessitate an extensive inventory of the resources of these islands." It was the purpose of Murie and his colleagues to provide such an inventory.

I have not found a narrative account of the *Brown Bear* expeditions which would indicate just how much of the effort was devoted to the western Aleutians, but there is evidence that the westernmost islands were visited during each of the 3 years involved and that Amchitka Island received a considerable amount of attention.

1936

An unpublished "Report on Amchitka Island," provided from the files of the U. S. Fish and Wildlife Service, Anchorage, Alaska, dated Aug. 11, 1936, and written by H. W. Jewell and H. D. Gray, notes: "The dates of our visits to Amchitka Island are July 24 and August 1, 1936." A review of Murie (1959) reveals, from his comments on various species of avifauna, that the 1936 cruise included, in addition to Amchitka, at least the following other western islands: Adak, Kanaga, Kiska, and Attu. It seems reasonable to assume that some additional islands among the many from Atka westward were visited in 1936.

1937

Another unpublished report provided from the files of the U. S. Fish and Wildlife Service, Anchorage, Alaska, gives the itinerary of the *Brown Bear* party for the 1937 season. In brief, the ship provisioned at Unalaska in late May and then proceeded to Attu with stops at Umnak, Atka, and Kiska. Attu was reached on June 7, and from there the party worked eastward, stopping at some islands not visited in 1936. From July 4 to July 18, Murie was left on Amchitka and Steenis on Kanaga while the *Brown Bear* returned to Unalaska for supplies with Scheffer and Gray remaining aboard to continue their scientific duties. The cruise continued after Murie and Steenis were picked up, the Aleutian work ending in early September at Unimak. From there the party departed for Seattle.

*See Chaps. 6 and 20 of this volume for a history of the administrative permutations experienced by the Reservation or Refuge and changing concepts of management.

1938

Victor B. Scheffer, scientific leader of the 1938 cruise of the *Brown Bear,* contributed a section entitled "Invertebrates and Fishes Collected in the Aleutians, 1936–1938" to the report by Murie. Some inferences concerning the western islands visited during 1938 can be drawn from collection sites and dates given for fish specimens mentioned in his contribution. Scheffer (1959) cites examples of marine and anadromous fish collected at Attu (August 16), Kiska (August 19), and Amchitka (August 22). Apparently the expedition was making its way eastward from the end of the chain in mid-August, and many other western islands were probably visited during this final cruise.

The *Brown Bear* survey of the Aleutians accomplished a great deal, although it is unfortunate that so long a delay occurred before publication of the official report of the expeditions (Murie, 1959). In keeping with the stated purposes of the survey, field studies concentrated on birds and mammals. Voluminous, although unpublished, internal U. S. Fish and Wildlife Service (FWS) reports were made promptly to guide decisions for wildlife management of the many diverse islands of the Refuge; these appear to have served their purpose well.

Other aspects of the island biota were not wholly neglected. Extensive, although by no means exhaustive, collections were made of marine and terrestrial plants; marine, freshwater, and terrestrial invertebrates; and marine and freshwater fishes. The collections were made available to appropriate specialists in the scientific community and formed the basis for a number of separate publications in technical journals (see Bartsch and Rehder, 1939; Clark, 1939; Murie, 1940a, 1940b, 1945; Schultz, 1939).

The following section will show that the *Brown Bear* party of 1936 also made a contribution to the archaeological exploration of the Aleutians, although this endeavor was somewhat tangential to the main purposes of the survey.

HRDLIČKA

While the U. S. Bureau of Biological Survey was investigating the flora and fauna of the Aleutians, a small party from the Smithsonian Institution, led by the physical anthropologist Aleš Hrdlička, was digging into the question of prehistoric human occupation of the islands. Hrdlička's work in the Aleutians, which reached westward to include the Commander Island group, was a natural extension of his earlier studies on the Alaskan mainland and on Kodiak Island. Those

investigations were, in turn, stimulated by his belief (Hrdlička, 1930) that "Alaska and the opposite parts of Asia hold, in all probability, the key to the problem of the peopling of America."

Hrdlička's most extensive field study of the archaeology of mainland Alaska and a concurrent ethnological investigation of Alaskan Indians and Eskimos were carried out in the summer of 1926. His account of this work and the conclusions he reached are given in Hrdlička (1930). In that report he reached no definitive judgment regarding the role of the Aleutian Islands in the "peopling of America" or on the relationship of the Aleuts to other northwestern aborigines. What is somewhat surprising is that he suggests (in Fig. 29 of the 1930 report) the Kamchatka–Commander Islands–Aleutian Islands route as one of several potential pathways for "probable movements of people from northeastern Asia to Alaska . . . ." This suggestion is at variance with the conclusions of the earlier archaeological workers in the western islands, Dall and Jochelson; these investigators agreed that the Aleutian chain was occupied by peoples migrating from the east, not from the west.

Ten years after Hrdlička's 1926 anthropological survey of mainland Alaska, he turned his attention to a field study of the Aleutian and Commander Islands. At least as late as the start of the 1936 to 1938 series of expeditions, Hrdlička apparently still entertained the idea of a possible west-to-east human migration route from Asia via the Aleutians with the Commander Islands possibly a part of the pathway.

Hrdlička (1945) gives the most detailed account to that date of Aleutian anthropology as well as a wealth of detail on the early accounts of the Aleuts at time of contact as recorded by Russian and other observers. And, of interest in the present context, he provides a delightfully personal and graphic picture of the day-to-day problems and difficulties of conducting scientific work in the islands. His 1936 to 1938 expeditions were modest in size and almost Spartan in character. Hrdlička relied on volunteers, mainly college students, for help in the field; he worked alongside his assistants, sharing with them the labor and discomforts of excavation and cave exploration, and he relieved the tedium of evenings and periods of forced inaction by giving his student helpers formal lectures on such subjects as "Major Indian Remains and Mounds" and "Domestication of Animals in America." To his self-imposed duties as a scientific leader, laborer, and lecturer, Hrdlička added the further task of cooking for the party; his daily notes sometimes refer to the problems involved in this chore, given the limited range of supplies from which to construct his menus.

The Smithsonian Aleutian expeditions, like those of most earlier investigators, depended for logistic support on the help of the U. S. Government agencies (Coast Guard, Bureau of Biological Survey, and Coast and Geodetic Survey) and on the Alaska Commercial Company. Doubtless this kind of dependence determined to some extent where the expeditions were able to work. But a review of the daily logs for the three seasons indicates that the western islands, including Amchitka, were the scene of a considerable amount of the work.

1936

Hrdlička's party stopped briefly at Atka on July 6 (after spending some time at more easterly sites) and worked at Kiska and Little Kiska from July 7 to 27. On July 25 the Bureau of Biological Survey vessel *Brown Bear* arrived, providing a pleasant diversion that Hrdlička acknowledges in his notes:

> They [the *Brown Bear* party] take us out to the staunch, good, new, chubby ship, give us an excellent warm supper, and we spend the rest of the evening in their company. But that is not all. Dr. Murrie (sic) leads me to another part of the boat and there presents me with a sack full of skulls and bones, and another with a mummy, from the hot cave on Kagamil Island . . . . This is the first tangible news both as to the location of the cave and its contents, and I am deeply grateful.

1937

The party reached Adak on July 5. The period July 7 to 15 was spent in what proved to be an unproductive visit to the Commander Islands. At Bering Island, Hrdlička encountered so much red-tape obstruction on the part of the Russian administrator that the attempt to do any field work on these islands was given up. The party then returned to Attu, westernmost of the Aleutian Islands, and from July 16 to August 17 divided its efforts among Attu, Agattu, and several islands in the western part of the Andreanof group.

1938

This season's schedule finally enabled Hrdlička to excavate on Amchitka, which he considered to be a site of considerable importance to an understanding of Aleutian prehistory. That year work in the western islands began at Kanaga on June 9. Amchitka was reached on June 12, and Hrdlička notes that three members of the party moved into ". . . a little house just put up there by the Bureau of Fisheries." Others occupied a "native hut." The expedition remained on Amchitka until July 5 and excavated in two sites near the head of Constantine

Harbor (probably Sites 2 and 3 of Desautels et al., 1970). Preparing to leave Amchitka to make another attempt at working in the Commander Islands, Hrdlička noted in his diary: ". . . will leave with regrets—would have liked to stay here much longer."

This time the visit to the Commander Islands, though brief, accomplished its purpose.* Hrdlička concludes, in summarizing the results of this reconnaissance: "One point alone is now definitely established—*the Commander Islands were not a stepping stone in the peopling of America . . . .*"

One important conclusion Hrdlička reached, on the basis of his three seasons' work in the Aleutians, was that two distinct peoples, of different physical type and with minor cultural differences as well, occupied the islands in sequence. He refers to the older as "pre-Aleut" and the later as "Aleut," distinguishing them mainly on grounds of differences in cephalic index. He believed that some of the earlier pre-Aleuts survived to historic times and also that there had been some mixing of pre-Aleut and Aleut stocks.

Hrdlička (1945) was critical of the conclusions reached earlier by Dall (1877a) and Jochelson (1925) not only because they had failed to recognize what he believed to be a fact (the existence of two distinct prehistoric human populations on the island) but also because they had postulated a somewhat longer human occupation of the Aleutians than Hrdlička considered demonstrable. He concluded that the oldest deposits could all ". . . fit well within the Christian era." He offers no final judgment regarding the important question as to whether the Aleutian Islands were peopled by migration from the North American mainland or directly from Asia or the Kurile Islands by peoples moving in a west-to-east direction. The nearest he gets to this point is his definite exclusion of the Commander Islands as a possible stopping point along a west-to-east migration route.

Later investigators, including Laughlin† (1951) and Spaulding (1953), question the validity of much of Hrdlička's analysis of Aleutian prehistory, chiefly on the grounds that he ignored the implications of stratigraphic sequence in his excavations and that he allowed preconceived theoretical notions to overshadow empirical evidence. Nevertheless, his pre-Aleut/Aleut categories persist, in somewhat altered form, in the Paleo-Aleut/Neo-Aleut distinctions recognized by modern anthropologists.

GABRIELSON

During the summer of 1940, Ira N. Gabrielson, then Director of the U. S. Fish and Wildlife Service, traveled through the Aleutians aboard the *Brown Bear* and made extensive ornithological collections. He notes in *The Birds of Alaska* (Gabrielson and Lincoln, 1959) that Amchitka was one of the islands visited on the 1940 cruise. Murie (1944) published a new subspecies of Rock Ptarmigan (*Lagopus mutus gabrielsoni*) which was based on specimens collected by Gabrielson at Amchitka in June 1940.

GUGGENHEIM

The first systematic attempt to identify and map the archaeological sites on Amchitka Island (primarily the shell heaps or middens associated with prehistoric settlements) was made by Paul Guggenheim while he was stationed on the island during World War II. Guggenheim, a medical doctor rather than a professional archaeologist, nevertheless had special qualifications for undertaking this task. As a college student he had been a member of Hrdlička's 1937 expedition and he had retained a keen interest in Aleutian prehistory. More important, from his experience with Hrdlička, he recognized the significance of the information contained in the middens.

Guggenheim (1945) describes his largely unsuccessful attempts to discourage promiscuous and destructive artifact hunting during his 10-month tour of duty on the island (May 1, 1943, to Mar. 6, 1944). Looting of the shell mounds was indulged in alike by officers, enlisted men, and civilians during the military occupation of Amchitka despite Guggenheim's efforts to prevent this. He reports that the military command made some attempts to prevent indiscriminate digging, but these seem not to have been a very effective deterrent. His suggestions that the military occupation be used as an opportunity to support professional archaeological investigations were never taken up.

According to Guggenheim, his own collections, some obtained by digging and some by purchase or as gifts from others, eventually ". . . found their way into the Smithsonian. . ."; their scientific value is questionable because of the methods under

*Hrdlička also reports that an interesting side trip was made to a Russian biological station on Copper Island. Alan G. May, one of his assistants, later published a more complete account of this station: ". . . the only Sea Otter Experimental Station in the world." (May 1943.) Captive sea otters were being maintained in both saltwater and freshwater and were reportedly breeding in captivity.

†W. S. Laughlin was a student member of Hrdlička's 1938 field party.

which they were obtained (see McCartney, Chap. 5, this volume). His contribution to Aleutian archaeology lies in the site inventory he made for Amchitka Island. Although this inventory was not complete, it showed that the island is remarkably rich in identifiable prehistoric sites. Guggenheim showed the location of 49 sites (40 certain and 9 probable) distributed more or less uniformly around the shoreline and on offshore islets. This represents nearly two-thirds of the sites identified in the intensive surveys conducted during recent AEC operations on Amchitka and reported by Desautels et al. (1970). Undoubtedly the reconnaissance and mapping done and reported by Guggenheim facilitated the recent surveys. So, despite the damages sustained by archaeological remains on Amchitka during World War II, some benefits also accrued owing to the fact that one member of the occupying force had earlier been exposed to the influence of Aleš Hrdlička.

SUTTON AND WILSON

Occupation of Attu Island by U. S. military forces during the last years of World War II afforded an opportunity for two American scientists stationed on the island, G. M. Sutton and R. S. Wilson, to make field observations of the avifauna of Attu. Sutton and Wilson (1946) published an annotated list of the winter birds which was based on observations made during the period Feb. 20 to Mar. 18, 1945. Wilson (1948) lists the birds he saw on Attu during the summer of 1945.

The two papers enumerate a total of 35 species: 10 seen only during summer, 11 seen only during winter, and 14 present during both seasons. The lists are, of course, not definitive since the observers were not able to spend much time in the field or to travel over the entire island. With two exceptions all the species listed are included in the latest listing of the birds of Amchitka Island (White et al., Chap. 11, this volume). Sutton and Wilson report sightings of the Gray Sea Eagle and the Herring Gull, but Murie (1959) expresses doubt about the validity of the Gray Sea Eagle sighting. No specimens of either species were collected.

UNITED STATES GEOLOGICAL SURVEY (USGS)

The geology of the western Aleutians was little investigated until relatively recent times. Capps (1934), reporting on his visit to a few of the islands in 1932, cites only four published references, and these appear to deal mainly with the eastern islands and the Alaskan peninsula. Capps, a USGS geologist, accompanied a U. S. Navy hydrographic reconnaissance made aboard the U.S.S. *Gannett.* He was able to go ashore briefly at Adak, Atka, Kiska, and Attu. His report provides only a preliminary overview of the geology of these islands.

The USGS began a detailed study of the Aleutians in 1946, initially focusing attention on volcanoes that were considered possible threats to U. S. military installations. The genesis of this study, the field portion of which continued through 1952, is described by Kennedy and Waldron (1955): "In October 1945 the War Department (now Department of the Army) requested the Geological Survey to undertake a program of volcano investigations in the Aleutian Islands—Alaska Peninsula area. The first field studies, under general direction of G. D. Robinson, were begun as soon as the weather permitted in the spring of 1946." This reference also mentions the existence of an unpublished USGS report that is based on ". . . a reconnaissance investigation of the Alaska Peninsula and the Aleutian Islands" made by T. A. Jaggar in 1927.

Field support for the investigations was provided by various branches of the U. S. military forces. In addition, the Geological Survey motor ship *Eider* was used as a base for some of the field operations.

Results of the 1946 to 1952 field studies were published in *Investigations of Alaskan Volcanoes,* U. S. Geological Survey, Bulletin 1028, Parts A—U, and in a number of journal papers. A review of Bulletin 1028 shows that much of the study was devoted to the western Aleutians; the relevant parts of this Bulletin are tabulated in Table 1.

No attempt has been made to identify and list the various other papers that are based on these USGS investigations and published in the technical literature.

PEABODY MUSEUM, HARVARD UNIVERSITY EXPEDITION

An anthropological study in the Aleutians was carried out in 1948 and 1949 under the auspices of the Peabody Museum, Harvard University. Laughlin (1951), writing on Alaskan prehistory and ethnology, refers briefly to the expedition, crediting support for it to the Viking Fund, Inc., and the Office of Naval Research. Details regarding the field investigations have not been found; so how much effort was devoted to the western islands is not clear.

Laughlin, in the reference noted, gives a short résumé of the earlier archaeological and ethnological investigations in the Aleutians, with special

Table 1—Parts of USGS Bulletin 1028 Devoted to Western Aleutians

Subject	Part (Bulletin 1028)	Author and date
Great Sitkin Island	B	Simons and Mathewson (1955)
Northern Adak Island	C	Coats (1956a)
Kanaga Island	D	Coats (1956b)
Some western islands	E	Coats (1956c)
Ocean floor, northeast Rat Islands	G	Snyder (1957)
Little Sitkin Island	H	Snyder (1959)
Delarof and West Andreanof Islands	I	Fraser and Barnett (1959)
Gareloi Island	J	Coats (1959a)
Segula, Davidof, and Khvostof Islands	K	Nelson (1959)
Adak and Kagalaska Islands	M	Fraser and Snyder (1959)
Semisopochnoi Island	O	Coats (1959b)
Amchitka Island	P	Powers, Coats, and Nelson (1960)
Rat Island	Q	Lewis, Nelson, and Powers (1960)
Kiska Island	R	Coats, Nelson, Lewis, and Powers (1961)
Near Islands	U	Gates, Powers, and Wilcox (1971)

emphasis on skeletal remains recovered by Hrdlička and Jochelson. New data are presented on anthropometry and distribution of blood groups among present-day Aleut populations. These, together with linguistic and cultural features, are used as the basis for elucidating relationships between the Aleuts inhabiting the eastern and western parts of the chain and between Aleuts and other Eskimo peoples.

In this paper Laughlin retains the Pre-Aleut and Aleut terminology recognized by Hrdlička. In later papers he and other anthropologists have substituted the terms Paleo- and Neo-Aleut to distinguish the two somewhat different aboriginal stocks that peopled the Aleutians (Spaulding, 1953; Laughlin, 1963).

UNIVERSITY OF MICHIGAN EXPEDITIONS

Ethnobotanical and archaeological studies in the Aleutian Islands, under the auspices of the University of Michigan, were started in 1948. These field investigations were continued for several years thereafter with support from the Office of Naval Research and the Michigan Memorial Phoenix Project. T. P. Bank II, of the University of Michigan, Department of Botany, initiated the field work and was the author of most of the publications resulting from the project.

In a popular account of the first summer season in the islands, Bank (1956) lists the objectives of the expedition: (1) to "make a complete collection of plants"; (2) ". . . to explore and map the least known of the islands"; (3) ". . . to visit the few scattered villages where Aleuts were still living and to record their fast-disappearing native customs, especially those pertaining to old uses of plants for foods, medicines, and poisons"; and (4) ". . . to compile a manual of useful plants and animals in the Aleutians." The field party during the first season was a modest one: Bank, then a graduate student, and one assistant. They got as far west as Atka, traveling by military ships and aircraft, made plant collections, explored some archaeological sites, and established working relations with Aleut informants.

I have found no comprehensive description of the studies carried out by the University of Michigan expeditions and no evidence that any of the four stated objectives was fully realized. However, in a paper submitted for publication in 1952, Bank (1953a) reported: "In all, four trips have been made to the Aleutians, during which more than 20 islands were visited." In a footnote to this paper, Bank is identified as "Field Director,

University of Michigan Expeditions to the Aleutian Islands, 1948-52," from which it can be inferred that the investigations extended at least over the 5-year period indicated.

Bank (1952) gives a generalized view of the plant communities associated with the topographic features of the two main island types represented in the Aleutians: "mountainous" and "plateau" islands. He also (Bank 1952, 1953a) notes the importance of drainage as a determinant of plant-community type and calls attention to the inherent instability of plant communities in the islands: "The ecological concept of succession is hard to apply to communities which continue to fluctuate in an unstable way so that a so-called climax grouping today may be shown later to have been only temporary." Ethnobotanical findings of the expeditions are given in Bank (1953b, 1953c), which discuss the uses made of plants by the Aleuts and the vegetational cover associated with ancient Aleut village sites.

Spaulding (1962) reported the results of the principal archaeological investigation carried out by the Michigan group in 1949, i.e., excavations in two prehistoric dwelling sites on Agattu Island* near the western end of the chain. An important outcome of this work was the recovery of wood and charcoal samples suitable for radiocarbon dating from the refuse mounds. Charcoal from an intermediate depth in one of the excavations was assigned an age of 1300 ± 150 years. The average age of two wood samples from near the base of the same mound was estimated as 2565 ± 300 years. These findings suggest that the prehistoric peoples reached the western islands at an early time, supporting Dall's estimate made three-quarters of a century earlier.

UNITED STATES FISH AND WILDLIFE SERVICE (FWS)

As World War II ended and military control of the Aleutians was relaxed, the FWS undertook field investigations in some of the islands comprising the Aleutian Islands National Wildlife Refuge. Two subjects, sea otters and birds, received special attention, with principal stress being placed on the former. This emphasis was a natural one.

On the basis of a number of observations, it was known that the once-decimated Aleutian sea otter population had grown to sizeable proportions, especially around some of the western islands, under the protection initiated in 1911 (Abegglen, Chap. 20, this volume). There was an acute need for more information on sea otter distribution and biology to guide management of the resource. It was also recognized that the Aleutians are an important breeding ground for waterfowl, although fox farming, established earlier on many of the islands, was hardly compatible with successful use of the habitat by nesting birds.

Amchitka Island was a logical choice as a field laboratory for sea otter and avifaunal studies. It had a large sea otter population and was potentially a good breeding habitat for waterfowl. The island had additional advantages as a site for field work: an airstrip, a harbor, and a system of roadways developed by the military.

Between 1949 and 1952, R. D. Jones, Refuge Manager, collected carcasses of a number of dead or moribund sea otters on Amchitka beaches and submitted them to pathologists at the Arctic Public Health Center (then in Anchorage, Alaska) for examination. Rausch and Locker (1951) and Rausch (1953) reported the results of their parasitological studies of these animals. Several internal parasites, at least two of which are pathogenic, were isolated; some parasites were found in most carcasses examined. However, the investigators could not implicate the parasites as a major cause of sea otter mortality at Amchitka. Rausch (1953) hinted that a too high sea otter population density may have been a contributing factor and recommended efforts to redistribute (transplant) sea otters from Amchitka to other suitable habitats.

Early transplant attempts were unsuccessful; captive animals died before they could be removed from the island from causes that were not readily apparent. In 1954 a study of the physiological reactions of captive otters was carried out at Amchitka by investigators from Purdue University assisted by FWS personnel and supported by FWS funding. The results of this study were reported by Kirkpatrick, Stullken, and Jones (1955) and Stullken and Kirkpatrick (1955). The conclusion was that captive sea otters generally died from the combined effects of inadequate (too infrequent) feeding and environmental stress. Some progress was made in maintaining animals in captivity for long periods, but the problems involved in transplanting were not entirely solved.

One FWS staff member who collaborated with the Purdue investigators was Calvin J. Lensink, who went on to conduct an intensive study of the status and distribution of the sea otter in Alaska. The findings of this investigation, reported by Lensink (1960, 1962), established the fact that northern sea otter stocks, nearly wiped out before 1911, had increased substantially after protection

*Aleš Hrdlička excavated sites on Agattu in 1937 but at a location several miles from the Krugloi Point sites where the Michigan party worked.

was imposed. Lensink also found that a large proportion of the Alaska sea otter population was concentrated around some of the western Aleutians; Amchitka was estimated to have the largest sea otter population of any island in the chain.

In 1955, Karl W. Kenyon, FWS Wildlife Biologist, began a study of sea otter biology that continued, in the field and in the laboratory, for over a decade. Much of his research was done in the western Aleutians and especially at Amchitka. The work culminated in the publication of a monograph covering essentially every aspect of the biology and natural history of the sea otter (Kenyon, 1969). It was largely through Kenyon's observations and experiments that the problem of captive mortality was solved, making it feasible to successfully transport animals to suitable habitats hundreds of miles from the point of capture. Sea otters have since been reintroduced into areas from which they had earlier been eliminated (Abegglen, Chap. 20, this volume).

Other facets of natural history were not neglected during the FWS sea otter investigations. Krog (1953) reported his observations on birds of Amchitka made during his visit to the island in 1952 in connection with sea otter parasitology studies. He includes a section on food habits of the Bald Eagle, noting evidence of eagle predation on young otters. Kenyon (1961) published an annotated list of the birds of Amchitka Island, a list totaling 69 species. He gives a brief history of the FWS program to exterminate foxes and rats and speculates on the probable adverse effects of these predators on avian populations.

The report by Kenyon and Rice (1961) on the abundance and distribution of the Steller sea lion is based mainly on surveys made in 1959 and 1960. A large proportion of the total estimated population was in the western Aleutians; a total of 1750 animals was estimated for Amchitka. Kenyon (1965) also reported on the food habits of harbor seals at Amchitka.

Other investigations of various aspects of the Amchitka ecosystem have been made in recent years by FWS personnel. For the most part, the results of these studies are unpublished and are available only in FWS files.

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION

After the Alaskan salmon fisheries study of 1903 (see the catalog of Alaskan fishes by Evermann and Goldsborough, 1907) and the Aleutian cruise of the *Albatross* in 1906 (Gilbert and Burke, 1912), there seems to have been a long period of relative inactivity in oceanographic and fisheries research in the western Aleutian region by American investigators. Some information was accumulating on the oceanographic features and commercial fisheries potential of the area, but there was no attempt at organized exploration until the second half of the twentieth century. The state of knowledge of oceanography of the North Pacific and Bering Sea and the sources of information were reviewed by Fleming (1955) and Dodimead, Favorite, and Hirano (1963). These reviews were published as Bulletins 2 and 13, respectively, of the International North Pacific Fisheries Commission (INPFC).

The INPFC was established in 1953 by an International Convention entered into by Canada, Japan, and the United States. Since the inception of the Commission, it has been the chief coordinating agency and the principal source of support for oceanographic and fisheries research in the seas around the Aleutian chain. The main focus of INPFC research is on conservation of commercial fisheries resources (principally Pacific salmon) and on allocation of rights to these resources among the participating nations. However, much basic information on the marine biota and the oceanography of the region derives from INPFC activities. The scope of INPFC research in the oceans adjacent to the western Aleutians between 1955 and 1960 is shown in Manzer et al. (1965, Figs. A-1 to A-6). These figures plot the location of stations occupied by INPFC research vessels during each year of the 6-year period; Japanese or American vessels, or both, occupied stations in the western Aleutian Islands during at least part of every year of the period covered. Many stations were well offshore, reflecting the objectives of the cruises, but a number were located near the chain, particularly in the vicinity of major passes between the North Pacific Ocean and the Bering Sea. Results of INPFC research are presented in annual reports, a bulletin series, and in various technical journals and government publications (Canadian, Japanese, and American).

WILIMOVSKY

The first systematic effort to investigate the inshore fish fauna of the Aleutians was made by Wilimovsky and his associates as part of a regional ichthyological inventory. Wilimovsky (1964) reports: "The purpose of this phase of the study was to conduct an ichthyological reconnaissance of the heretofore little known inshore fauna of the Aleutian Islands. Field investigations extended over a three-year period and were supplemented by limited material presently extant in museum collections." It is significant that, in his brief review of

previous investigations, Wilimovsky refers exclusively to early collections, e.g., those reported by Bean, Turner, and Evermann and Goldsborough. He also notes that "Recent Russian general works . . . make no major increase in the knowledge of the area."

Wilimovsky lists 135 inshore fish species* from the Aleutian Chain. Of these, about two-thirds of the species were found to occur in the western islands and about one-third were found at Amchitka. He emphasizes the reconnaissance nature of the study, the implication being that a more intensive investigation would probably add to the inventory. More important, he points out that "The really diverse and rich fauna is to be found in the immediate sub-tidal zone. We hardly know the composition of this stratum at a single location and future efforts should be concentrated on this belt." Simenstad et al. (Chap. 19, this volume) show that the recent Amchitka investigations did, in fact, provide an opportunity for more intensive sampling of the fish fauna in deeper waters around the island.

Wilimovsky concludes, on the basis of his extensive collections, that "After eliminating species occurring throughout the North Pacific basin, the remaining Aleutian Island fish fauna shows a closer relation to the American continent than to boreal Asia." He also notes the high proportion of Cottidae in the fauna and the existence of several endemic cottid forms that ". . . range from the mid-Aleutians westward to the Komandorskis."

RUSSIAN INVESTIGATIONS

Russian scientists made important contributions to knowledge of marine biology and oceanography of the North Pacific basin during the period covered by this chapter. Studies made in the vicinity of the Commander Islands are of special interest to us since these islands are, geographically, an extension of the Aleutian chain (O'Clair, Chap. 18, this volume). This review does not do justice to the Russian contributions, however, since I have had access to only a few translated references; much of the important Russian-language source material has not been translated into English.

The *Atlas of the Invertebrates of the Far Eastern Seas of the USSR* (Pavlovskii, 1955) cites 80 Russian works, published between 1878 and 1953, as ". . . the main general references on the Far Eastern seas." Many more specialized reports dealing with particular classes of invertebrates are cited in other sections of the Atlas. Few of these numerous references are available in English translation.

Finally, mention should be made of the Bering Sea Comprehensive Scientific–Commercial Expedition of the Soviet institutes TINRO* and VNIRO†, more commonly referred to simply as the Bering Sea Expedition, which initiated a series of oceanographic cruises in the Bering Sea and North Pacific Ocean in 1958. The purposes of the expedition are best set forth by Moiseev (1964):

> Thus, the vast potential of the northeastern Pacific Ocean remained untapped, especially with respect to benthic and demersal items . . . . At the same time, catches of most stocks of flatfish, herring, crabs, and other items had reached their limit due to natural population fluctuations (sic), and fishing even had to be reduced because of the depressed condition of these staple stocks of Far Eastern fishery.
>
> The Bering Sea Expedition therefore had the problem of discovering new fertile fishing grounds for the Far Eastern trawling fleets, highly experienced and well equipped for this type of fishing.

This statement, by one of the architects of the expedition, suggests that the principal objective was the discovery of commercially exploitable fishery stocks, especially those susceptible to harvesting by Soviet trawlers. Studies of oceanography and marine biology were focused mainly on features that had a direct bearing on the fishery. Most cruises worked primarily in the eastern Bering Sea or in the Alaska Gulf, although one 1960 cruise followed the Commander Islands–Aleutian Islands arc, making several crossings between the Bering Sea and the Pacific Ocean (one such crossing was apparently through Amchitka Pass). Indirectly, the expedition has added significantly to knowledge on a regional level of such features as oceanic circulation; physical, chemical, and biological properties of the major water masses; and the biology of commercially important marine fauna.

SUMMARY

From the foregoing it is clear that Amchitka was by no means a *terra incognita* at the start of the investigations reported in this volume. Every aspect of the natural history of the western Aleutians had already been studied to some extent. Amchitka, one of the larger and more accessible islands in that part of the chain, had not been slighted by previous investigators. There were still

*Mostly intertidal, as indicated by the discussion of collection techniques.

*Pacific Ocean Scientific Research Institute of Fishery and Oceanography, U.S.S.R.

†All-Union State Research Institute of Marine Fisheries and Oceanography, U.S.S.R.

important gaps in the knowledge of Amchitka ecosystems when plans for the AEC-supported bioenvironmental program were being formulated in 1967, but the earlier work discussed in this chapter provided a valuable base for the studies reported in subsequent chapters.

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