PUGET SOUND AND APPROACHES

A Literature Survey

VOLUME II

Geology	*Geomagnetism*
Volcanology	*Geodesy*
Seismology	*Hydrography*

University of Washington Department of Oceanography

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SEATTLE 5, WASHINGTON

PUGET SOUND AND APPROACHES
A LITERATURE SURVEY

Volume II

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FOREWORD

The Literature Survey of Puget Sound and Approaches has been completed by the Department of Oceanography of the University of Washington as authorized by the Office of Naval Research Contract Nonr-447(00), Task Order 477(06). Under the terms of this contract the Department of Oceanography has provided a listing and analysis of all published and unpublished literature pertaining to the oceanography and factors influencing the oceanography of Puget Sound.

To effectively accomplish general oceanographic research in an area in which outside influences of every type play an important or undetermined role, every possible factor must be taken into consideration. For this reason all of the factors that may influence the oceanography of Puget Sound have been included. The form of the paper is essentially that of an abstract of the current knowledge on each subject. Appended to each subject is a detailed, annotated bibliography of all relevant publications and unpublished reports and data, whether used in the abstract or not. If no information is available on a certain subject this has been mentioned in order to present the status of our knowledge to date.

PUGET SOUND AND APPROACHES
A LITERATURE SURVEY

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SECTION 4: GEOLOGY

17 April 1953

GEOLOGY

REGIONAL GEOLOGIC STUDY

PHYSIOGRAPHY

The Cascade Mountains have a general elevation of about 6,000 feet, with peaks rising to elevations of 8,000 to 10,000 feet. Mount Rainier, which is about 70 miles southeast of Seattle, rises to 14,408 feet. The mountain range is broken by winding passes whose elevations range from 3,300 feet to nearly 5,000 feet.

The Olympic Mountains, which occupy the Olympic Peninsula west of Puget Sound, rise to elevations of more than 7,000 feet, culminating in Mount Olympus which reaches a height of 7,954 feet. Elevations in excess of 4,000 feet cover an arc of 60° of the horizon west of Seattle.

The Cascade Mountains, with westward spurs, the mountains of Vancouver Island, and the Olympic Mountains surround Puget Sound leaving gaps only by the Strait of Juan de Fuca, and Tenino Pass to the southwest (Fig. 1-3).

The topography of the Puget Sound Basin is due primarily to glacial action. The glacier was a lobe of the Cordilleran ice sheet which moved southward over the region. The glacial debris was deposited on a sloping bedrock floor which rises to the south. The southern limit of ice deposition, which varies about 10 to 15 miles south of Puget Sound, marks the southern boundary of the Puget Sound Basin. This southern border is a morainic belt which varies in altitude from 150 to more than 1,400 feet above sea level.

Northward from the morainic belt the general level descends toward Puget Sound. Hills rise above the plain, and in some places, as around Seattle, they form areas of rolling country. Numerous lakes and swamps are found on the plain. In many places the substratum consists of outwash gravels. The gravel, which is widespread south of Tacoma, is almost free of clay and forms barren prairies which locally are too porous to permit the formation of streams. In the areas where clay is present within the gravel, water is retained and dense forests are found.

In some areas, pre-glacial rock hills rise above the level of the glacial deposits. Squak Mountain, southeast of Seattle, and the Blue Hills, between Puget Sound and Hood Canal, are examples of such hills. The main area of such pre-glacial rock hills is found in a broad belt extending southeast from Vancouver Island to the Cascade Mountains and includes the San Juan Islands and the spurs of the Cascades in the vicinity of Mount Vernon. See Fig. 4-1 for locations.

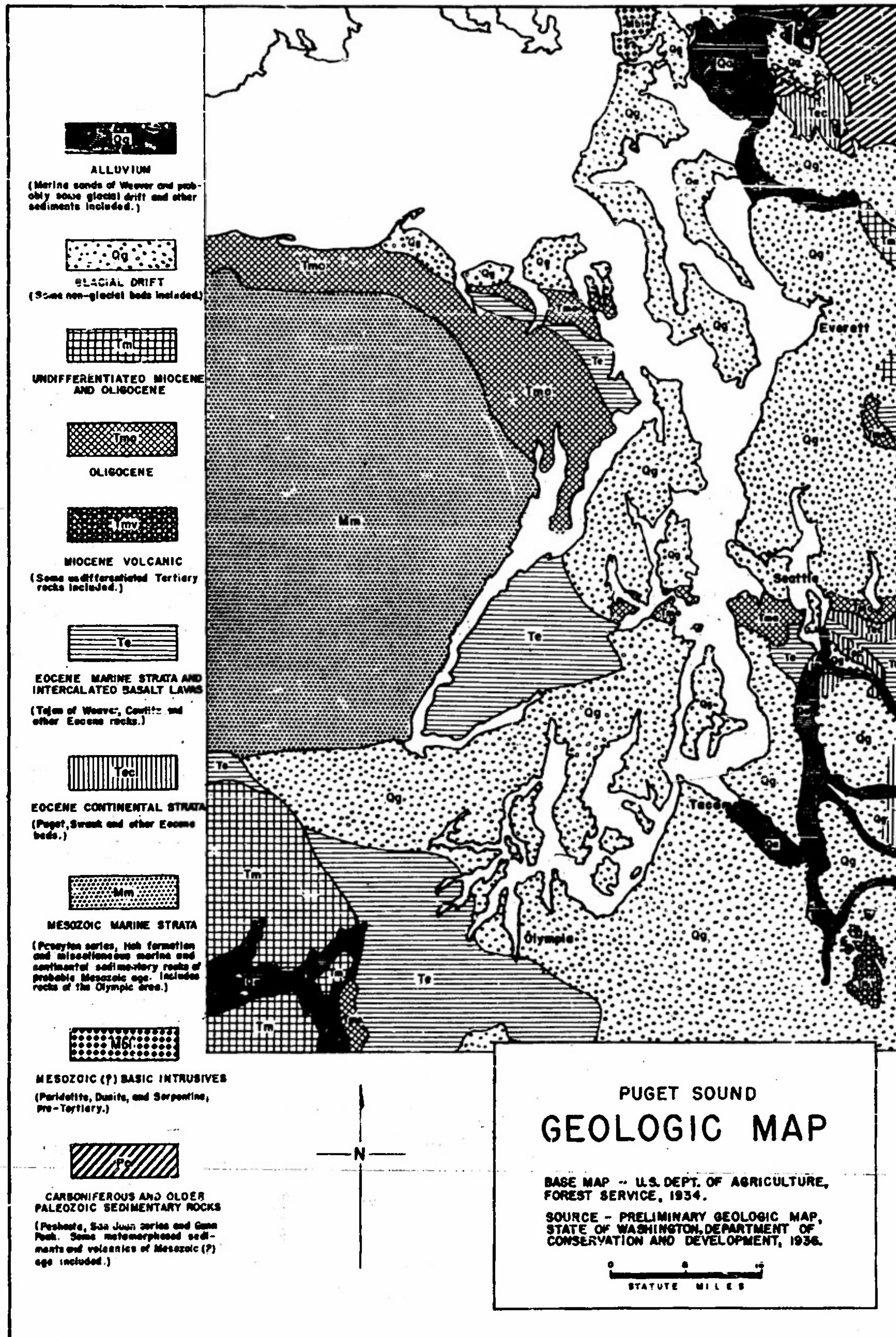

Qa
ALLUVIUM
(Marine sands of Weaver and probably some glacial drift and other sediments included.)
Qg
GLACIAL DRIFT
(Some non-glacial beds included)
Tm
UNDIFFERENTIATED MIOCENE AND OLIGOCENE
Tmo
OLIGOCENE
Tmv
MIOCENE VOLCANIC
(Some undifferentiated Tertiary rocks included.)
Te
EOCENE MARINE STRATA AND INTERCALATED BASALT LAVAS
(Tejon of Weaver, Cowlitz and other Eocene rocks.)
Tec
EOCENE CONTINENTAL STRATA
(Puget, Swauk and other Eocene beds.)
Mm
MESOZOIC MARINE STRATA
(series, Hoh formation and miscellaneous marine and continental sedimentary rocks of probable Mesozoic age. Includes rocks of the Olympic area.)
Mbi
MESOZOIC (?) BASIC INTRUSIVES
(Peridotite, Dunite, and Serpentine, Pre-Tertiary.)
Pc
CARBONIFEROUS AND OLDER PALEOZOIC SEDIMENTARY ROCKS
(San Juan series and Some metamorphosed sediments and volcanics of Mesozoic (?) age included.)
Everett
Seattle
Tacoma
Olympia
N
PUGET SOUND
GEOLOGIC MAP
BASE MAP -- U.S. DEPT. OF AGRICULTURE, FOREST SERVICE, 1934.
SOURCE - PRELIMINARY GEOLOGIC MAP, STATE OF WASHINGTON, DEPARTMENT OF CONSERVATION AND DEVELOPMENT, 1936.
STATUTE MILES

Fig. 4-1

Puget Sound is a partially drowned, glacially modified, drainage system. The northern portion of the system is the Strait of Juan de Fuca and the southern portion branches into the various inlets or "canals." The troughs are very steep sided below water level with the general elevation of the floor about 600 feet below sea level and they have a maximum depth of about 900 feet (see section on Hydrography). The stream valleys which enter Puget Sound are the filled portions of the inlets or canals. Other troughs are filled with fresh water forming lakes, such as Lake Washington and Lake Sammamish, east of Seattle. See Fig. 4-2 for profiles across Puget Sound Basin.

Fragmentary terraces ranging in altitude from 20 to 100 feet above sea level are found in many places around the shore of Puget Sound. The physiography of the Puget Sound area has been described by Fenneman (Fenneman 1931).

STRATIGRAPHY

Pre-Tertiary Stratigraphy

Rocks older than the Tertiary are not exposed in the Puget Sound area south of the San Juan Islands. Since the pre-Tertiary rocks form the basement upon which the Tertiary and later rocks have been deposited, they are described here.

The pre-Tertiary rocks are exposed on Vancouver Island and on the San Juan Islands. The geology of the San Juan Islands has been studied in detail by McLellan (McLellan 1927). A summary of his descriptions of the pre-Tertiary rocks is found in Table 4-1.

Tertiary Stratigraphy

The Tertiary stratigraphy of the area has been described by Weaver (Weaver 1937). The Tertiary stratigraphy has been summarized in Table 4-2. See also Bailey Willis, "Some Coal Fields of Puget Sound," (Willis 1898b).

Pleistocene Stratigraphy

The entire area of Puget Sound south of the Strait of Juan de Fuca is covered with Pleistocene deposits, except for small areas at Restoration Point on Bainbridge Island, Alki Point in Seattle, the region around Bremerton Inlet, and the summits of the pre-glacial rock hills such as Squak Mountain and the Blue Hills.

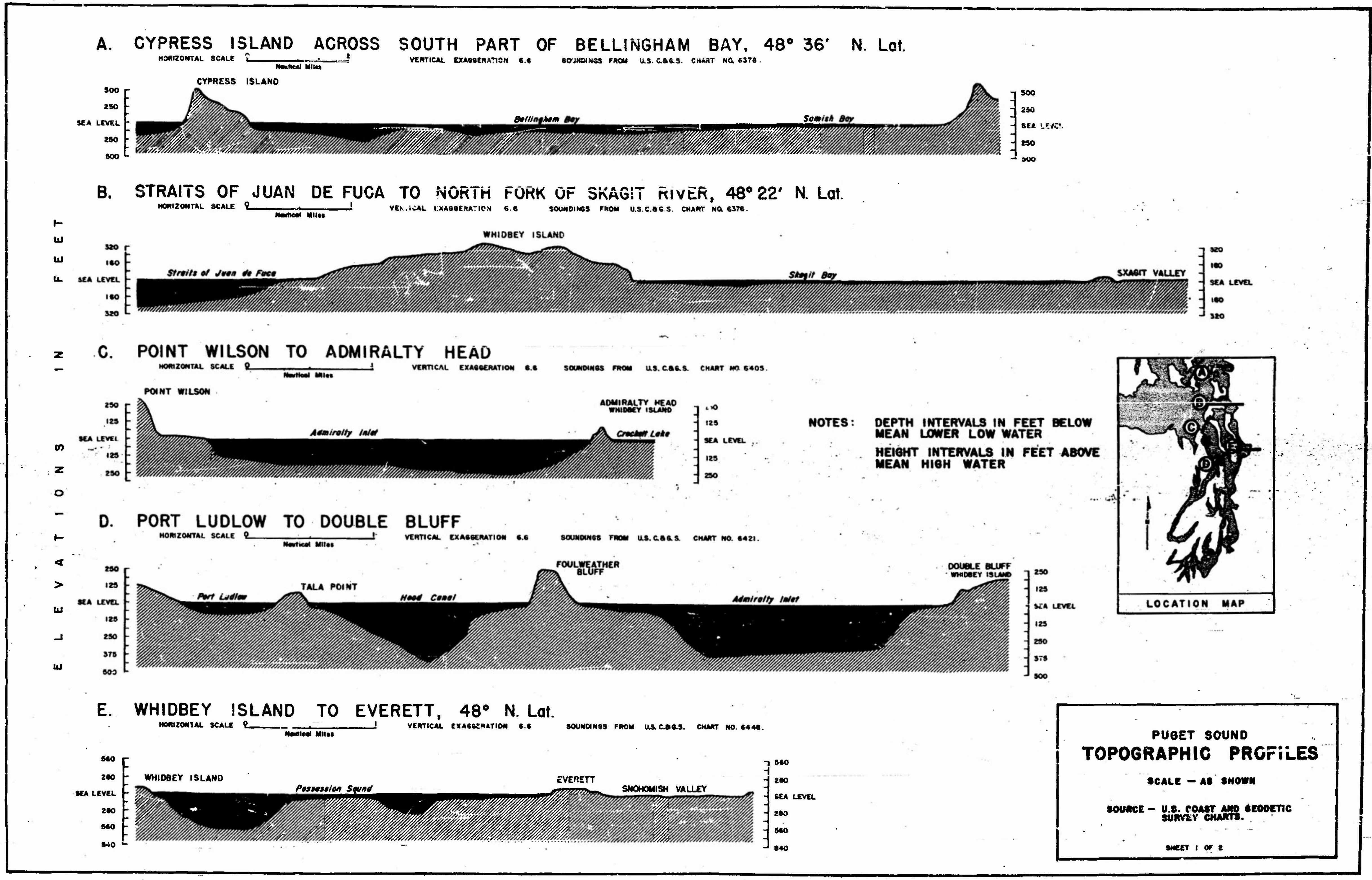

A. CYPRESS ISLAND ACROSS SOUTH PART OF BELLINGHAM BAY, 48° 36′ N. Lat.
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S. C.&G.S. CHART NO. 6378.
CYPRESS ISLAND
Bellingham Bay
Samish Bay
SEA LEVEL
B. STRAITS OF JUAN DE FUCA TO NORTH FORK OF SKAGIT RIVER, 48° 22′ N. Lat.
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S.C.&G.S. CHART NO. 6376.
WHIDBEY ISLAND
Straits of Juan de Fuca
Skagit Bay
SKAGIT VALLEY
C. POINT WILSON TO ADMIRALTY HEAD
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S. C.&G.S. CHART NO. 6405.
POINT WILSON
Admiralty Inlet
ADMIRALTY HEAD
WHIDBEY ISLAND
Crockett Lake
NOTES: DEPTH INTERVALS IN FEET BELOW MEAN LOWER LOW WATER
HEIGHT INTERVALS IN FEET ABOVE MEAN HIGH WATER
D. PORT LUDLOW TO DOUBLE BLUFF
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S. C.&G.S. CHART NO. 6421.
Port Ludlow
TALA POINT
Hood Canal
FOULWEATHER BLUFF
Admiralty Inlet
DOUBLE BLUFF
WHIDBEY ISLAND
LOCATION MAP
E. WHIDBEY ISLAND TO EVERETT, 48° N. Lat.
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S. C.&G.S. CHART NO. 6448.
WHIDBEY ISLAND
Possession Sound
EVERETT
SNOHOMISH VALLEY
ELEVATIONS IN FEET
PUGET SOUND
TOPOGRAPHIC PROFILES
SCALE – AS SHOWN
SOURCE – U.S. COAST AND GEODETIC SURVEY CHARTS.
SHEET 1 OF 2

Fig. 4-2 (1)

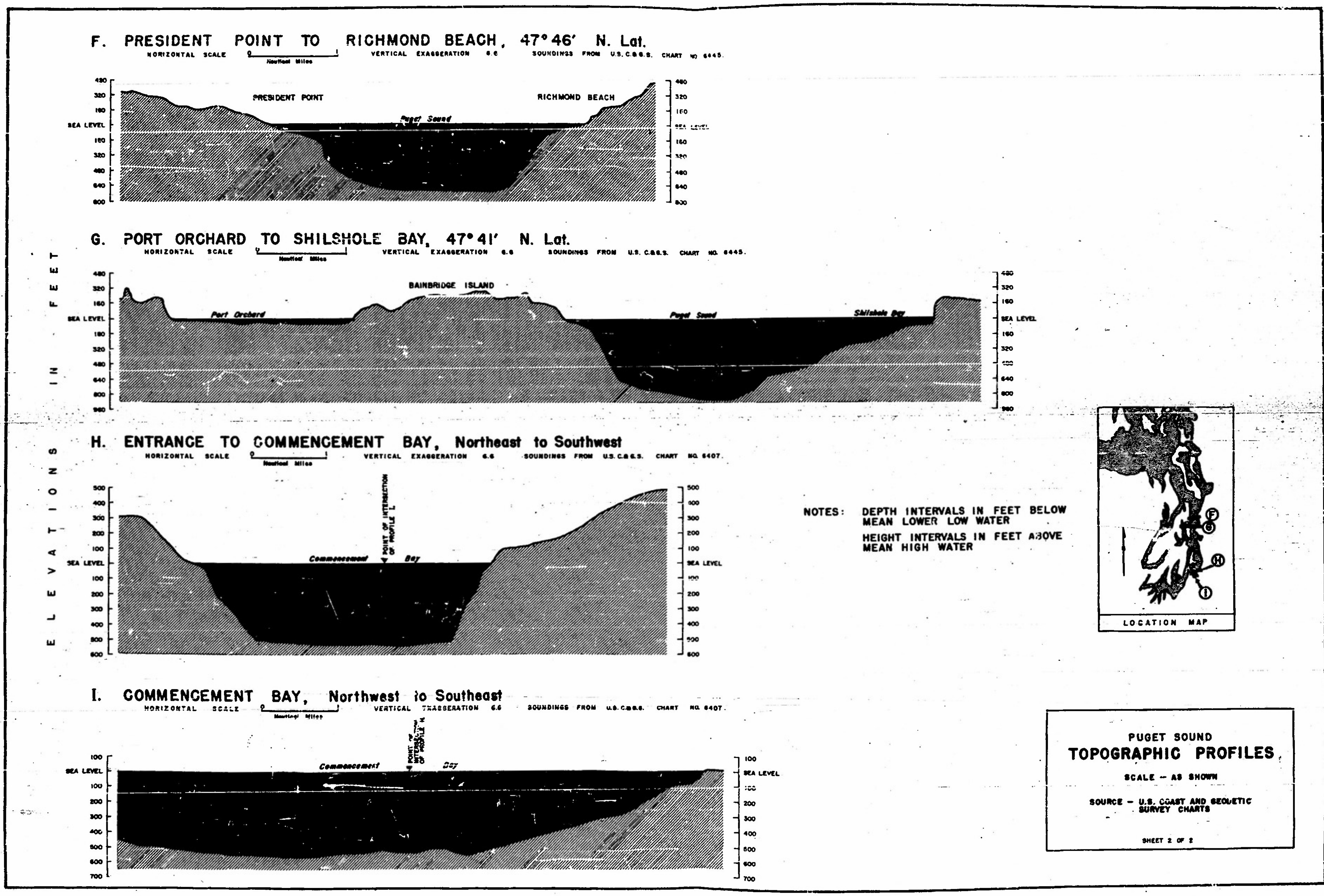

F. PRESIDENT POINT TO RICHMOND BEACH, 47° 46' N. Lat.
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S.C.&G.S. CHART NO 6445.
PRESIDENT POINT
RICHMOND BEACH
Puget Sound
G. PORT ORCHARD TO SHILSHOLE BAY, 47° 41' N. Lat.
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S. C.&G.S. CHART NO. 6445.
BAINBRIDGE ISLAND
Port Orchard
Puget Sound
Shilshole Bay
H. ENTRANCE TO COMMENCEMENT BAY, Northeast to Southwest
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S.C.&G.S. CHART NO. 6407.
POINT OF INTERSECTION OF PROFILE I.
Commencement Bay
I. COMMENCEMENT BAY, Northwest to Southeast
HORIZONTAL SCALE
Nautical Miles
VERTICAL EXAGGERATION 6.6
SOUNDINGS FROM U.S.C.&G.S. CHART NO. 6407.
POINT OF INTERSECTION OF PROFILE H
Commencement Bay
SEA LEVEL
ELEVATIONS IN FEET
NOTES: DEPTH INTERVALS IN FEET BELOW MEAN LOWER LOW WATER
HEIGHT INTERVALS IN FEET ABOVE MEAN HIGH WATER
LOCATION MAP
PUGET SOUND
TOPOGRAPHIC PROFILES
SCALE – AS SHOWN
SOURCE – U.S. COAST AND GEODETIC SURVEY CHARTS
SHEET 2 OF 2

Fig. 4-2 (2)

TABLE 4-1. Pre-Tertiary Formations of the Puget Sound Area.

PERIOD		FORMATION	THICKNESS	DESCRIPTION
Cretaceous	Upper	Nanaimo	Unknown	Unmetamorphosed conglomerate, arkosic sandstone, and shale. Found in the Northern San Juan Islands only.
Cretaceous	Lower	Spieden	Unknown	Mainly conglomerate with minor amounts of breccia, sandstone, shale and argillaceous sandstone. Found in isolated outcrops in the San Juan Islands.
Upper Triassic		Haro	1250 feet	Shale, slate and sandstone in the upper part. The lower 950 feet is conglomerate. Found in the extreme northern end of the San Juan Islands only.
Permian to Upper Mississippian		Leech River group	15,000 feet	Slaty schists and argillites, graywackes, conglomerates, breccias, phyllites, volcanic tuff, chert and coal. Metamorphosed by later intrusions. Found in the central core of the syncline of San Juan Island.
Mississippian to Devonian		Orcas group	10,000 feet	Thin, alternating beds of cherty quartzite and argillite, complexly folded and faulted.

Pre-Devonian - No Pre-Devonian rocks have been recognized in the area.

Table summarized from McLellan (McLellan 1927).

TABLE 4-2. Tertiary Formations of the Puget Sound Area.

PERIOD		FORMATION	THICKNESS	
Pliocene		-	Regional erosion, no deposition.	Elevation of the Olympic Mountains.
Miocene		-	Regional erosion, no deposition.	Depression of the sea floor to the west, draining the Puget Sound area.
Oligocene		Blakeley	8,000 feet	Conglomerates and sandy shales found in the sea cliffs at the entrance to Bremerton Inlet and on Bainbridge Island.
Eocene	Upper	Puget Group (Lower to Upper): Cowlitz	2,000 to 5,000 feet	Marine, brackish water and freshwater sandstones, shales and lignites. Found in the eastern part of the Puget Sound Basin only.
		Chuckanut	25 to 200 feet	Massive cross-bedded and stratified sandstone and sandy shale with intercalated conglomerate. Found in the San Juan Islands and in western Whatcom and Skagit Counties.
			10,000 to 12,000 feet	Massive sandstone, shale, carbonaceous shale and coal seams. Found in discontinuous exposures along the west slope of the Cascade Mountains. The rocks of the group have been thrown into plunging anticlines and synclines.
	Lower	Metchosin Volcanics	3,000 to 5,000 feet	Flow basalts and occasional andesites, wide spread in the Puget Sound area. The northern border is in contact with the older metamorphics and is steeply tilted due to later compression.

Table summarized from Weaver (Weaver 1937).

The Pleistocene has been studied in detail by many geologists. The most complete descriptions are those of Bretz (Bretz 1913) and Willis (Willis 1898a). Numerous papers concerning special problems or covering restricted areas are to be found in the literature, as may be seen by referring to the bibliography of this report.

Willis considers the glaciation to be confluent. He recognized and described deposits of two glacial advances. The earliest glacial advance was given the name "Admiralty" and the second was named "Vashon." A summary of his description of the Pleistocene deposits is given in Table 4-3.

Stark and Mullineaux (Stark and Mullineaux 1950) record the Pleistocene deposits in Seattle as outlined in Table 4-4.

A sequence of strata is shown in the Geological Cross Section at the Tacoma Narrows (Fig. 4-3). Typical bluff exposures of Pleistocene deposits along the shores of Puget Sound are illustrated by the section at Possession Point, Whidbey Island (Fig. 4-4).

GEOLOGIC HISTORY

The pre-Tertiary history of the Puget Sound area has not been described. The Tertiary history has been described by Weaver (Weaver 1937). A summary of his report follows.

The Metchosin volcanics arose through numerous fissures and accumulated on the floor of a submerged coastal plain which was being differentially lowered. The coastal plain is thought to have extended from Vancouver Island to Oregon during earliest Eocene time. The total amount of depression may have been as much as 4,000 feet, but the accumulation of the flows progressed at the same rate as the subsidence.

Following the deposition of the Metchosin volcanics the sediments which make up the Puget group were laid down. During this time the region was swampy and the climate subtropical. In the latter part of this time the area to the east was uplifted accounting for the deposition of the Chuckanut formation (Weaver 1937).

Marine waters advanced over the eastern portion of the basin depositing the Cowlitz formation. The eastern shore line was variable during this time as is shown by the interbedding of marine, brackish water, and freshwater deposits.

During the Oligocene the area to the east was sharply uplifted and the western portion of the Puget Sound Basin was depressed in an amount ranging from 4,000 to 8,000 feet, the Blakeley formation accumulating in the depression.

TABLE 4-3. Pleistocene Deposits of the Puget Sound Area.

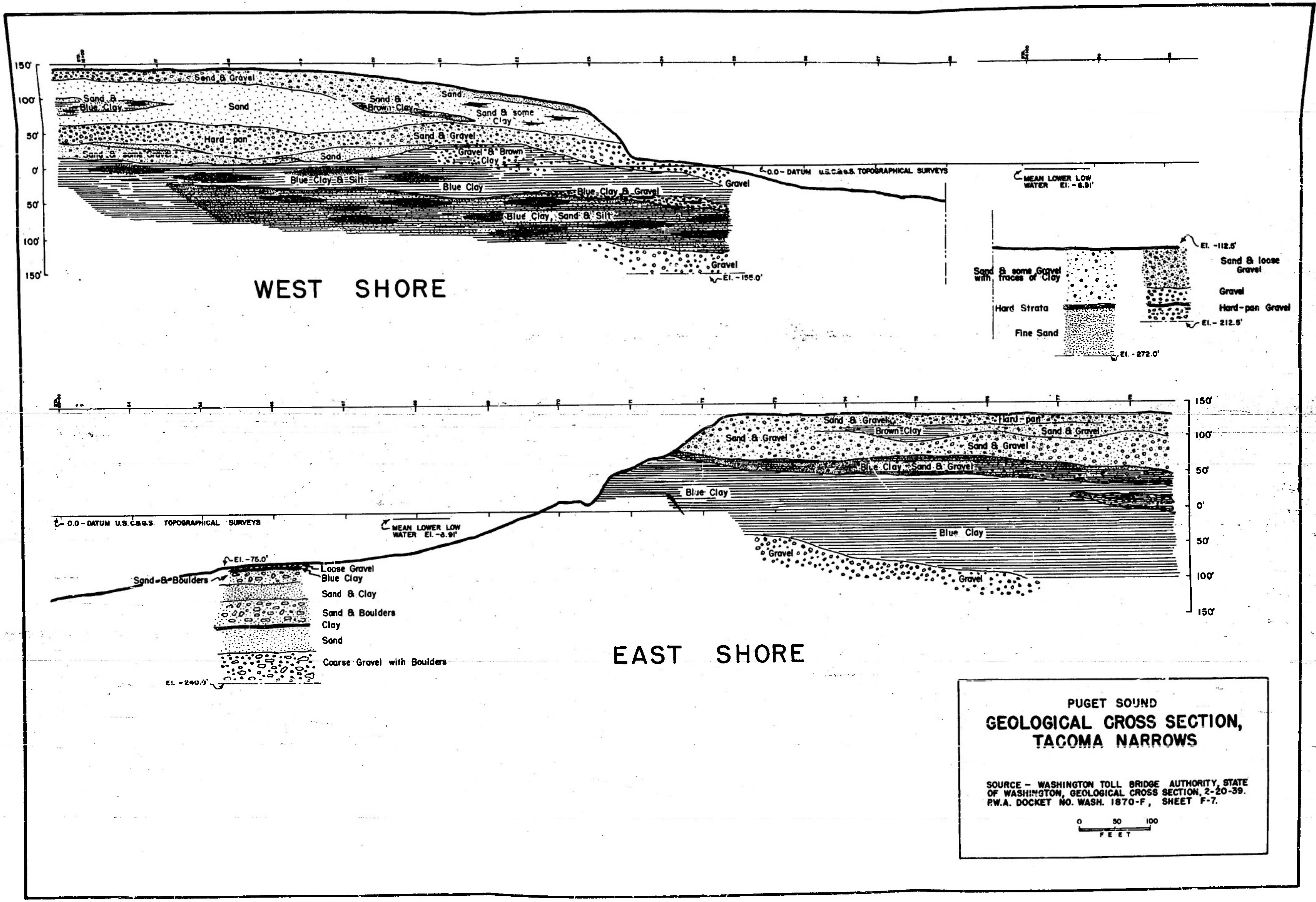
GLACIAL STAGE	FORMATION	DESCRIPTION
Vashon	Vashon drift	Coarse, well-rounded gravel with large boulders and sand lenses.
	Osceola clay	Horizontally stratified clay and fine sand.
	Douty gravel	Coarse gravel with boulders to 4 feet in diameter.
		Unconformity
Admiralty	Puyallup sands	Deltaic sands
	Orting gravel	Coarse, orange-colored sands and gravel.
	Admiralty clay	Minutely stratified blue clay and fine sand with gravel lenses.

Table summarized from Willis (Willis 1898a).

TABLE 4-4. Pleistocene Deposits in Seattle.

GLACIAL STAGE	FORMATION	THICKNESS	DESCRIPTION
Vashon	Vashon till	125 feet	Sand, clay and coarse rounded pebbles and cobbles.
	Lawton	250 feet	Medium grained sand with gravel lenses channeled by streams.
			Laminated and massive clay.
			Clay and interbedded silt and sand.
			Erosion surface
Admiralty	Duwamish	225 feet	Peat and silt at top, silt and fine sand, massive blue clay at bottom.
	Beacon till	75 feet (Base not exposed)	Clay and silt with rounded pebbles and cobbles.

Table summarized from The Glacial Geology of the City of Seattle (Stark and Mullineaux 1950).



PUGET SOUND
GEOLOGICAL CROSS SECTION, TACOMA NARROWS
SOURCE – WASHINGTON TOLL BRIDGE AUTHORITY, STATE OF WASHINGTON, GEOLOGICAL CROSS SECTION, 2-20-39. P.W.A. DOCKET NO. WASH. 1870-F, SHEET F-7.
0 50 100
FEET
WEST SHORE
EAST SHORE
150'
100'
50'
0'
50'
100'
150'
Sand & Gravel
Sand & Blue Clay
Sand
Sand & Brown Clay
Sand & some Clay
Hard-pan
Sand & Gravel
Gravel & Brown Clay
Blue Clay & Silt
Blue Clay
Blue Clay & Gravel
Blue Clay, Sand & Silt
Gravel
El. -155.0'
0.0-DATUM U.S.C.&G.S. TOPOGRAPHICAL SURVEYS
MEAN LOWER LOW WATER El. -6.91'
El. -112.5'
Sand & some Gravel with traces of Clay
Hard Strata
Fine Sand
El. -272.0'
Sand & loose Gravel
Gravel
Hard-pan Gravel
El. -212.5'
Brown Clay
Hard-pan
Blue Clay, Sand & Gravel
El. -75.0'
Sand & Boulders
Loose Gravel
Blue Clay
Sand & Clay
Sand & Boulders
Clay
Coarse Gravel with Boulders
El. -240.0'

Fig. 4-3

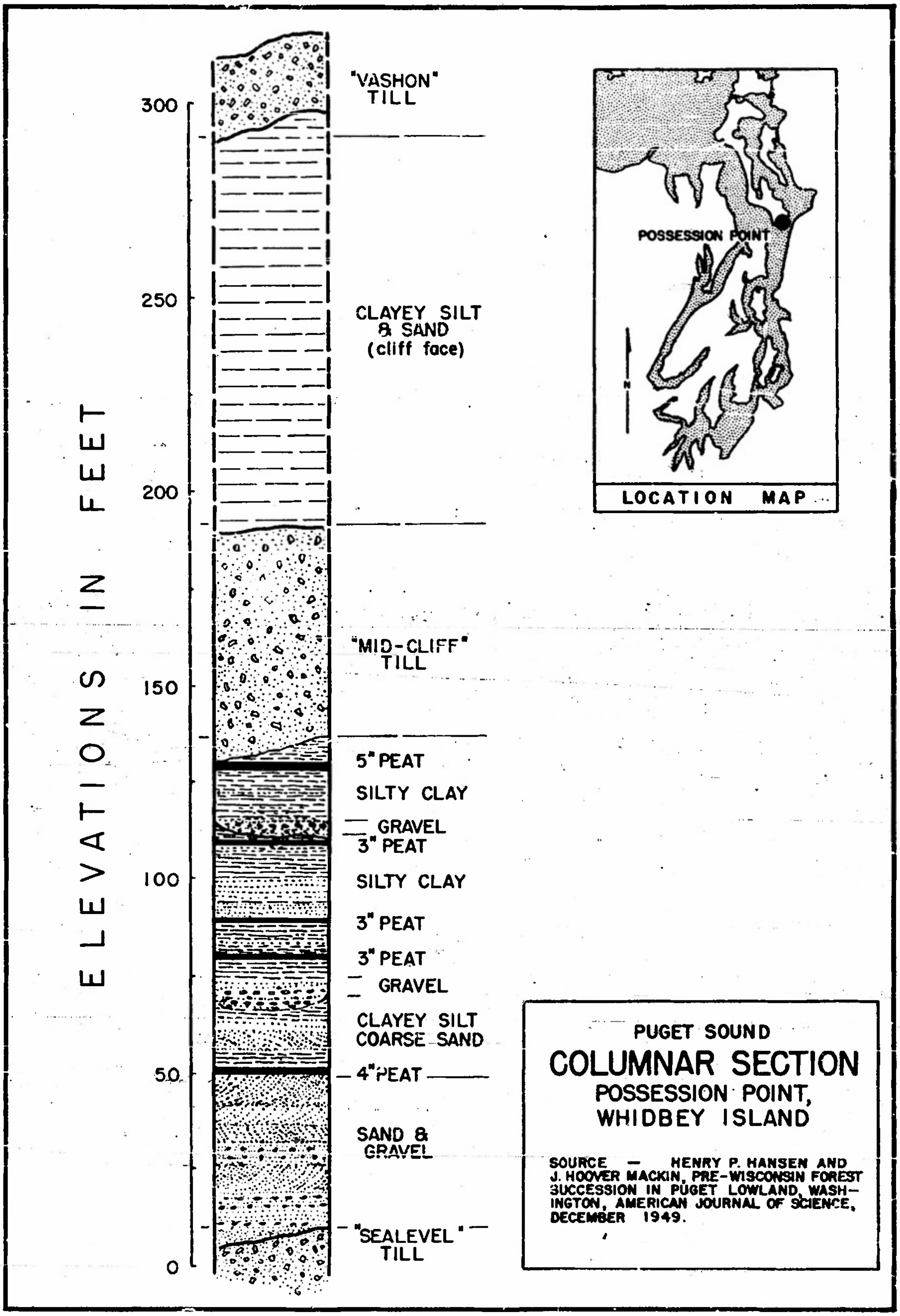

"VASHON" TILL
300
250
200
150
100
50
0
ELEVATIONS IN FEET
CLAYEY SILT & SAND (cliff face)
"MID-CLIFF" TILL
5" PEAT
SILTY CLAY
GRAVEL
3" PEAT
SILTY CLAY
3" PEAT
3" PEAT
GRAVEL
CLAYEY SILT
COARSE SAND
4" PEAT
SAND & GRAVEL
"SEALEVEL" TILL
POSSESSION POINT
N
LOCATION MAP
PUGET SOUND
COLUMNAR SECTION
POSSESSION POINT, WHIDBEY ISLAND
SOURCE — HENRY P. HANSEN AND J. HOOVER MACKIN, PRE-WISCONSIN FOREST SUCCESSION IN PUGET LOWLAND, WASHINGTON, AMERICAN JOURNAL OF SCIENCE, DECEMBER 1949.

Fig. 4-4

The shore line had retreated to the west by the beginning of Miocene time. Diastrophism at the close of the middle Miocene formed major anticlinal and synclinal warps which had a trend of N. 75° W. The Olympic Mountains were probably elevated for the first time. They consisted of ridges which trended easterly across the middle portion of the Puget Sound Basin to the Cascade Mountains. The uplifted ridges were eroded and leveled during the late Miocene and early Pliocene.

Regional diastrophism affecting the Pacific Coast of North America occurred during the late Pliocene. The Coast Range and the Cascade Mountains were elevated, the Puget Trough was lowered. The mountain ranges and the intervening trough were superimposed on the older northwest-southeast trending folds. Following this uplift of the Cascades the volcanic mountains, Mounts Hood, St. Helens, Adams, Rainier, and Baker came into existence.

The Pleistocene is represented by the deposits of two glacial stages which are presumably the equivalent of the two final glacial stages of eastern North America. The earliest glacial stage has been named the Admiralty by Willis and he applied the name Vashon to the second of the glacial stages (Willis 1899). In another paper Willis described the glacial deposits of Puget Sound (Willis 1898a).

Bretz, in a more recent paper, has described the glacial history in detail (Bretz 1913). He considers both glacial stages to be due to lobes of the Cordilleran ice sheet which advanced from the north. Admiralty drift has been found beneath the Vashon terminal moraine, but in no case has it been found beyond it. In the southern part of the area, the bulk of the material from the Vashon glaciation consists of outwash deposits, which filled the valleys that were formed in the interglacial time. In the northern part of the area, the ground moraine is only a thin mantle covering the pre-Vashon topography. In some local areas the Vashon drift is sufficiently thick to obscure the interglacial, stream-formed topography. The Vashon glacier deepened the old trunk valleys, but these valleys are found only in the deeper portion of Puget Sound.

As the ice retreated northward a series of glacial lakes formed between the ice front and the drainage divide to the south. When the basins filled they coalesced to form a master lake which has been named Lake Russell. After the ice melted northward to the point where the Strait of Juan de Fuca was opened, the basin was invaded by marine water. At that time the area was 250 feet below its present elevation.

Since the disappearance of the glacial ice the area has been upraised and tilted down to the south. The axis of tilting is thought to be south of the city of Seattle (Stark and Mullineaux 1950). The evidence for this tilting is seen in the upraised beaches to the north and the drowned valleys in the south.

The uplift has been suggested as a possible cause of landslides in the Puget Sound area (Hennes 1936). The gradational contact between the lower clay phase and the upper sand phase of the Lawton formation is the usual seep line on the steep hill slopes which are subject to landsliding (Stark and Mullineaux 1950).

GEOLOGIC STRUCTURE

The structure of the Puget Sound area is the result of two periods of diastrophism. The earlier deformation occurred during the Miocene and formed anticlinal and synclinal folds which trend from N. 60° W. to 75° W. The major upwarps are in part responsible for the present mountains of Vancouver Island and the Olympic Mountains. The Strait of Juan de Fuca occupies the synclinal trough. Toward the close of the Pliocene two major north-south trending uplifts and an intervening depression were formed. The uplifts formed the Olympic and Cascade Mountains and the depression is occupied by Puget Sound. The depression of Puget Sound is partly the result of downward faulting but its depth is due largely to erosion.

ECONOMIC GEOLOGY

Coal is at present the most important economic product. The coal fields are found in the east side of the basin and the coal is confined to the rocks of the Puget group. Willis (Willis 1886) made the first detailed report on the coal field. Most of the coal is bituminous, or sub-bituminous, but coking coal is found in Pierce County, and anthracite is produced in Whatcom County east of Bellingham.

Green (Green 1947) states that the coal production during the year 1946 was as follows: King County, 316,294 tons; Pierce County, 14,580 tons (including coking coal); Whatcom County, 109,000 tons of anthracite.

Coke made from coal of Pierce and Kittitas Counties is generally too high in phosphorous for some industrial uses, such as the ferro-alloys and calcium carbide. The ash content in the coking coals is so high that coke made from them runs close to 18 to 20 per cent ash (Lund and Sullivan 1947).

Sand and gravel is produced at many places in the Puget Sound area (Purdy 1952). It is now perhaps the most valuable economic product.

Oil has never been produced in the area even though more than fifty wells have been drilled in the immediate vicinity of Puget Sound. Most of the wells are less than 2,000 feet deep (Glover 1947).

SOILS

The soils of Puget Sound Basin were developed from glacial materials which were deposited on a bedrock surface. The glacial materials are largely outwash sands and gravels with smaller amounts of ground moraine and isolated patches of lake and swamp deposits. The mantle of glacial deposits is generally less than 50 feet thick in the northern part of the basin and more than 500 feet thick in the central part, again thinning to the south.

The soils of the area have been the subject of early reconnaissance surveys (Mangum 1911, 1912) but only certain areas have been studied and mapped by modern methods. Several surveys are in progress and in some cases the reports are in manuscript form.

The most extensive group of soils are those of the terraces and uplands. These timber-covered soils which extend over more than half of the area are stony and gravelly with consolidated substrata. The most important agricultural soils are found in the recent alluvium of the stream valleys and lake beds. They cover about one-fifth of the area and are found on the east side of the basin. About 90 per cent of the agricultural soils are under cultivation. They are composed of silts and loams with unconsolidated substrata.

The Bellingham area of Whatcom County is covered with silty, sandy or stony loam, but small areas of clay, swamp and marsh soils occur in the area (Mangum 1907).

Island County soils are mostly coarse or stony sands which support dense stands of timber. Minor amounts of peat, loam, and clay soils are found in scattered patches (Carr 1905).

In Snohomish County the soils are gravelly loams which are timber covered. The agricultural soils are the loams and silts of the stream valleys and lake beds. Most of the soils are podzolic having developed in a forested region of cool, moist climate (Anderson 1947).

About 60 per cent of the area of King County is covered with soils of the uplands and terraces. They are good forest soils. The main agricultural soils are the loams and silts of the river valleys and lake beds. These soils cover about 15 per cent of the area of the county and about 90 per cent of their area is cultivated (Poulson and others n.d.).

Most of Kitsap County has soils developed from a heterogeneous mixture of coarse sands and gravels with small amounts of silt and clay. In much of the area these soils have developed a layer of hardpan a few feet below the surface. Soils suitable to agriculture are of small extent and minor importance (Wildermuth 1939).

RECENT SEDIMENTATION

BOTTOM SEDIMENTS

The sediments of Puget Sound are derived from the streams which enter the Sound, cliff erosion, and the erosion of the submarine banks. The sediments vary in size from clay to cobbles. Muds are found in the enclosed inlets and in the deeper portions of the troughs below the sill depth. Sands are found at the river deltas, along the shores, and at the heads of the inlets. In areas of strong tidal scour the bottom is rocky. The areal distribution of the sediments is shown in Fig. 4-5.

Sedimentation by Rivers

Little direct information is available pertaining to sedimentation in Puget Sound. Indirect evidence points to heavy sedimentation at the mouths of the major rivers, especially those with glacier fields in their tributary regions (see section on Hydrology). Maximum sedimentation from the Puyallup River follows violent freshets. A series of soundings in the Puyallup Waterway at Tacoma following several violent freshets in November 1909, revealed in excess of one million cubic yards of sediment, most of which was brought down and deposited during one month of November. Maximum suspended load probably reaches 10 per cent by weight and probably is seldom less than 2 per cent (U. S. Army Corps of Engineers 1932). An examination of Fig. 4-6, Variation in Delta Profile, Puyallup Waterway, will show rate of delta accumulation and the manner in which the material sloughs off into the deeper basins.

An indication of the volume of sediment transported by the Snohomish River which enters Puget Sound at Port Gardner (Everett Harbor) is exemplified by dredging experience of the U. S. Engineer Corps.

> On February 1, 1912, work was commenced on the project of dredging a channel 75 feet wide and 8 feet deep at mean lower low water from the Fourteenth Street dock to the head of Steamboat Slough. This dredging was begun at the Fourteenth Street dock and progressed upstream 7,220 feet to a connection with the river channel that went through Steamboat Gap before being closed by the dike, when the work was suspended on May 22, 1912, on account of lack of funds. Dredging was resumed on January 13, 1913, this time beginning at Steamboat Slough and working downstream. Connection with the channel dredged in May, 1912, was made in February, 1914, but the channel was found shoaled to such extent that redredging was necessary over all the 7,220 feet of channel first dredged and it was necessary, moreover, to continue dredging southward for 1,600 feet below the Fourteenth Street dock and beyond the limits of the contract in order to obtain an 8-foot channel where 26 feet depth existed in 1912.
>
> (U. S. Army Corps of Engineers 1930.)

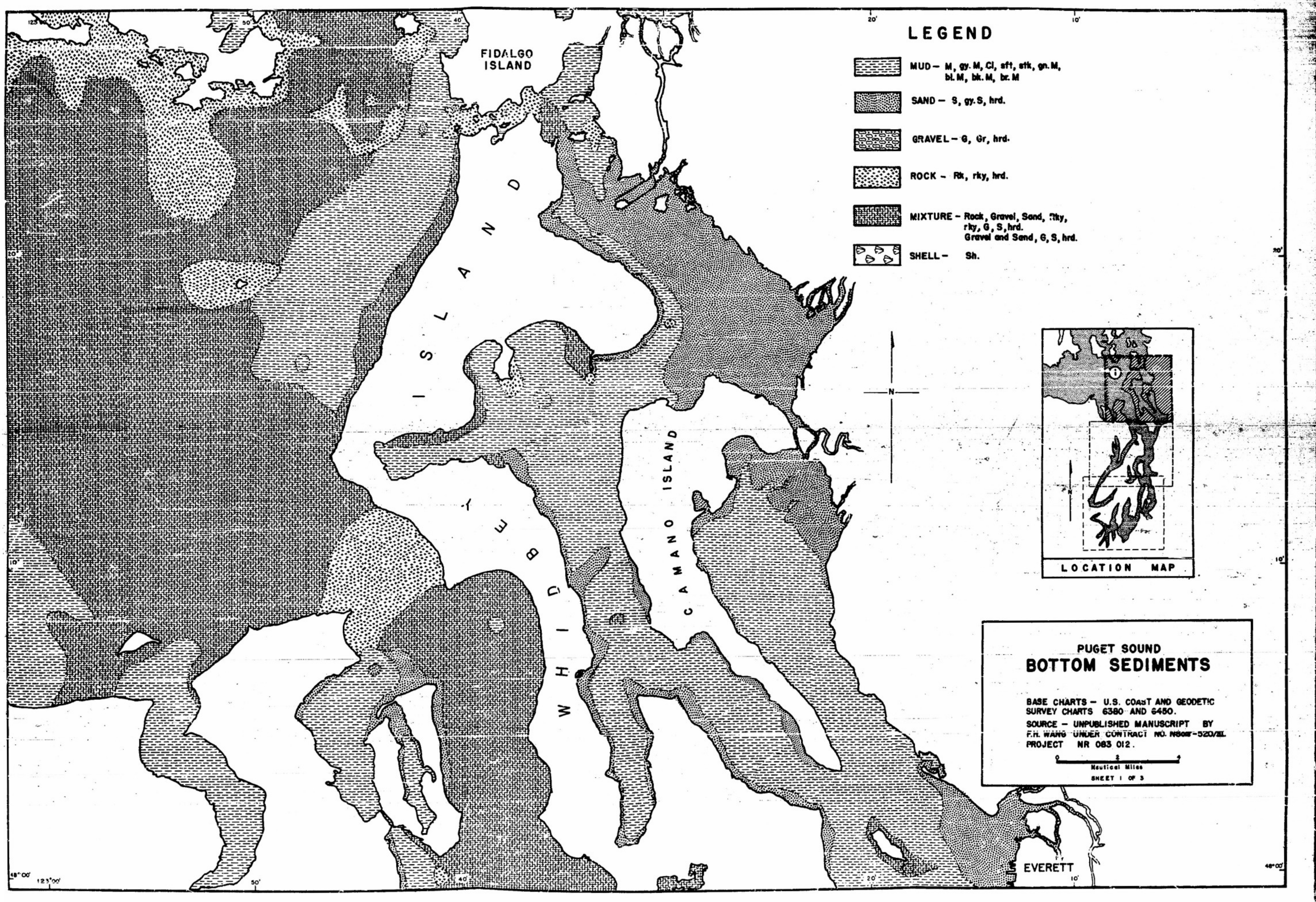

LEGEND
MUD – M, gy. M, Cl, sft, stk, gn. M, bl. M, bk. M, br. M
SAND – S, gy. S, hrd.
GRAVEL – G, Gr, hrd.
ROCK – Rk, rky, hrd.
MIXTURE – Rock, Gravel, Sand, Rky, rky, G, S, hrd. Gravel and Sand, G, S, hrd.
SHELL – Sh.
FIDALGO ISLAND
WHIDBEY ISLAND
CAMANO ISLAND
EVERETT
LOCATION MAP
N
PUGET SOUND
BOTTOM SEDIMENTS
BASE CHARTS – U.S. COAST AND GEODETIC SURVEY CHARTS 6380 AND 6450.
SOURCE – UNPUBLISHED MANUSCRIPT BY F.H. WANG UNDER CONTRACT NO. N8onr-520/III PROJECT NR 083 012.
Nautical Miles
SHEET 1 OF 3
123°00'
50'
40'
20'
10'
48°00'

Fig. 4-5 (1)

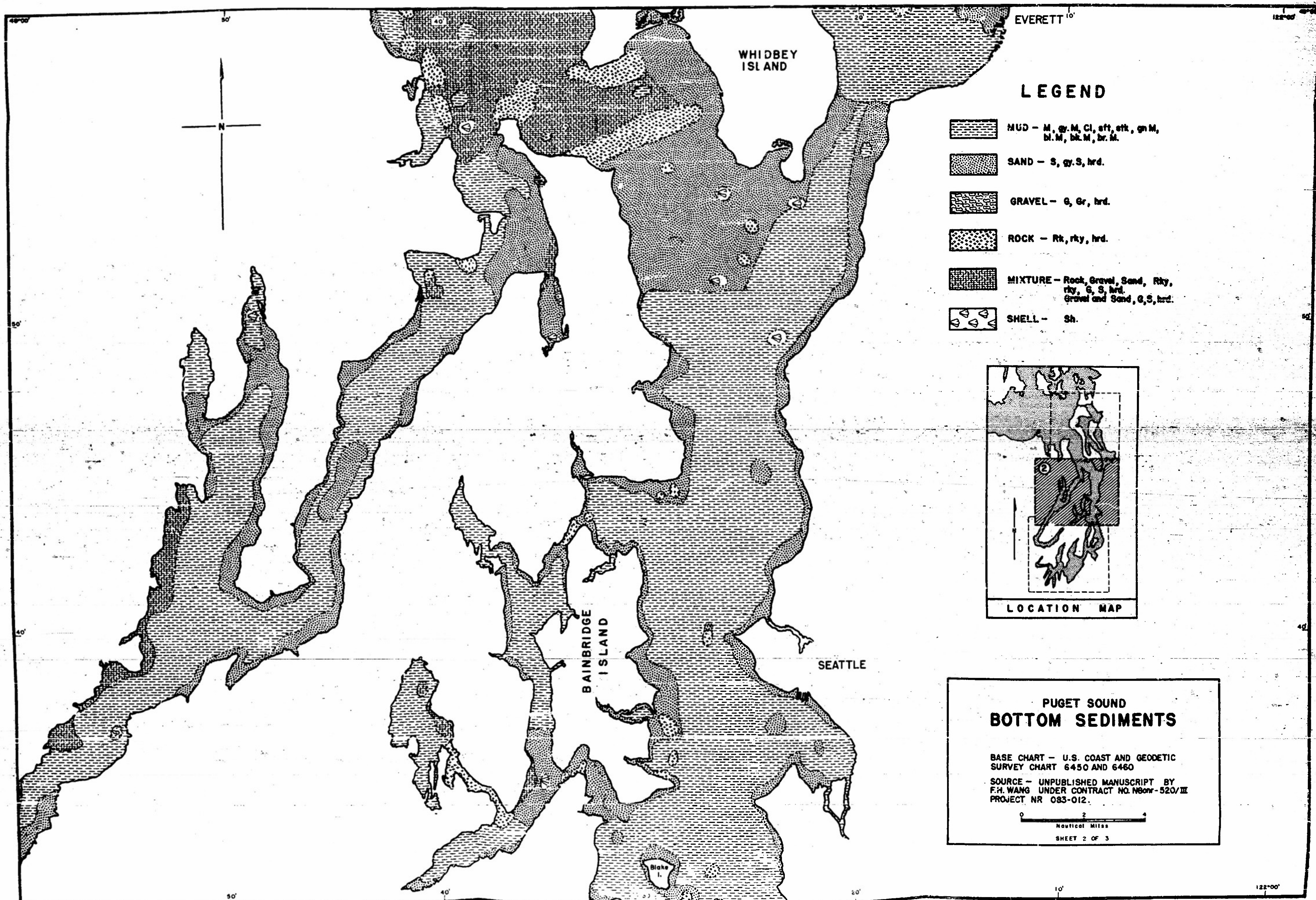

EVERETT
WHIDBEY ISLAND
LEGEND
MUD – M, gy.M, Cl, sft, stk, gn M, bl.M, bk.M, br.M.
SAND – S, gy.S, hrd.
GRAVEL – G, Gr, hrd.
ROCK – Rk, rky, hrd.
MIXTURE – Rock, Gravel, Sand, Rky, rky, G, S, hrd. Gravel and Sand, G, S, hrd.
SHELL – Sh.
N
LOCATION MAP
BAINBRIDGE ISLAND
SEATTLE
Blake I.
PUGET SOUND
BOTTOM SEDIMENTS
BASE CHART – U.S. COAST AND GEODETIC SURVEY CHART 6450 AND 6460
SOURCE – UNPUBLISHED MANUSCRIPT BY F.H. WANG UNDER CONTRACT NO. N8onr-520/III PROJECT NR 083-012.
0 2 4
Nautical Miles
SHEET 2 OF 3
122°00'

Fig. 4-5 (2)

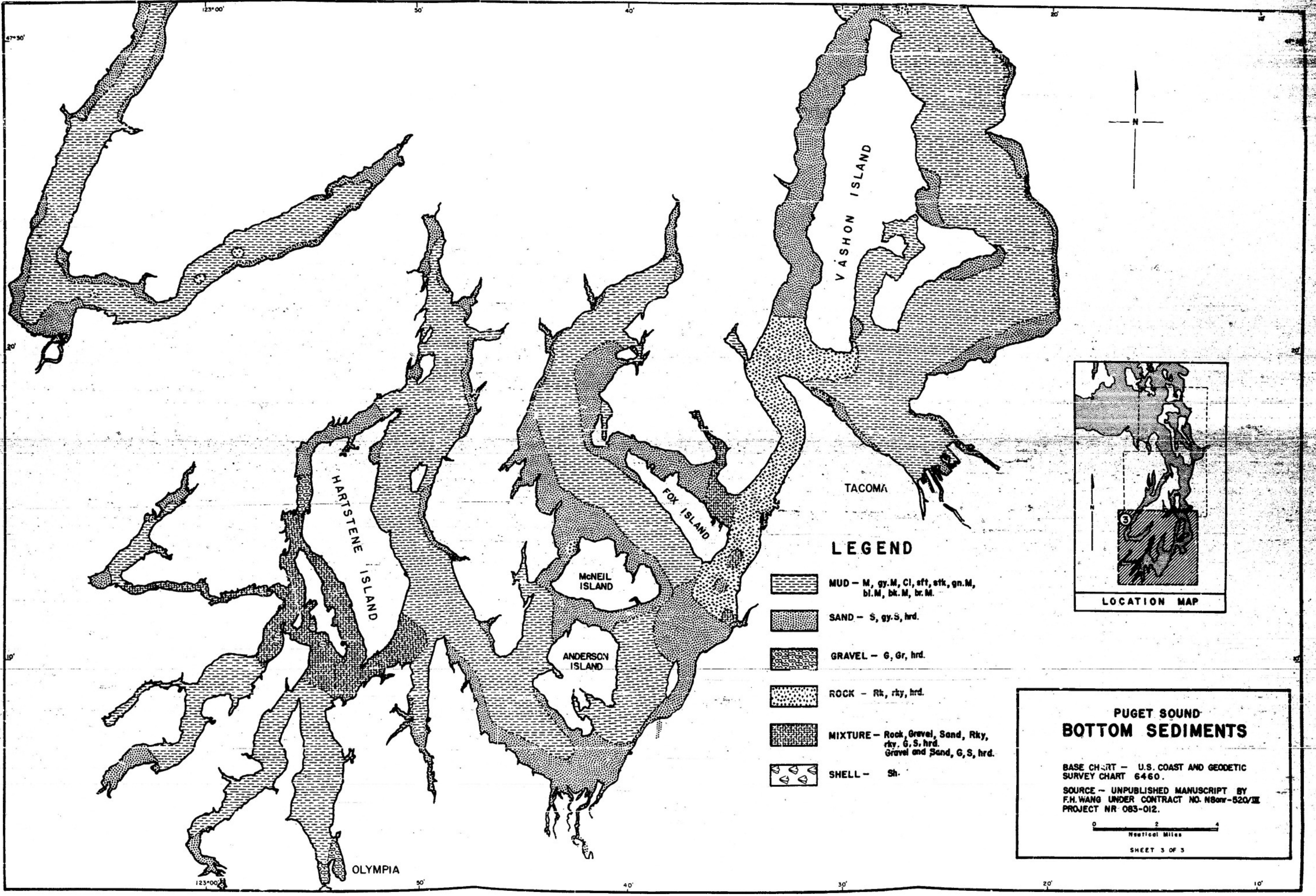
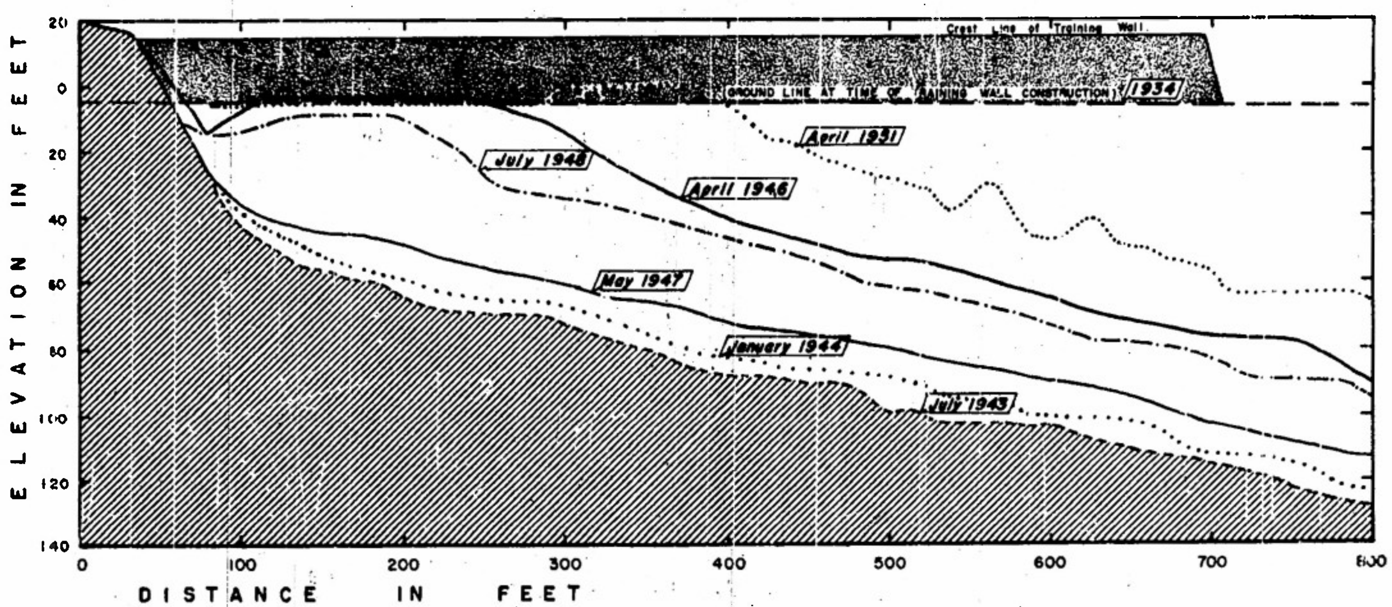

PUGET SOUND
BOTTOM SEDIMENTS
BASE CHART – U.S. COAST AND GEODETIC SURVEY CHART 6460.
SOURCE – UNPUBLISHED MANUSCRIPT BY F.H. WANG UNDER CONTRACT NO. N8onr-520/III PROJECT NR 083-012.
Nautical Miles
0
2
4
SHEET 3 OF 3
LEGEND
MUD – M, gy.M, Cl, sft, stk, gn.M, bl.M, bk.M, br.M.
SAND – S, gy.S, hrd.
GRAVEL – G, Gr, hrd.
ROCK – Rk, rky, hrd.
MIXTURE – Rock, Gravel, Sand, Rky, rky, G, S, hrd. Gravel and Sand, G, S, hrd.
SHELL – Sh.
LOCATION MAP
VASHON ISLAND
TACOMA
FOX ISLAND
McNEIL ISLAND
ANDERSON ISLAND
HARTSTENE ISLAND
OLYMPIA
N
123°00'
50'
40'
30'
20'
10'
47°30'
20'
10'

Fig. 4-5 (3)



NOTE: A 700 ft. training wall constructed in 1934 was completely destroyed by a slide in April 1943.

PUGET SOUND

VARIATION IN DELTA PROFILE

PUYALLUP WATERWAY

SOURCE — U.S. ARMY CORPS OF ENGINEERS, TACOMA HARBOR, WASHINGTON, PUYALLUP WATERWAY, MAP FILE NO. E-3-4-40.

Fig. 4-6

Deep Filling

An analysis of Hydrographic Surveys H-1426b (1878-79) and H-6104 (1935) reveals possible sedimentation in 100 fathom depths north of Ketron Island, southern Puget Sound. Survey H-1426b shows soundings of 100 to 103 fathoms while survey H-6104 reveals only a very slight depression in this vicinity to depths of 91 to 93 fathoms. Other soundings in depths of 70 to 90 fathoms in the area west and north of Ketron Island on surveys H-1426b and H-6104 are in good agreement and reveal no indications of marked changes in the bottom. It is the opinion of the Coast and Geodetic Survey that the 100 and 103 fathom soundings are somewhat in error and that the differences with depths of survey H-6104 are probably not predominantly the result of filling. The sounding records of survey H-1426b were examined for errors in recording and plotting and none were found (U. S. Department of Commerce Coast and Geodetic Survey 1953).

Referring to Fig. 9-2 which shows bottom at 103 fathoms in the Ketron Island area one may calculate that the filling required to diminish the depth 12 fathoms is about 3,800,000 cubic yards. With the closely adjacent Nisqually and Puyallup Rivers this volume of sediment may be deposited in the Sound in an exceedingly short time.

Scour and Fill

Examination of Fig. 4-5, Bottom Sediments of Puget Sound, will immediately show rocky areas where swift tidal currents scour the bottom. Fill areas appear noticeably at the mouths of rivers.

Rate of Sedimentation

The rate of denudation of the area which supplies sediment to Puget Sound indicates an overall rate of sedimentation of about 0.4 millimeter per year. Radioactivity measurements in Skagit Bay indicate filling at the rate of 0.58 millimeter per year (Blank 1950).

Mechanical Analysis of Bottom Cores and Shore Sediments

Analysis of cores taken across the Sound in a line from 47°96.5' N, 122°28.9' W to 47°47.5' N, 122°23.9' W indicates that the sediments change from finer sands on the west and east slopes of the channel to predominantly silt and clay at the greatest depth near mid-channel. The ratio of silt to clay increases with decrease in sand content, or geographically from the sides toward the center of the channel. See Table 4-5 for Mechanical Characteristics of Bottom Cores (University of Washington Department of Oceanography 1952b).

TABLE 4-5. Mechanical Characteristics of Bottom Cores Taken Across Puget Sound Lying Between Positions 47°46.5' N 122°28.9' W and 47°47.5' N 122°23.3' W.

Core No.	Water Depth [in feet]	Core Length [in centimeters]	Sand % (over 0.0625 mm)	Silt % (0.0039 to 0.0625 mm)	Clay % (under 0.0039 mm)	Water Content (% of dry weight)
5E	115	12	82	8	10	45
10G	141	19	85	7	8	25
11G	148	24	81	10	9	25
7G	213	31	63	20	17	30
6G	259	26	77	15	8	35
13G	322	29	70	17	13	30
35F	328	28	57	26	17	55
14G*U	338	27	64	19	17	40
14G*L	338	27	--	--	--	35
5G	364	31.5	60	27	13	45
15G	532	24	77	13	10	30
2G	558	22	60	27	13	55
1G	617	43	30	43	27	85
19F	597	47.5	18	51	31	105
18F	597	45	16	53	31	100
21E	525	19.5	26	48	26	110
30G	315	28.5	82	9	9	30
29G	236	8	87	6	7	30
41G	187	5	--	--	--	35
1F	164	10.5	82	5	13	30
43G	154	11.5	85	7	8	40

*Core 14G was divided into upper 14G U and lower 14G L parts for analysis.

Table modified from University of Washington Department of Oceanography 1952b.

Natural Radioactivity of Bottom Sediments

The radium content of bottom sediments collected at various locations in Puget Sound and adjoining waters over a depth range of 15 to 1,500 feet had been determined by Utterback, Sanderman, and co-workers (Blank 1950; Burcham 1942; Creager 1948; Reinertsen 1947; Sanderman and Utterback 1941; Utterback and Sanderman 1938, 1948; Wilson 1942). The analyses are summarized in Table 4-6. Unless otherwise indicated the values are for grab or core samples and are reported on a dry weight basis.

The radium content of sediments in the region from Puget Sound to southeastern Alaska vary from 0.16×10^{-12} to 1.57×10^{-12} grams of radium per gram of dry sample with an average for core samples in the Puget Sound area of 0.5×10^{-12} to 0.6×10^{-12}. Concentrations in glacial-fed inlets of southeastern Alaska average over twice that for the Puget Sound area. The radium content of these coastal and near-shore sediments appears comparable to that of rocks in the vicinity or in tributary drainage basins. Studies for the variation of radium content of the sediments with grain size and geological character of the sediment, for depth within the cores, and evidences of biological concentration, have not as yet shown any definite patterns locally useful for identifying the sediment layers or establishing the origin, and movement of the sediments.

The uniformly low values of the inshore sediments are in contrast to higher values averaging about 8×10^{-12} with a range of 1.9×10^{-12} to 21.4×10^{-12} g. Ra/g. sample reported for 16 offshore sediment samples collected by the CARNEGIE in the North Pacific (Piggot 1933) and to the lower average value of 8×10^{-15} grams of radium per cubic centimeter of water reported for sea water off the California coast (Evans, Kip, and Moberg 1938). Radium analyses of local waters from the vicinity of San Juan Islands show a radium concentration of 5×10^{-15} grams of radium per cubic centimeter of water (Devaputra, Thompson, and Utterback 1932) and 6×10^{-17} grams of radium per cubic centimeter of water by more refined analytical methods (Evans, Kip, and Moberg 1938). Accepting the latter figure the local sediments contain about 10,000 times the radium concentration as the overlying water.

Special Studies

In certain areas of Puget Sound anomalous conditions exist in which coarse materials by-pass finer sediments and move into the deeper basins leaving fine sediments on the slopes.

The University of Washington Department of Oceanography, as authorized by the Bonneville Power Administration, is currently [1952] studying

TABLE 4-6. Radium Concentration of Bottom Samples Collected in Puget Sound and Adjoining Regions.

LOCATION	TYPE OF SAMPLE	NO. OF SAMPLES	RADIUM CONTENT 10^{-12}g. Ra / g. sample Range	Mean
Puget Sound (Southern and main Sound)	Grab	5	0.26-0.40	0.37
Tacoma Narrows (Bridge pier borings 10 to 120 feet)	Boring	8	0.44-0.63	0.54
Hood Canal	Core	5	0.33-0.86	0.51
Admiralty Inlet	Grab	1	0.40	0.40
Skagit Bay to Saratoga Passage	Core	4	0.53-0.65	0.58
East Sound	Grab-core	4	0.41-0.60	0.50
Strait of Juan de Fuca	Grab	2	0.37-0.49	0.44
Strait of Georgia (Near Mouth of Fraser River)	Grab	3	0.30-0.64	0.52
Vancouver Island and British Columbia inshore waters 49°30' N to 51°10' N	Grab	12	0.16-0.30	0.24
Queen Charlotte Islands inshore waters	Grab	6	0.40-0.75	0.53
British Columbia and Alaska inshore waters 54°05' to 59°14' N	Grab	23	0.47-1.57	0.97
Southeastern Alaska (Selected glacial-fed inlets--Portland Canal, Taku Inlet, Lynn Canal, 55°44' to 59°14' N)	Grab	8	1.13-1.57	1.37

Table summarized from Blank 1950; Burcham 1942; Creager 1948; Reinertsen 1947; Sanderman and Utterback 1941; Utterback and Sanderman 1938, 1948; Wilson 1942.

the sediments of Puget Sound in connection with a proposed cable crossing between Point Wells and President Point. The Puget Sound sediments are also being studied by Mr. Frank Wang of the Oceanographic Laboratories of the University of Washington, and will be described in detail in a forthcoming doctoral dissertation.

SUBMARINE SLUMPING AND LANDSLIDING

No work is known to have been done in Puget Sound on the problem of submarine slumping and landsliding. The only major investigation known to be in progress is the one currently sponsored by the Bonneville Power Administration for the Snohomish-Kitsap Submarine Cable Crossing. Quoting in part from an unpublished report the following problem is outlined:

> Soundings and profile obtained across the Puget Sound Channel opposite Richmond Beach now show a portion on both sides to have an abnormally steep slope, approaching 1 on 1 1/2. Core sampling definitely indicates a bedrock formation known as the Admiralty clay, to be exposed on a portion of this slope. These banks are too steep for water saturated sediment to accumulate and a limited amount of sloughing or submarine landsliding undoubtedly may take place whenever the quantity of muck becomes too great.

(U. S. Dept. of the Interior Bonneville Power Administration 1952).

The report further states that these steep banks may represent a line of old shore line cliffs, now flooded by the regional rise in ocean level. Additional evidence could be interpreted suggesting that these steep slopes represent lines of intermittent displacement or fault rift coincident with earthquake tremors in the Puget Sound area (Newcomb 1949). See section on Seismology.

ALONGSHORE TRANSPORT

Transportation alongshore often begins in drowned valleys, such as Puget Sound, during the adolescent stage of development. As the supply of sediment from the rivers and shore erosion increases beyond the stage of immediate deposition transportation alongshore will commence and the growth of forelands will take place.

Tidal Cusps

Numerous examples of tidal cusps are to be found in Puget Sound. F. P. Gulliver (Gulliver 1898) describes the cuspate forelands and alongshore features of Puget Sound as being in several categories of which the V-Bar and Lagoon-Marsh type constitute textbook examples. Examination of the U. S. Coast and Geodetic Survey charts will reveal many examples in addition to those shown by Gulliver.

Chart 6405.
V-Bar: Walan Point, Kala Point
Lagoon-Marsh: south of Pt. Hudson at Port Townsend, Pt. Wilson;
Spit: north of Marrowstone Island, south of Indian Island.

Chart 6421.
Lagoon-Marsh: west of Foulweather Bluff;
Spit: north of South Point;
Tombolo: Hood Head.

Chart 6422.
Lagoon-Marsh: Broad Spit;
Spit: Long Spit.

Chart 6445.
V-Bar: Point Monroe;
Lagoon-Marsh: West Point, Point Jefferson, Meadow Point, President Point;
Spit: Miller Bay.

Chart 6446.
Lagoon-Marsh: Point Williams.

Chart 6461.
Tombolo: Steamboat Island.

Puget Sound offers an excellent opportunity to study these shore processes. With the aid of Topographic Survey charts of the U. S. Coast and Geodetic Survey, the progress or evolution of these features may be easily traced. Should this be undertaken, much insight may be had on the problem of the overall sedimentation rate in the Sound.

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SECTION 5: VOLCANOLOGY

15 January 1953

VOLCANOLOGY

VOLCANIC PEAKS

The volcanic peaks of the Cascade Mountains of western Washington are Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams (Fig. 1-3). The volcanic peaks are composed largely of dark, basaltic lavas which accumulated around the vents (Coombs 1939).

There are no volcanic peaks in the Olympic Mountains.

Eruptions and Activity

Only Mount St. Helens is known to have had recent eruptions. Eruptions were reported in 1842 and 1854. Pumice was deposited in the vicinity of The Dalles, Oregon, following the 1842 eruption (Verhoogen 1937).

Activity of Mount Baker was reported in 1854, 1858, and 1870 (Davidson 1885). Neither ash nor lava were ejected during the reported activity.

Volcanic activity has been reported in association with seismic disturbances, but in none of the reported instances were ash or lava ejected. Mount Rainier has been the subject of most of the reports. Mount Rainier is surrounded by lava flows and has volcanic ash on the northeast side. The flows and the ash deposits are of limited extent reaching but a few miles from the base of the mountain. Steam, in minor amounts, occasionally issues from the summit crater of Mount Rainier (Coombs 1935). Mount Baker and Mount Adams also emit a small quantity of gas and steam.

VOLCANIC DEPOSITS

Deposits of pumicite are found to the northeast of Glacier Peak and Mount St. Helens, but neither of these locations are within the Puget Sound Basin (Carithers 1946).

A layer of volcanic ash ranging in thickness from less than one-quarter inch to about two inches has been found in various scattered peat bogs of Puget Sound (State of Washington Department of Conservation and Development 1952). The ash apparently came from a single source which is believed to be Glacier Peak. Deposition was probably about 6,000 years ago. The ash has been used as a basis of correlation in determining the post Pleistocene forest succession in the Puget Sound area (Hansen 1947).

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(Description of the general geology, petrography, physiography and geomorphology of the park.)

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1938b. Volcanism in the Cascade Range. The Mountaineer, vol. 31, no. 1, pp. 23-24.
(Description of locations and activity of volcanoes.)

1939. Mount Baker, a Cascade Volcano. Bulletin of the Geological Society of America, vol. 50, no. 10, pp. 1493-1509.
(A petrologic study of the lavas.)

Davidson, George
1885. Recent Volcanic Activity in the United States. Science, vol. 6, p. 262.
(Discussion of the eruptions of Mount Baker in 1854, 1858, and 1870.)

Diller, J. S.
1899. Latest Volcanic Eruptions of the Pacific Coast. Science, new series, vol. 9, pp. 639-640.
(Discussion of evidence of a recent eruption of Mount St. Helens.)

Emmons, S. F.
1877. The Volcanoes of the United States Pacific Coast. Bulletin of the American Geographic Society of New York, vol. 9, pp. 25-60.

Hagne, Arnold and Joseph P. Iddings
1883. Notes on the Volcanoes of Northern California, Oregon, and Washington Territory. American Journal of Science, 3d Series, vol. 26, no. 152, pp. 222-235.
(Relationship of volcanoes including those adjacent to the Puget Sound area.)

Hanson, H. P.
1947. Postglacial Forest Succession, Climate and Chronology in the Pacific Northwest. Transactions of the American Philosophical Society, vol. 37, 137 pages.
(Occurrence of volcanic ash layers in peat bogs may possibly be used for chronology.)

Russell, I. C.
1897. Volcanoes of North America. The MacMillan Co., New York, 346 pages, illustr., index.
(Contains brief descriptions of Mount St. Helens, Mount Rainier, and Mount Baker.)

State of Washington Department of Conservation and Development
1952. Personal communication on Volcanic Ash in the Puget Sound Area. Letter from Marshall T. Huntting, Geologist, Division of Mines and Geology, to Frank H. Wang, dated June 27, 1952.
(A statement concerning the occurrence and location of ash deposits in the state and Puget Sound area.)

Verhoogen, Jean
1937. Mount St. Helens, A Recent Cascade Volcano. University of California Publications, Bulletin of the Department of Geological Science, vol. 24, no. 9, pp. 263-302.

SECTION 6: SEISMOLOGY

15 January 1953

SEISMOLOGY

SEISMIC ACTIVITY

The Puget Sound Basin is the southernmost portion of a seismic belt that extends to Alaska (Gutenberg 1950). The major shocks occur in the south end of the Puget Basin and the seismic activity dies out just south of Olympia (Fig. 6-1). Some of the shocks are slightly deeper than normal (Vesanen and Jones 1951a).

A catalog of the seismic activity of the Pacific Coast from 1769 to 1928 has been compiled by Townley and Allen (Townley and Allen 1939). Bradford compiled a catalog of the earthquakes of the Puget Sound Basin (Bradford 1935). He found that 181 earthquakes were reported between 1833 and 1934. The number of reported earthquakes has become greater during the recent years. This is probably a reflection of the increase in population rather than an increase in the number of earthquakes.

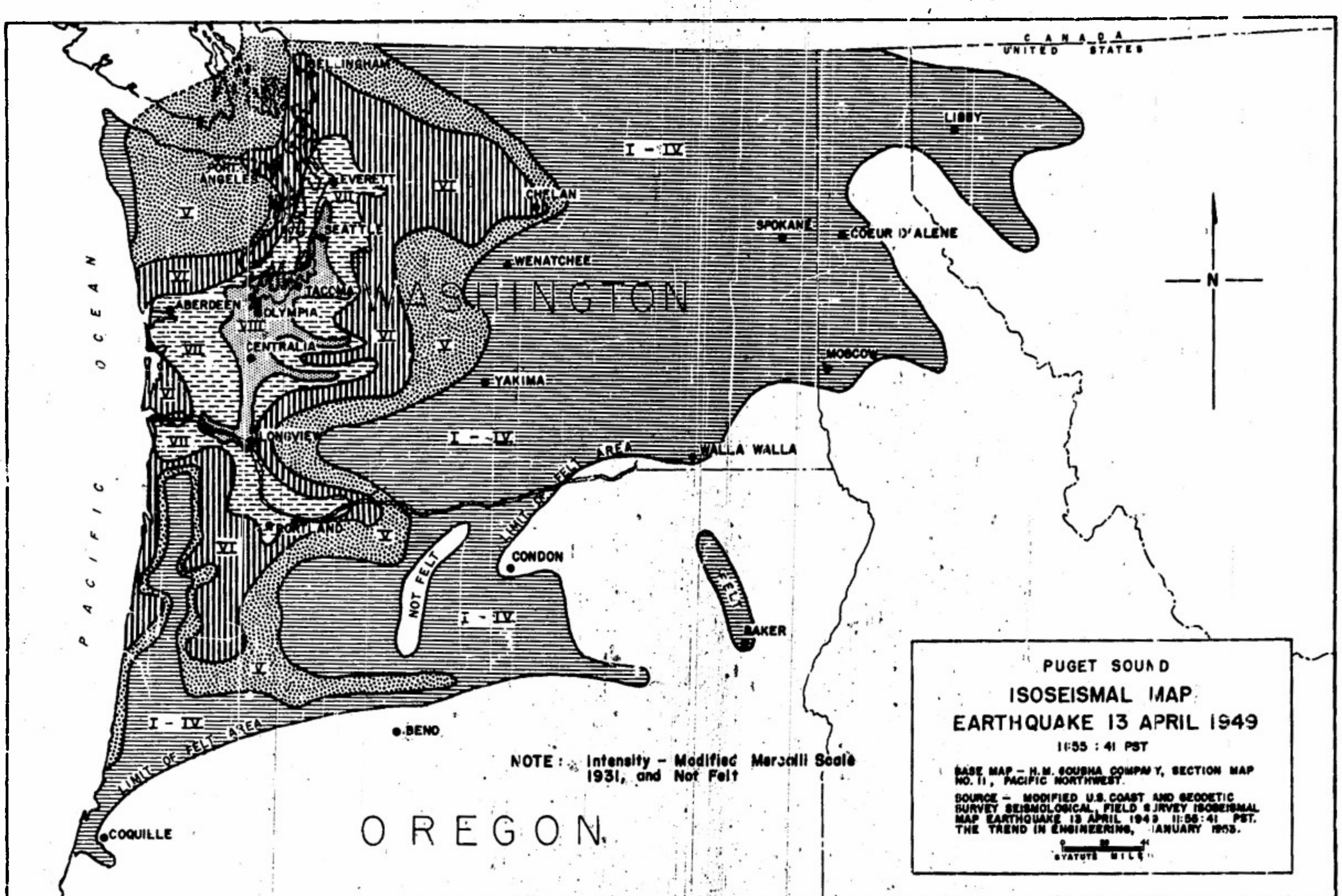
Bradford considered the reports of 116 earthquakes to be reliable. The intensity of these earthquakes range from II to VIII on the modified Mercalli scale. They are tabulated as follows:

Intensity	No. of Earthquakes	Intensity	No. of Earthquakes
II	15	VI	10
III	34	VII	13
IV	30	VIII	1
V	13		Total 116

The other 65 reported earthquakes were probably of very low intensity and local nature.

A study of the Seismological Notes in the various issues of the Bulletin of the Seismological Society of America discloses that 24 earthquakes occurred in the Puget Sound area between the years 1934 and 1952. Four of the earthquakes that occurred during this time were among the most intensive known to this area.

A major earthquake took place on 12 November 1939. Its intensity was VII on the modified Mercalli scale. It caused property damage in the amount of $1,000,000 and was felt over an area of 212,000 square miles. The greatest damage was at Centralia, Elma, and Olympia, Washington (Coombs and Barksdale 1942). The epicenter was located at 47°2' N. lat. and 123°0' W. long. (Heck 1947).



PUGET SOUND
ISOSEISMAL MAP
EARTHQUAKE 13 APRIL 1949
11:55 : 41 PST
BASE MAP - H.M. GOUSHA COMPANY, SECTION MAP NO. 11, PACIFIC NORTHWEST.
SOURCE - MODIFIED U.S. COAST AND GEODETIC SURVEY SEISMOLOGICAL FIELD SURVEY ISOSEISMAL MAP EARTHQUAKE 13 APRIL 1949 11:55:41 PST. THE TREND IN ENGINEERING, JANUARY 1953.
STATUTE MILES
NOTE: Intensity - Modified Mercalli Scale 1931, and Not Felt
CANADA
UNITED STATES
WASHINGTON
OREGON
PACIFIC OCEAN
N
BELLINGHAM
PORT ANGELES
EVERETT
SEATTLE
TACOMA
OLYMPIA
ABERDEEN
CENTRALIA
LONGVIEW
PORTLAND
CHELAN
WENATCHEE
YAKIMA
SPOKANE
COEUR D'ALENE
LIBBY
MOSCOW
WALLA WALLA
CONDON
BAKER
BEND
COQUILLE
LIMIT OF FELT AREA
NOT FELT
FELT
I - IV
V
VI
VII
VIII

Fig. 6-1

The second major earthquake was that of 14 February 1946. This earthquake had an intensity of VII and caused considerable damage in Seattle and Tacoma. (No estimate has been made of the total damage.) Buildings located in fill areas and along the waterfront were the most seriously damaged. The epicenter was located at 47°3' N. lat. and 122°7' W. long. (Barksdale and Coombs 1946).

Earthquakes of Intensity VIII

Two recent earthquakes with provisional epicenters in Georgia Strait, British Columbia, are among the strongest shocks on record for the Puget Sound area.

For the earthquake of 23 June 1946, the following is extracted from Earthquake History of the United States (Heck 1947):

> Heavy damage occurred in the epicentral region. The bottom of Deep Bay in Georgia Strait was reported by the Canadian Hydrographic Department to have sunk from 9 to 84 feet. A 10-foot vertical ground shift occurred on Read Island. Ground settlements up to 100 feet were noted at other points. South of the boundary in the state of Washington some chimneys fell at East Sound and a concrete mill was damaged at Port Angeles. It was felt strongly at Olympia, Seattle, Tacoma, Raymond, and Bellingham. Seattle, where tall buildings were damaged in the upper portions, was the hardest hit in the Puget Sound Area.

One of the severest quakes on record occurred 12 April 1949. It caused the loss of 8 lives, injury to 62 persons, and property damage estimated from 15 million to 50 million dollars. Buildings in fill area were severely damaged but those on undisturbed glacial drift sustained only minor damage (Nuttli 1952). A large portion of a sandy spit jutting into Puget Sound, north of Olympia, disappeared during the earthquake. An isoseismal map of this earthquake is shown in Fig. 6-1. The map shows a maximum intensity of VIII with an epicenter near Olympia.

Transmission of Earthquake Waves

Bradford (Bradford 1932) in his study of microseisms gives data for the rates of transmission of earthquake waves in some of the formations of the Puget Sound region shown in Table 6-1.

Correlation Problems

The relationship of earthquakes to gravity anomalies is discussed in the section on Geodesy under Gravimetric Surveys.

TABLE 6-1. Rates of Transmission of Earthquake Waves in Some Formations of the Puget Sound Region.*

Clallam formation
(Northwest-southeast axis)

	Longitudinal wave	Transverse wave
Average	2.1 km/sec.	1.4 km/sec.
Maximum	3.0 km/sec.	2.0 km/sec.
Minimum	1.0 km/sec.	0.9 km/sec.

Moraine deposits
(An area 41 miles by 36 miles, extending south and southwest from the instrument, with its center at Tacoma.)

	Longitudinal wave	Transverse wave
Average	2.2 km/sec.	1.9 km/sec.
Maximum	4.2 km/sec.	2.7 km/sec.
Minimum	1.4 km/sec.	0.8 km/sec.

Tejon formation

	Longitudinal wave	Transverse wave
Average	2.8 km/sec.	1.9 km/sec.
Maximum	4.2 km/sec.	2.7 km/sec.
Minimum	1.4 km/sec.	0.8 km/sec.

Enumclaw volcanics
(40 miles southeast of the instrument)

	Longitudinal wave	Transverse wave
Average	2.8 km/sec.	1.9 km/sec.
Maximum	4.2 km/sec.	2.7 km/sec.
Minimum	1.4 km/sec.	0.8 km/sec.

*For description of formations, see the section on Geology.

Table compiled from Microseisms, Their Characteristics, Occurrences, and Possible Origin (Bradford 1932).

Special Studies

In the summer of 1951 a group from the Carnegie Institution of Washington made seismic studies in the eastern part of Puget Sound. With the cooperation of the Coast Guard about 20 explosions were made. Seismic recorders were located from Okanogan (150 miles northeast of Seattle) to Hoquiam and to Cape Flattery on the west with numerous points between. Reflections from the expected discontinuity between crustal rocks and the rocks of the mantle were sought but no evidence was found. The final report has not yet been published (Jan. 1953, Carnegie Institution of Washington Department of Terrestrial Magnetism 1953).

SEISMOGRAPH STATIONS

There are only two seismograph stations in operation in the Puget Sound area. There is an instrument at the University of Washington in Seattle and another at Victoria, British Columbia. A United States Coast and Geodetic Survey Seismograph station was installed at Grand Coulee, Washington in 1947, but it has been discontinued.

The University of Washington has a five component Sprengnether Seismograph. It has three short period components (to 1.3 seconds), two horizontal and one vertical. The other two are horizontal long period components (to 8 seconds). The instrument was installed in August, 1949, and the records are on file at the University of Washington, Geology Department. The records for the period from 1906 to 1949 are on file at the office of the United States Coast and Geodetic Survey, Washington, D.C.

The seismology station at Victoria, British Columbia began operating in 1897 with a Milne seismograph for the horizontal components and a Weichert seismograph for the vertical component. In 1922 a Milne-Shaw seismograph was installed and a Benioff vertical seismometer was added in 1948 (Canada Department of Mines and Technical Surveys 1952).

Prior to 1949 accurate instrument data on weak local shocks in the Puget Basin region have been almost entirely lacking.

Seismograph stations are to be established at Longmire, Neah Bay and Olympia, Washington.

A new system for recording, storing and presenting seismographic data has been installed at the University of Washington. The three components of earth displacement are recorded on standard sound-recording magnetic tape. The system is undergoing tests at the present time (Jacobsen and Barter 1952).

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Barksdale, J. D. and H. A. Coombs
1946. The Puget Sound Earthquake of Feb. 14, 1946. Seismological Society of America, Bulletin, vol. 36, pp. 349-354. (Intensity of the earthquake is given as VII. Damage to industrial buildings on filled ground. Epicenter located at $47^{o}3'$ N. lat. and $122^{o}7'$ W. long., 15 miles west of Tacoma and 18 miles north of Olympia.)

Bradford, D. C.
1932. Microseisms, Their Characteristics, Occurrences, and Possible Origin. Thesis, University of Washington, Seattle, Washington, 107 pages. (Contains table of the rates of transmission of earthquake waves through some of the formations of the Puget Sound area.)

1935. Seismic History of the Puget Sound Basin. Seismological Society of America, Bulletin, vol. 25, pp. 138-153. (Earthquake history of Puget Sound with discussion of recorded earthquakes from 1833 to 1934.)

Canada Department of Mines and Technical Surveys
1952. Personal communication on seismic data in Puget Sound. Letter from W. G. Milne, Director, Dominion Astrophysical Observatory, to Peter McLellan, dated July 2, 1952. (Included map of epicenters of 1951 earthquakes in Vancouver Island area and references to research and limitations of the Observatory.)

Carnegie Institution of Washington Department of Terrestrial Magnetism
1953. Personal communication on earth-currents, gravity anomalies, geomagnetism, and seismology in the Puget Sound area. Letter from M. A. Tuve, Director, to Peter McLellan, dated January 13, 1953. (No information on earth-currents, gravity anomalies, or geomagnetism. Seismic work done in the eastern part of Puget Sound.)

Coombs, Howard A.
1952. Seismic Activity in Washington from 1865 to the Present. Bulletin of the Geological Society of America, vol. 63, no. 12, part 2, pp. 1350-1351. (Abstract.)

Coombs, Howard A. and J. D. Barksdale
1942. The Olympic Earthquake of Nov. 13, 1939. Bulletin of the Seismological Society of America, vol. 32, no. 1, pp. 1-6, 1 table, 1 map, 1 photo.
(Earthquake was felt over an area of 212,000 square miles. The maximum intensity was VII on the modified Mercalli scale. Most severe damage at Centralia, Elma and Olympia. Epicenter was near Olympia.)

Gutenberg, B.
1950. Earthquakes in North America. Science, vol. 111, no. 2883, pp. 319-324.
(Broad review of the earthquake zones of North America.)

1952. Microseisms with Periods of 5-8 Seconds in the Pacific Coastal Area, November 25 to December 6, 1951. Bulletin of the Geological Society of America, vol. 63, no. 12, part 2, p. 1353. (Abstract.)
(Original records of microseisms (including Seattle) are studied.)

Heck, N. H.
1947. Earthquake History of the United States: Part I. Continental United States (exclusive of California and western Nevada) and Alaska. U. S. Department of Commerce Coast and Geodetic Survey, Serial 609; 83 pages, Washington, D.C.
(Pages 63 to 69 list earthquakes in Washington and Oregon with descriptions of each.)

Heiskanen, W.
1951. On Seattle earthquakes and gravity anomalies. Bulletin of the Seismological Society of America, vol. 41, no. 4, pp. 303-306, 1 table, 1 map.
(Suggests possible relationships between earthquakes and negative gravity anomalies in the Puget Sound area.)

Holden, E. S.
1887. List of Recorded Earthquakes in California, Lower California, Oregon, and Washington Territory. California State Printing Office, Sacramento.

1898. Catalogue of Recorded Earthquake Shocks on the Pacific Coast, 1769 to 1897. Smithsonian Miscellaneous Collections, no. 1087.)

Jacobsen, A. B. and LeRoy Barter
1952. Seismographic Data Recording System. The Trend in Engineering at the University of Washington, vol. 4, no. 3, pp. 9-12, Engineering Experiment Station, University of Washington. (A new system for recording, storing, and presenting seismographic data is described. The unique features of the instrument are evaluated. The instrument will replace the one now in use at this University and should provide better information on earthquakes in the Puget Sound area.)

McAdie, A. G.
1907. Catalogue of Earthquakes on the Pacific Coast, 1897 to 1906. Smithsonian Miscellaneous Collections, no. 1721, part of vol. XLIX.

Miller, Alfred L.
1943. Earthquake Lessons from the Pacific Northwest. The Trend in Engineering at the University of Washington, vol. 5, no. 1, pp. 13-32, Engineering Experiment Station, University of Washington. (A discussion of the 1949 earthquake from an engineering viewpoint. U.S.C. and G.S. isoseismal map reproduced.)

Nuttli, O. W.
1952. The western Washington earthquake of April 13, 1949. Bulletin of the Seismological Society of America, vol. 42, no. 1, pp. 21-28, 3 text fig. (The earthquake intensity is given as VIII on the modified Mercalli scale, the focal depth was 70 km., and the epicenter was located in Puget Sound, just east of Ketron Island, 10 miles southwest of Tacoma.)

Townley, Sidney D. and Maxwell W. Allen
1939. Descriptive catalogue of earthquakes of the Pacific Coast of the United States 1769 to 1928. Bulletin of the Seismological Society of America, vol. 29, no. 1, pp. 1-279. (Catalogue showing the time, location, duration, and description of each recorded earthquake.)

Ulrich, F. P.
1949. Reporting the Northwest Earthquake. Building Standards Monthly, June, pp. 8-11, photos, isoseismal map. (Description of the damage to the buildings and estimates of the total damage.)

U. S. Department of the Interior Bonneville Power Administration
1952. Communication on fault-offsets in Puget Sound affecting Snohomish-Kitsap Submarine Cable Crossing. Letter from F. W. Farr, Structural Mechanical Unit to A. A. Osipovich, Chief, Transmission Design Section, dated February 21, 1952. (Problems concerning submarine geology and seismology of the area to submarine slumping.)

Vesanen, E. E. and J. W. Jones
n.d. On Seismicity in the State of Washington. To be published in the Transactions of the International Geodetic and Geophysics Union, presented at the Belgium meeting, 1951. (Unpublished.) (Discussion of earthquakes of Washington, with general conclusions.)

1951a. Seismographic Station Bulletin, 1950. University of Washington Publications in Seismology, Seattle, Washington, no. 1, 55 pages.
(The first part of this bulletin contains readings of main impulses of distant shocks; the second part contains readings of the first recorded phase of local and short distant shocks.)

1951b. Seismographic Station Bulletin, July-December, 1949. University of Washington Publications in Seismology, Seattle, Washington, no. 2, 20 pages.

1952. Seismographic Station Bulletin, 1951. University of Washington Publications in Seismology, Seattle, Washington, no. 3, 49 pages (dittoed).
(During 1951, 312 earthquakes were recorded at the University of Washington Seismographic Station. Thirty-three of these shocks were local [distance less than two degrees].)

SECTION 7: GEOMAGNETISM

15 January 1953

GEOMAGNETISM

MAGNETIC OBSERVATIONS

A study of the magnetic observations made in the Puget Sound area discloses no magnetic disturbances of sufficient magnitude to be significant in problems of ships' navigation. The area is probably typical of much of the northwestern part of the United States (U. S. Department of Commerce Coast and Geodetic Survey 1952a).

Publications of the Coast and Geodetic Survey, Serial 602 (Howe and Knapp 1938) and Serial 667 (Deel and Howe 1948), contain results of observations made ~~at~~ magnetic stations in Washington.

Magnetic Surveys

The U. S. Coast and Geodetic Survey has been making magnetic observations since 1833 and since 1947 has been collecting results of magnetic observations from the entire world. Principal efforts of the Coast Survey's research are directed toward the study of the compass, i.e., magnetic problems of secular change, magnetic fields, and the construction of magnetic charts.

Magnetic Charts

The following charts are available which include the Puget Sound area in their scope:

(1) Isogonic Chart for 1945, United States.
(2) Isoclinic Chart for 1945, United States.
(3) Lines of Equal Horizontal Intensity for 1945, United States.
(4) Lines of Equal Vertical Intensity for 1945, United States.
(5) Changes of the Magnetic Elements from January 1, 1935 to January 1, 1945. (Including Isoporic Lines.)

Aeromagnetic Surveys

No aeromagnetic maps are available for the Puget Sound area. Two aeromagnetic maps of southwest Washington have recently been placed in the open file of the Geological Survey in Washington, D.C. An aeromagnetic profile along the Washington coast from Grays Harbor, north to approximately the Hoh River, has been flown by the Geological Survey. This material has not yet been compiled (U. S. Department of the Interior Geological Survey 1952).

Correlation Problems

No correlation is known to exist between the problems of geomagnetism and gravity and those of seismicity (U. S. Department of Commerce Coast and Geodetic Survey 1952). For relationship of earthquakes to gravity anomalies, see Gravimetric Surveys in section on Geodesy.

EARTH-CURRENTS

Earth-currents (natural electric currents in the ground) are at times large enough to affect the operation of telegraph lines and electric power systems. No general survey of these conditions has been made in Puget Sound. However, conditions causing such earth-currents, as the rapid surge of tidal currents in the various passages, though they may be predominantly local in character, are numerous and theoretically of frequent occurrence. Earth-currents are a possible source of error where highly sensitive electrical recording and detecting instruments are used in oceanographic or other research.

Letters were sent to the various telegraph and electric power companies operating along the shores of Puget Sound to determine whether or not earth-currents have been a factor in actual operational experience.

Operational Experience

The Western Union Telegraph Company reports as follows:

> A number of years ago our telegraph lines were affected by earth-current storms. However, at this time our circuits were working physical with ground return between cities located in different parts of the country. For the past several years most of our facilities were established with carrier operation and we have not experienced any trouble due to earth-currents since carrier operation was initiated.
>
> Our terminating equipment on the carrier channels is electronically connected to various locations within the Puget Sound area.

(The Western Union Telegraph Company 1952).

The experience of the Pacific Telephone and Telegraph Company is as follows:

> Earth potential differences (caused by earth-currents) have resulted in difficulties in the operation of our ground return

telegraph circuits. Such difficulties were variant in nature and apparently reached their worst peaks during periods of magnetic storms. This interference was somewhat troublesome and among other considerations probably hurried the replacement of ground return facilities with those of the carrier and voice frequency types which effectively use a metallic wire path instead of ground return. This type of facility is now employed almost entirely in the provision of our long and medium haul telegraph facilities.

We still have many short haul telegraph facilities and dial impulse circuits which use ground return and which could be subject to interference caused by ground potential differences. However, this interference has been overcome by using a compensating wire or leg to neutralize the effect of ground potential difference.

Since the objectionable effects of earth currents on our facilities have been largely overcome for some years, we have not believed it necessary to instigate any study on this subject, nor have we made any summary of such troubles as may be recorded on our telegraph operation daily logs.

(The Pacific Telephone and Telegraph Company 1952).

The Bonneville Power Administration reports as follows:

Please be advised that no abnormal conditions that could be attributed to such currents were observed in our system, including its electronic equipment in communication. It should be kept in mind, however, that our system went into operation to a large extent only for the last ten years, i.e., before the last strong sun spots disturbance took place.

(U. S. Department of the Interior Bonneville Power Administration 1952).

The Coast and Geodetic Survey does not have any information concerning earth currents in the Puget Sound area (U. S. Department of Commerce Coast and Geodetic Survey 1952a).

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(No information on earth-currents, gravity anomalies, or geomagnetism. Seismic work done in the eastern part of Puget Sound.)

Deel, Samuel A.
1946. Magnetic declination in the United States, 1945. U. S. Coast and Geodetic Survey, Serial 664, 67 pages, Washington, D.C.
(Intended for use in making compass surveys. Contains the distribution of the magnetic declination in the United States and its annual rate of change for the beginning of 1945. Puget Sound area included.)

Deel, Samuel A. and H. Herbert Howe
1948. United States magnetic tables and magnetic charts for 1945. U. S. Coast and Geodetic Survey, Serial 667, 137 pages, Washington, D.C.
(Contains observed values and 1945 values of declination, dip, and horizontal intensity for all repeat stations and similar data for other observations from 1937 to 1947; secular-change tables and magnetic charts.)

Howe, H. Herbert and David G. Knapp
1938. United States magnetic tables and magnetic charts for 1935. U. S. Coast and Geodetic Survey, Serial 602, 163 pages, Washington, D.C.
(Contains observed values and 1935 values of the magnetic declination, dip, and horizontal intensity for all stations occupied about 1937; secular change tables and magnetic charts.)

The Pacific Telephone and Telegraph Company
1952. Personal communication on Earth Currents in the Puget Sound Area. Letter from R. D. Miller, Chief Engineer, Seattle Office for Washington and Idaho Area, to Peter McLellan, dated Aug. 22, 1952.
(Earth potential differences have resulted in difficulties in operation of ground return telegraph circuits. Magnetic storms were periods of peak difficulties. These objectional effects have been overcome.)

University of Wisconsin Department of Geology
1952. Personal communication on Gravity and Magnetic Studies in the Puget Sound Area. Letter from G. P. Woollard, to Peter McLellan, dated Oct. 31, 1952.

U. S. Department of Commerce Coast and Geodetic Survey
1950. Isogonic Chart for 1950, United States. Chart no. 3077, scale 1:5,000,000.
(Includes adjacent parts of Canada and Mexico. One of a series issued at 5-year intervals.)

1952a. Personal communication on Magnetic Observations in the Puget Sound Area. Letter from Robert W. Knox, Acting Director, to Peter McLellan, dated Aug. 13, 1952.
(No magnetic disturbances of significant magnitude occur in Puget Sound to be significant in problems of ships' navigation.)

1952b. Personal communication on Magnetic Surveys in Puget Sound Area. Letter from Elliott B. Roberts, Chief, Division of Geophysics, Washington, D.C., to Peter McLellan, dated Nov. 28, 1952.
(No aeromagnetic surveys or unpublished data.)

U. S. Department of the Interior Bonneville Power Administration
1952. Personal communication on Earth-Currents in the Puget Sound Area. Letter from O. A. Demuth, Chief, Branch of System Engineering, Portland, Oregon, to Peter McLellan, dated Aug. 22, 1952.
(No abnormal conditions observed but the system was not in operation during the last strong sunspot disturbance.)

U. S. Department of the Interior Geological Survey
1952. Personal communication on Aeromagnetic Surveys in Puget Sound Area. Letter from H. R. Joesting, Chief, Geophysics Branch, Washington, D.C., to Peter McLellan, dated Nov. 28, 1952.
(Two aeromagnetic maps of southwestern Washington are in open file. A profile along the coast is being compiled.)

The Western Union Telegraph Company
1952. Personal communication on Earth Currents in the Puget Sound Area. Letter from R. W. Sikora, Area Superintendent, Plant and Engineering, Portland Area, Portland, Oregon, to Peter McLellan, dated Aug. 20, 1952.
(In the past, telegraph lines were affected by earth current storms. The ground return circuits have since been replaced.)

SECTION 8: GEODESY

29 April 1953

GEODESY

BASIC CONTROL AND MAPPING

DATUM

Mean lower low water is the datum for nautical charts in the Puget Sound region. Topographic mapping by the U. S. Coast and Geodetic Survey is referred to the mean high water datum. Topographic mapping by the U. S. Geological Survey and other agencies is referred to mean sea level. Refer to section on Oceanography: Tides, for derivation of the tidal datum planes for Puget Sound.

CONTROL SURVEY NETS

The two control survey nets extended into the Puget Sound area by the U. S. Geological Survey, U. S. Coast and Geodetic Survey, and U. S. Engineers, for control as used in nautical charts and topographic maps, now has been established as set forth below.

Horizontal Control

The horizontal control survey net consisting of arcs of first- and second-order triangulation has been completed. This control network is shown on "Triangulation Diagram, State of Washington," published in 1950. Additional triangulation in the Puget Sound area can be found on U. S. Coast and Geodetic Survey Triangulation Diagram charts 6380, 6382, 6449, 6450, and 6460. While complete and adequate for hydrographic surveying, this network is not adequate for large scale planimetric mapping.

Since many of the triangulation markers are constantly being destroyed by man and the sea, a constant replacement program is necessary to preserve the present network of triangulation markers. Almost all those installed along the edge of southern Puget Sound in the survey of 1935 have since been destroyed due to wave action and slumping of the land. Destruction also results from human activities in construction within and around metropolitan areas of the Sound.

First- and second-order triangulation is generally conducted by the U. S. Coast and Geodetic Survey for both geodetic investigation and map control. Lower orders of triangulation intended only for map control are undertaken by the U. S. Geological Survey.

Vertical Control

The vertical control survey net consisting of lines of first- and second-order spirit leveling which is the basis for determining elevations has not been completed. This control network is shown on "Index Map, Control Leveling, State of Washington" published in 1950. At the present time [1952] work is being done in the northern Puget Sound area in the vicinity of Blaine, Marysville, Burlington, Anacortes, and Oak Harbor. Areas of Puget Sound not covered by control leveling are Whidbey Island, Camano Island, the San Juan Islands, and part of the Great Peninsula.

TOPOGRAPHIC MAPPING

Many of the quadrangle sheets of the Topographic Map of the United States, Washington, were completed about the year 1900 by the U. S. Geological Survey. The U. S. Engineers in recent years have cooperated with the U. S. Geological Survey in revising some of the older topographic maps, and in completing additional maps by photogrammetric means. The status of topographic mapping is shown on "Index to Topographic Mapping, State of Washington."

Mapping of the shore topography adjacent to Puget Sound is carried out in detail with each hydrographic survey by the U. S. Coast and Geodetic Survey. See section on Hydrography: Topographic Surveys, for reference to indices.

Private Cartographic Establishments

Maps and charts produced by private cartographic establishments in the Puget Sound area cover a wide variety of types and uses, but the types produced in the largest quantity are the communication and recreation maps for advertising. The private map companies conduct no field surveys but use material available in existing charts and maps. In areas where the land is not adequately mapped, base maps are traced from out-of-date maps or from aerial photos, which probably were drawn or flown for other purposes and are inaccurate.

Status of Cartography

Table 8-1 displays the status of cartography in the Puget Sound area outlining what services are available and the types of maps and charts that are produced in and for the area. Appendix 8-A provides a listing of local maps, charts, and indices.

TABLE 8-1. Status of Cartography in the Puget Sound Area.

ORGANIZATION	MAP AND CHART SERVICE PROVIDED						TYPE OF MAPS AND CHARTS PRODUCED									
	Field Mapping	Office Drafting	Maps Completed	Contract Work	Full-time Co.	Map Repro.	Distri-bution	Naviga-tion	Topo-graphic	Plani-metric	Outline	Cadas-tral	Communi-cation	Recrea-tion	Resource
USCE, Seattle	X	X	X						X	X					
Bonneville Power Adm., Portland	X	X	X			X	X							X	X
USC & GS, Seattle	X	X			X		X	X							
US Forest Service, Portland	X	X	X			X	X		X	X				X	X
USGS, Sacramento	X				X		X		X	X					X
US Soil Conservation Service, Portland	X	X	X				X		X	X					X
Dept.of Mines & Tech. Surveys, Ottawa	X				X		X		X	X				X	X
Dept.of Lands & Forests, Victoria	X	X	X		X	X	X		X	X				X	X
Kroll Map Co., Seattle		X	X	X	X	X	X					X	X	X	X
Maps Unlimited, Seattle		X	X	X		X	X				X		X	[illegible]	X
Metsker Maps, Seattle		X	X	X	X	X	X								
Northwest Mapping, Seattle		X	X	X	X	X	X				X	X	X	X	X
U.of W. Carto. Lab., Seattle		X	X	X		X					X	X	X	X	X

DEVELOPMENT OF NEW TECHNIQUES. A plastic shading technique (Heath 1952) has been perfected under the direction of Dr. John C. Sherman of the University of Washington Department of Geography. This rapid method of applying relief to a map has been used in the construction of Fig. 1-3.

PHOTOGRAMMETRIC MAPPING

The Puget Sound Basin has been completely covered by one set of vertical aerial photos, which were taken by the United States Army in 1936. Some later aerial surveys have been completed, but such coverages have been scattered and in most cases flown by inexperienced personnel. Of these later aerial surveys, the best photography was attained by surveys undertaken for private or federal timber surveys.

The majority of the aerial photos in this area are not used in mosaic construction or photo-interpretation work, but as individual vertical or oblique pictures. Aerial photo use in mosaic construction and photo-interpretation has usually been confined to soil or tree typing by the U. S. Soil Conservation Service and U. S. Forest Service.

Procurement of Aerial Photos

Two indices entitled, "Status of aerial photography of the United States" and "Status of aerial mosaics or photo maps of the United States," are published by the U. S. Geological Survey, Washington 25, D.C. This agency also maintains a Map Information Office which will, on request, furnish information on the status of the latest coverage of maps or aerial photos for any specific area. This information includes the scale of the photos, and the agencies that have negatives.

Other government agencies have index sheets showing aerial photo coverage which are generally on fifteen minute quadrangles or on a county basis. Most private photogrammetric organizations also have index maps that can be consulted at their respective offices.

An index map of aerial photography of Canada is available through a central agency, the National Air Photo Library, Ottawa.

Status of Photogrammetry

Table 8-2 displays the status of aerial photogrammetry in the Puget Sound area outlining such items as availability and procurement, etc.

TABLE 8-2. Status of Photogrammetry in the Puget Sound Area.

ORGANIZATION	USE OF PHOTOS BY AGENCY		AVAILABILITY AND PROCUREMENT OF AERIAL PHOTOS						AERIAL SURVEY FACILITIES		PHOTO INTERPRETATION	
					Aerial Coverage		Photos Available					
	Map Const.	Mosaic Const.	Index Sheets	Photos	Verticals	Obliques	Headquarters	Regional or Local Office	Aerial Camera	Air Plane	Use of Keys	Interpretation
USCE, Seattle	X	X										
USC & GS, Wash., D.C.	X	X			X	X	X					
US Forest Service, Portland	X	X		X	X	X		X			X	X
USGS, Wash., D.C.			X	X	X	X	X					
US Prod.-Marketing Adm., Salt Lake City	X	X	X	X				X				
US Soil Conservation Service, Wash., D.C.	X	X					X				X	X
Dept. of Mines & Tech. Survey, Ottawa			X	X	X	X	X					
Dept. of Lands & Forests Air Surveys Div., Victoria	X	X	X	X	X	X	X		X	X		X
Carl M. Berry Photogrammetric Eng., Seattle	X	X		X	X	X	X		X	X		X

TABLE 8-2. Status of Photogrammetry in the Puget Sound Area (continued).

ORGANIZATION	USE OF PHOTOS BY AGENCY		AVAILABILITY AND PROCUREMENT OF AERIAL PHOTOS						AERIAL SURVEY FACILITIES		PHOTO INTERPRETATION	
					Aerial Coverage		Photos Available					
	Map Const.	Mosaic Const.	Index Sheets	Photos	Verticals	Obliques	Headquarters	Regional or Local Office	Aerial Camera	Air Plane	Use of Keys	Interpretation
Gardner & Hitchings Inc., Seattle	X											X
Hayner & Assoc., Seattle	X											X
Herold Aerial Photos, Seattle				X	X	X	X		X	X		
Pacific Aerial Surveys, Seattle		X		X	X	X	X		X	X		
North Seattle Airpark Inc., Bothell, Wash.									X	X		
Aero Survey Ltd., Vancouver, B.C.	X	X		X	X	X	X		X	X		X
Photographic Surveys (Western), Vancouver, B.C.	X	X		X	X	X		X	X	X		X

SPECIAL TECHNIQUES. The United States Soil Conservation Service and the United States Forest Service have developed special use interpretation keys designed for typing soils and trees from aerial photos in the Puget Sound Basin.

A new technique in determining current measurements has been developed by the U. S. Army Corps of Engineers at the Portland District Office. This technique uses aerial photos to ascertain river currents in areas which are inaccessible or where the current is so rapid that ordinary methods cannot be employed (Oros 1952).

SPECIAL AIDS TO NAVIGATION

Puget Sound is easily navigated in clear weather. It is one of the few sheltered areas on the north Pacific coast that may be entered in all weather conditions. See section on Geography: Shore Line Features for additional discussion.

During periods of reduced visibility local mariners have relied upon the echo from their vessel's whistle to maintain a mid-channel course. Radar now supplements this advantage, utilizing the steep bluffs found along the Sound. The great depth of water renders the hand lead useless in many places.

At the present time [1952] the Coast and Geodetic Survey supplies 16 charts that cover the Puget Sound area. Shown on these charts are about 67 lights, 30 buoys, 27 fog signals, 3 radio beacons, and 1 radio direction finder calibration station--all maintained by the U. S. Coast Guard. There are also many specially marked stacks, pile dolphins, and privately maintained lights. All known publications concerning navigational aids in Puget Sound are included in the bibliography for this section.

GRAVIMETRIC SURVEYS

GRAVIMETRIC OBSERVATIONS

In 1951 the University of Washington Department of Geology began a regional study of the magnitude and distribution of gravity anomalies in the state of Washington. Gravity observations are being made at intervals of five to ten miles along traverse routes spaced approximately fifteen miles apart throughout the state. Three hundred and fifty observations have been made in the Puget Sound Basin. The program will take at least two and one-half years for completion (Jones 1952a).

During the period 1891 to 1951, fewer than fifty gravity observations were made in western Washington.

Evaluation of Gravity Observations

Anomalies found in the Puget Basin indicate the presence of some of the largest negative and positive gravity anomalies in the United States. The magnitude and the abruptness of change of the anomalies (Fig. 8-1) are indicative of large disturbing masses of rock close to the surface of the earth. Preliminary correlations indicate definite relationships between surface geology and the anomalies. The anomalies are too large, however, to be explained entirely by superficial geologic structure (Jones 1952a).

Correlation Problems

From an article entitled, "Gravimetry at the University of Washington," by John W. Jones, the following paragraph is quoted:

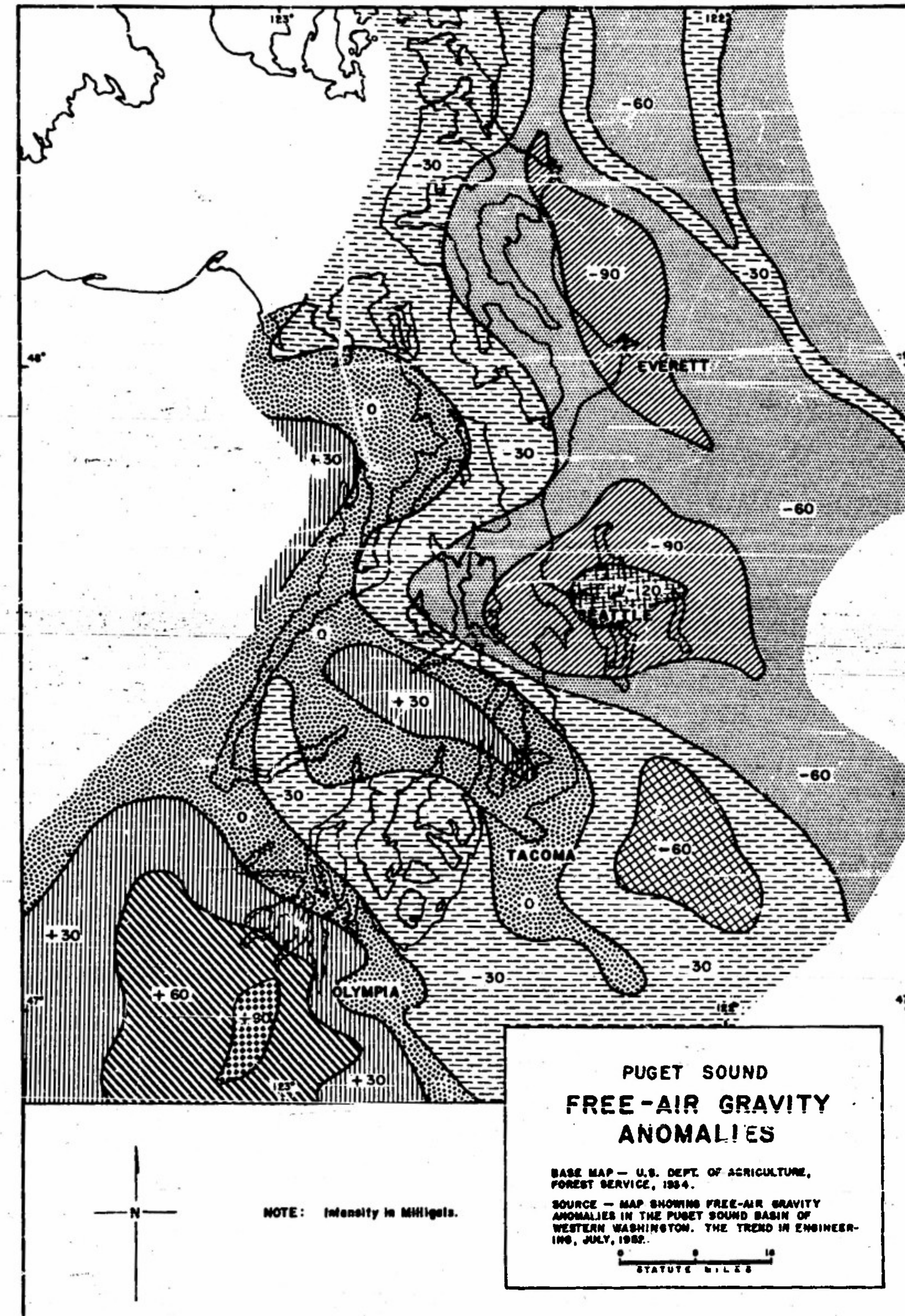
> The relationship of anomalies to earthquakes has been one interesting development in this study. The line of maximum seismic activity extends through the center of the Puget Basin along a north-south line closely following the deep negative anomaly depressions shown on the map. The negative "hollows" at Seattle, Everett, and to the north of Everett are locations where seismic activity has been concentrated in the past. The area where the anomalies change from strongly negative to strongly positive in the vicinity of Olympia is the site of another concentration of seismic activity. To the east of the axis of the basin at locations of less pronounced negative "hollows" or eastward extensions of the large anomaly depressions, minor concentrations of earthquakes occur. This evidence certainly indicates that the earthquakes are related to

the large variations of gravity. Since large blocks of rock displaced from their normal positions in the earth's crust by regional forces are one cause of gravity anomalies, we might well expect the anomalies to have a relationship to earthquakes, which are manifestations of such forces.

(Jones 1952a.)

DEFLECTION OF THE VERTICAL

Additional data pertinent to gravity investigations in the Puget Sound are those of deflections of the vertical. The strong deflections in the area reduce the validity of precise position fixing. Results of stations occupied in the Puget Sound area are presented in Table 8-3.



PUGET SOUND
FREE-AIR GRAVITY
ANOMALIES
BASE MAP — U.S. DEPT. OF AGRICULTURE, FOREST SERVICE, 1934.
SOURCE — MAP SHOWING FREE-AIR GRAVITY ANOMALIES IN THE PUGET SOUND BASIN OF WESTERN WASHINGTON. THE TREND IN ENGINEERING, JULY, 1952.
STATUTE MILES
NOTE: Intensity in Milligals.
N
EVERETT
SEATTLE
TACOMA
OLYMPIA
-60
-30
-90
-120
0
+30
+60
+90

Fig.8-1

TABLE 8-3. Deflections of the Vertical in the State of Washington - Puget Sound Area.

Geodetic Station		Latitude			A-G in meridian	Longitude				A-G in prime vertical
No.	Name	Year	Astronomical	Geo-detic		Year	Astronomical	Geo-detic	A-G	
			° ′ ″	″	″		° ′ ″	″		″
693	Alki (Alki south-west base)	- -	47 34 ----	34.502	- -	1923	122 25 07.92	09.152	- 1.23	- 0.83
694	Ayocks Point 2	- -	47 30 ----	26.485	- -	1935	123 02 54.80	71.614	-16.81	-11.36
697	King	1935	47 43 08.79	13.165	-4.38	1935	122 44 37.15	50.430	-13.28	- 8.93
698	Miller	- -	48 59 ----	19.366	- -	1908	122 45 10.77	00.940	9.83	6.45
701	Port Townsend astronomical	- -	48 07 ----	03.983	- -	1888	122 45 04.10	13.635	- 9.54	- 6.37
702	Tacoma astronomical station	1894	47 15 46.96	46.825	.14	1894	122 26 52.76	50.152	2.61	1.77
703	Union	1935	47 21 26.47	27.370	- .90	1935	123 06 06.29	11.936	- 5.65	- 3.83
706	Wash 2	1935	47 21 22.26	29.713	-7.45	1935	122 48 20.99	21.020	- .03	- .02

Table modified from Duerksen (Duerksen 1941).

Appendix 8-A

MAPS, CHARTS, AND INDICES FOR PUGET SOUND

Anderson, Oliver P. and Company (Seattle)
1889. Guide Map of Seattle.
(Shows tideland to be filled and canal to be constructed by Seattle and Lake Washington Waterway Company.)

Arrowsmith, John
1859. Map of the Province of British Columbia and Vancouver Island with portion of United States and Hudson Bay Territories.

Automobile Club of Washington
1952a. Lake Washington - Quadrangle 2.

1952b. Mount Baker - Quadrangle 1.

1952c. Mount Rainier - Quadrangle 3.

1952d. Olympic Peninsula - Quadrangle 6.

1952e. Willapa Bay - Quadrangle 5.
(Takes in the Olympia, Washington area.)

Babcock, Garrison
1936. Puget Sound Flood Control and Power Development. (A state improvement project. 4 maps. Blue Line.)

Baker, Charles H. and Company (Seattle)
1891. Birds-eye View of the Puget Sound Country.
(An accurate perspective projection showing the topography, resources and development of northwest Washington and British Columbia.)

Bowman, Amos
1894. Map of Fuca's Sea (sometimes called Puget Sound).
(British Columbia and Washington territory and its relation to the River Valleys and interoceanic traffics of the world, 4 insets showing details of harbor and railroad lines.)

British Admiralty, His Majesty's Stationery Office (London)
1934-1945 British Admiralty Charts. Puget Sound area covered by 6 charts. No. 1914-1947-1427-1792-1717-2689.

1951. Catalogue of Admiralty Charts.

British Admiralty, Hydrographic Office (London)
1846. America, West Coast--Puget Sound.
(Drawn by R. M. Inskip. London Hydro. Office of the Admiralty.)

British Columbia, Department of Lands and Forests, Survey and Mapping Branch, Air Survey Division (Victoria)
1951. Index to British Columbia Aerial Survey Coverage.
(Index map showing aerial survey coverage and type of photography.)

British Columbia, Department of Lands and Forests, Survey and Mapping Branch, Geographic Division (Victoria)
1952a. Index Map to Lithographed Maps Including Geographic, Land, Pre-Emptors, Degree and Topographic Series.

1952b. Relief Picture Map of British Columbia.
(A colored map showing relief of British Columbia and northern part of Pacific Northwest.)

Canadian Department of Mines and Technical Survey, Survey Mapping Branch, Hydrographic Service (Ottawa)
1940. Charts no. 3593, Vancouver Island and adjacent shores of B.C.

1951a. Catalogue of Nautical Charts, Tidal and Current Publications.

1951b. Chart no. 3449 Race Rocks to Turn Point.

Canadian Department of Mines and Technical Surveys, Map Distribution Office, Surveys and Mapping Branch (Ottawa)
n.d. National Topographic Series.

Canada Department of Mines and Technical Surveys, Topographical Survey (Ottawa)
1951. Topographic Map Index of Canada.

Denoyer Geppert Company (Chicago)
1940. Physical and Political Map of Pacific Northwest.
(Edited by H. H. Martin and Otis W. Freeman. One of the Denoyer Geppert physical-political series compiled and drawn by R. B. Blair.)

1943. Historic Pacific Northwest.
(Edited by Carl H. Mapes.)

Douglas (London)
1784. A summary of the various advantages resulting from voyages of discovery, undertaken and performed under the present Reign, with charts of the Northwest Coast Exploration by Capt. Cook and Clarke 1778-1779.

Eastwick, Morris and Company
1877. Map of Puget Sound and Surrounding Washington Territory. (Compiled from official government surveys.)

Elliott, W. (San Francisco)
1948. Engineers Official Map of the Pacific Northwest. (Compiled and engraved by W. Elliott, Judge.)

Federal Inter-Agency River Basin Committee Subcommission on Hydrology.
1949. Pacific Coast Drainage in Washington. Map no. 75. (Precipitation, storage, temperature, evaporation, meteorological stations. Show survey courses. Prepared under U. S. Weather Bureau.)

Great Northern Railway Company (Chicago)
1896. An Atlas of the Northwest. (Atlas of Northwest published by Rand McNally, Chicago, Illinois.)

Harbor Department, Port Warden
1918. Map of Central Waterfront District. (Drawn by A. A. Paysse.)

Hearne Brothers Map Company (Seattle)
1940. Hearne Brothers - Polyconic Projection Map of Seattle, Tacoma and Vicinity.

1950. Official Hearne Brothers Polyconic Projection Map of Greater Seattle and Vicinity. (A wall map with inset maps of Auburn, Enumclaw and Vashon Island, Washington.)

King County Engineers (Seattle)
1933. Map of King County.

Leferre, I. A. (San Francisco)
1884. Map of Puget Sound and Gulf of Georgia with Parts of Washington Territories and British Columbia. (Compiled and drawn by I. A. Leferre. San Francisco Photo Litho.)

Metskers Map Company (Seattle)
n.d. Metskers Atlas of King County, Seattle. (85 maps included.)

1940. Playground of America. (Metskers Map of the Puget Sound Country.)

Morris, Frank and W. R. Heath (Seattle)
1952. Marine Atlas of the Northwest, Olympia to Skagway.
(A navigation atlas for small boat owners. Charted courses, and aerial photos of harbor entrances and main passes.)

National Geographical Society, Cartographic Section (Washington, D.C.)
1941. A Map of Northwest United States and Neighboring Canadian Provinces.
(Prepared in cartographic section of National Geographic Society for National Geographic Magazine.)

Northwest Regional Council. In Cooperation with Pacific Northwest Regional Planning Commission and the Bonneville Power Administration
1942. Economic Atlas of the Pacific Northwest.

Office of Engineer Officer, Headquarters Department of Columbia, Vancouver Barracks, Washington Territory
1885. Map of Area Bordering Southeast Puget Sound (Seattle to Olympia).
(Showing railroads and military roads.)

Oregon-Washington Railroad and Navigation Company (Portland)
1911. Map of Pacific Northwest.
(Issued by Oregon-Washington Railroad and Navigation Company showing railroads in area.)

Phelps, Thomas Stowell
1930. Plan of Seattle 1855-56.
(Showing position occupied by Decatur's crew and line barricade erected and road constructed.)

Raisz, Erwin
1941. Landforms of the Northwestern States.

Reynolds, Clara P. (Seattle)
1927. A Sea Gull's View of Seattle.
(Printed by Pioneer Printing Company.)

Seattle Map Company (Seattle)
1904. Bird's-eye View of Seattle and Vicinity.
(Panoramic view of Seattle and surrounding country.)

Seattle Public Works, Board of (Seattle)
1891. Seattle Sewerage Map.
(Williams, B., Civil Engineer.)

U. S. Army Corps of Engineers, District Office (Portland)
1945. Columbia River Basin.
(Irrigation and Power Projects in the Pacific Northwest.)

U. S. Department of Agriculture (Washington, D.C.)
1936. Atlas of American Agriculture.

U. S. Department of Agriculture, Bureau of Soils
1910a. Land Classification, Reconnaissance Survey, Puget Sound Basin, Washington, Olympia Sheet.
(Prepared by U. S. Soils Bureau and Washington Geological Survey, drawn by A. Hoen-Baltimore.)

1910b. Soil Map, Reconnaissance Survey Puget Sound Basin, Washington, Olympia Sheet.
(Prepared by U. S. Soils Bureau and Washington Geological Survey, drawn by A. Hoen, Baltimore.)

1914. Kelp Groves of the Pacific Coast and Islands of the United States and Lower California. Office of the Sec. Report No. 100. Maps No. 8-9-11-12-14-15 cover the Puget Sound Basin.

1939. Soil Survey of Kitsap County.

U. S. Department of Agriculture, Pacific Northwest Regional Committee for Post War Program (Portland)
1943. Atlas of Agriculture of Pacific Northwest Regions.

U. S. Department of Agriculture, Soil Conservation Service
1941. Atlas of Climatic Types in the United States.
(Misc. Pub. No. 421. Covers 1900-1939.)

U. S. Department of Commerce Coast and Geodetic Survey
n.d.a. Index to Hydrographic Surveys.
(No. 6300, sheets 1 and 2; no. 6380, sheets 1 and 2; no. 6450, sheets 1 and 2; no. 6460, sheets 1 and 2.)

n.d.b. Index of Topographic Surveys.
(No. 6300, sheets 1 and 2; no. 6380, sheet 1; no. 6450, sheets 1 and 2; no. 6460, sheets 1 and 2.)

1935-1949. Coast and Harbor Charts.
(26 charts have been constructed for the Puget Sound Basin. Chart 6300 to 6480.)

1944a. Triangulation Diagram.
(Puget Sound-Admiralty Inlet to Seattle. Chart 6450.)

1944b. Triangulation Diagram.
(Puget Sound-Seattle to Olympia. Chart 6460.)

1947a. Tidal Current Chart, Puget Sound-Northern Part.
(Serial No. 713.)

U. S. Department of Commerce Coast and Geodetic Survey
1947b. Triangulation Diagram.
(Straits of Juan de Fuca-Eastern Part. Chart 6382.)

1947c. Triangulation Diagram.
(Georgia Strait Triangulation Diagram. Chart 6380.)

1948. Tidal Current Chart, Puget Sound Southern Part.
(Serial No. 696.)

1950a. Control Leveling State of Washington. Index map.

1950b. Isogonic Chart for 1950.
(United States Chart No. 3077.)

1950c. Triangulation Diagram, State of Washington. Index chart.

1952a. Catalog of Nautical Charts and Related Publication. Serial no. 665.

1952b. Sectional Aeronautical Charts.
(Two charts, Bellingham (Y-1) and Seattle (X-1), cover the Puget Sound area.)

U. S. Department of Commerce Weather Bureau (Washington, D.C.)
n.d.a. Airway Meteorological Atlas for the United States.

n.d.b. Climatic Charts for the United States.

n.d.c. Frost Charts for the United States.

1949. Pacific Coast Drainage in Washington.
(Map No. 75 of a series on the Columbia River Basin and adjacent areas.)

U. S. Department of Interior Bureau of Reclamation (Washington, D.C.)
1948. Pacific Northwest.
(Proposed dams, reservoirs, and irrigation in Washington.)

U. S. Department of the Interior, Geological Survey, Map Information Office (Washington, D.C.)
1951. Aerial Photography of the United States Index Map.
(Showing all areas known to be photographed by or for Federal, State, and commercial agencies. Also gives agency holding film.)

U. S. Department of Interior Geological Survey
1937. Plan and Profile of Green River, Washington.
(From 4 miles above mouth to 9-mile dam site, Sheet A 1937.)

U. S. Department of Interior Geological Survey (Washington, D.C.)
n.d. Topographic Maps, U.S.G.S. Quadrangle Sheets and U. S. Corps of Engineers Planimetric Maps.
(53 maps cover the Puget Sound Basin.)

1899. U. S. Geological Survey Atlas, Tacoma Folio.
(Folio No. 51.)

1906. U. S. Geological Survey Atlas, Snoqualmie Folio.
(Folio No. 139.)

1950. Index to Topographic Mapping in Washington.

U. S. War Department, Corps of Engineers (Washington, D.C.)
n.d. Topographic Mapping of the Corps of Engineers.
(Index map showing areas covered by topographic map prepared under war alert. Areas covered by other mapping prepared by or under direction of the Corps of Engineers, and outline of Corps of Engineers, and outline of Corps of Engineers Domestic Map Index.)

Washington Map and Blue Print Company (Seattle)
1913. Map of Seattle Tidelands.
(Shows Harbor Island Terminals and vicinity.)

Washington State Department of Fisheries (Seattle)
1950a. Commercial Salmon Fishing Map, Puget Sound.
(Areas and Preserves as defined in Section 37938 order no. 256, Director of Fisheries 1950.)

1950b. Shrimp Map, Puget Sound.
(Areas and Preserves as defined in Section 47, 48, and 67, Director of Fisheries 1950.)

Washington State College Agricultural Experimental Station (Pullman)
1933. Seasonal Distribution of Precipitation.

1945a. Division of Farm Management, Agricultural Economics. Economic Land Use Class Map, King County, Washington.
(Classifies land of King County into 6 classes, and 3 potential classes.)

1945b. Division of Farm Management and Agricultural Economics. Economic Land Use Class Maps, Snohomish County, Washington.
(Classifies land of Snohomish County into 6 classes, and 3 potential classes.)

Washington State Geological Survey
1936. Washington State Geology.
(Preliminary Geological Map, Bulletin No. 32.)

Washington State Pollution Control Commission Technical Section
n.d. Drainage Areas of Washington State.

Washington Stevedore Company (Seattle)
1905. Chart of Puget Sound.
(Showing ports of Seattle, Tacoma, Bellingham Bay, Everett, Mukilteo, Blakely Harbor, Port Ludlow, Port Gamble and Eagle Harbor.)

White, D. A. (Tacoma)
1908. Map of the Puget Sound Country.

BIBLIOGRAPHY

Bowie, William

1917. Investigations of gravity and isostasy. U. S. Department of Commerce, Coast and Geodetic Survey, Special Publication 40, 196 pages, Government Printing Office, Washington, D.C. (Contains gravity measurements made within the Puget Sound Basin.)

1924. Isostatic investigations and data for gravity stations in the United States established since 1915. U. S. Coast and Geodetic Survey, Serial no. 246, Special Publication no. 99, 91 pages, Government Printing Office, Washington, D.C. (A comprehensive discussion of gravity and isostatic conditions and investigations in the United States. Basic principles are discussed in relation to observations. It is pointed out that the great differences in the anomalies of the Seattle area are due to local causes close to the surface.)

1926. Isostatic condition of the United States as indicated by groups of gravity stations. U. S. Coast and Geodetic Survey, Serial no. 366, 11 pages, Government Printing Office, Washington, D.C. (Discusses the data presented in Special Publication 99 in the light of a regrouping of the gravity stations. Large negative anomalies of Puget Sound are discussed.)

Carnegie Institution of Washington Department of Terrestrial Magnetism

1953. Personal communication on earth-currents, gravity anomalies, geomagnetism, and seismology in the Puget Sound area. Letter from M. A. Tuve, Director, to Peter McLellan, dated January 13, 1953. (No information on earth-currents, gravity anomalies, or geomagnetism. Seismic work done in the eastern part of Puget Sound.)

Duerksen, J. A.

1941. Deflections of the vertical in the United States (1927 datum). U. S. Coast and Geodetic Survey, Special Publication 229, 16 pages, Government Printing Office, Washington, D.C. (This publication gives the deflections of the vertical at all latitude and longitude stations of first- and second-order accuracy in the United States, for which the geodetic positions are available on the North American Datum of 1927.)

1949. Pendulum gravity data in the United States. U. S. Coast and Geodetic Survey, Special Publication no. 244, 218 pages, Government Printing Office, Washington, D.C. (A description of the pendulum gravity measurements in the United States are given. Two tables of pendulum gravity data are given. One contains the adopted pendulum gravity data together with the gravity anomalies. The other contains the observed gravity data whenever more than one pendulum gravity determination has been made.)

Hayford, John F. and William Bowie
1912. The effect of topography and isostatic compensation upon the intensity of gravity. U. S. Department of Commerce, Coast and Geodetic Survey, Special Publication 10, 132 pages, Government Printing Office, Washington, D.C.
(Contains gravity measurements made in the Puget Sound Basin.)

Heath, W. R.
1952. A Simple Technique for Making Topographic Maps More Readable. The Mountaineer, vol. 45, no. 13, pp. 34-36, 39.
(Description and examples of plastic shading.)

Heiskanen, W.
1951. On Seattle Earthquakes and Gravity Anomalies. Bulletin of the Seismological Society of America, vol. 41, no. 4, pp. 303-305.
(Reviews the work of Bowie (1924) in the light of the Seattle earthquake.)

Jones, John W.
1952a. Gravimetry at the University of Washington. The Trend in Engineering at the University of Washington, vol. 4, no. 3, pp. 5-6, Engineering Experiment Station, University of Washington.
(Discussion of the problem including a map showing free-air gravity anomalies in the Puget Sound Basin of Western Washington.)

1952b. Gravimetric Investigations in the State of Washington. Bulletin of the Geological Society of America, vol. 63, no. 12, part 2, p. 1354.

Marshall, R. B.
1918. Spirit Leveling in the State of Washington 1896 to 1917 inclusive. U. S. Geological Survey, Bulletin 674, 204 pages.
(Precise and primary leveling.)

Montgomery, R. H.
1930. Precise Leveling in British Columbia. Canada, Department of the Interior, Geodetic Survey, Publication no. 24, 96 pages, 1 map.

1932. Precise Leveling on Vancouver Island. Canada, Department of the Interior, Geodetic Survey, Publication no. 38, 24 pages, 1 map.
(Description of leveling network. Mean sea level datum, Nanaimo, Port Alberni, Sidney, Victoria.)

Oros, Charles N.
1952. River Current Data from Aerial Photography. Photogrammetric Engineering, vol. 18, no. 1, pp. 96-99.
(Work done five miles upstream from The Dalles on the Columbia River.)

U. S. Navy Hydrographic Office
1951. Radio Navigation Aids. H.O. Publication No. 205. Government Printing Office, Washington, 422 pages.
(Direction finder stations, radio beacons, time signal navigational warnings, distress signals, medical advice and quarantine, long-range navigational aids and radio regulations for territorial waters.)

U. S. Treasury Department Coast Guard
1952. Complete List of Lights and Other Marine Aids, Pacific Coast of the United States, Volumes I-V, CG-162, 288 pages, Government Printing Office, Washington.
(This listing is intended to furnish more complete information concerning aids to navigation than can be conveniently shown on charts.)

Wagner, Henry R.
1937. The Cartography of the Northwest Coast of America to the Year 1800. University of California Press, Berkeley, vol. I, pp. 1-270, vol. II, pp. 271-543.
(A comprehensive presentation of the early charts and history of early mapping and exploration.)

SECTION 9: HYDROGRAPHY

11 February 1953

HYDROGRAPHY

HYDROGRAPHIC HISTORY

The first bathymetric survey following the discovery and charting of Puget Sound by Captain James Vancouver in 1792 was that initiated by Lt. Charles Wilkes in 1841 (Wilkes 1845). The results of this survey were published in Volume 23, Hydrography, chapter 16, of his report series (Wilkes 1858).

The original surveys show principally bottom type and characteristics. Being of a reconnaissance nature the soundings were not specifically reliable. The techniques used were those of the hand line and lead for making the measurements. Prior to 1920 soundings and bottom samples were taken at fairly large intervals, simply to obtain the overall characteristics of the area. After 1920, while soundings were still being made by hand, the technique of sounding was developed so that they followed in such rapid sequence that they approached the usefulness of the present echo sounder.

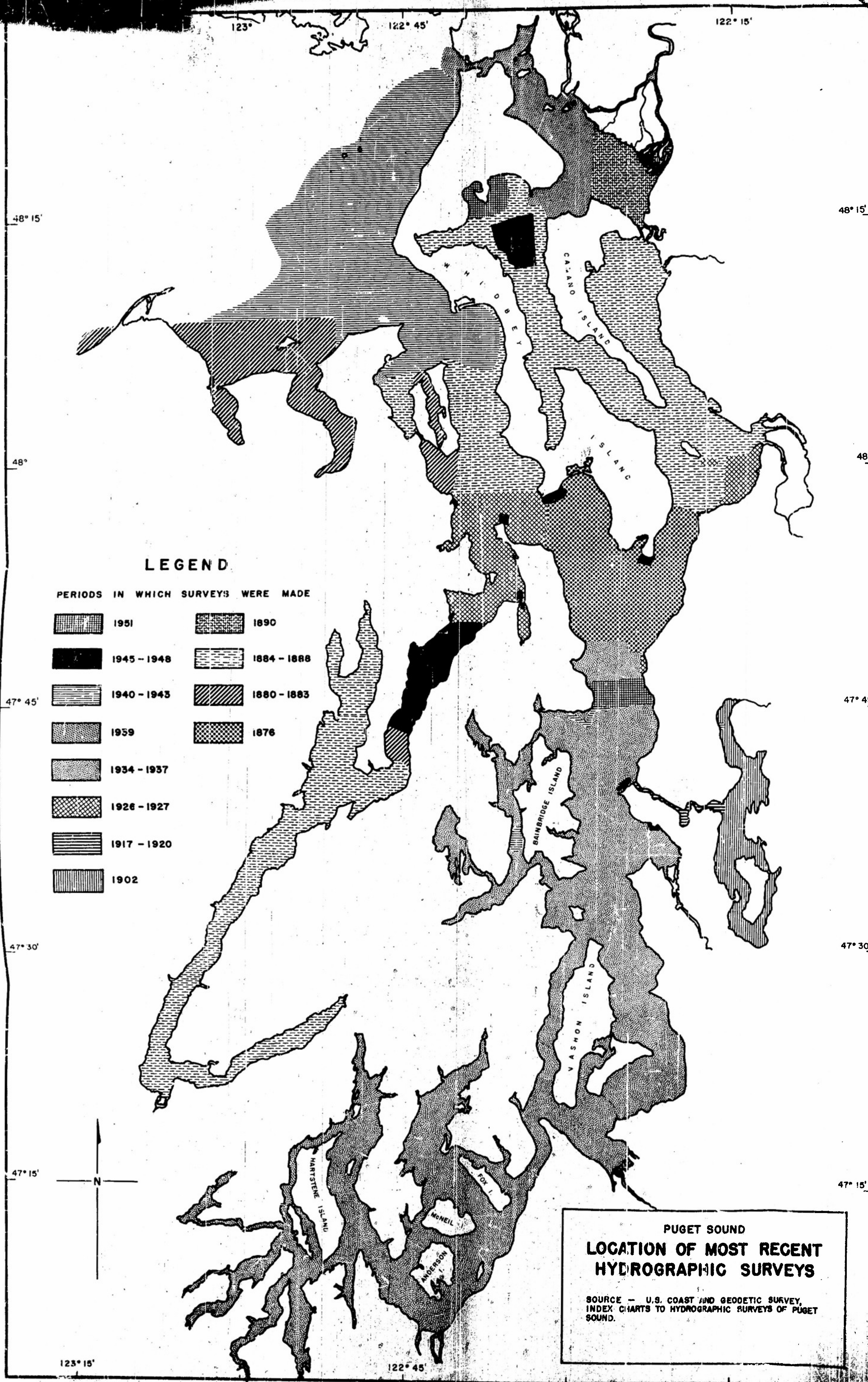
This hand line technique ended in the period 1935 to 1940, for the Puget Sound area. The 308 fathometer was installed for use in Puget Sound in the period 1939 to 1940. After 1940 surveys have been wholly electronic. These new surveys show detailed exposition of the bottom configuration.

U. S. COAST AND GEODETIC SURVEY FIELD SURVEYS

The original field surveys provide a comprehensive record of conditions existing at the specific time the survey was made, while the charts in current use generally employ data secured at various times. Therefore, though the chart may be of recent printing, the period in which the area was surveyed may be quite remote. Adequate use may be made of the original field survey records when specific information is desired or a larger scale preferred than that used on the published chart.

Hydrographic Surveys

For the Puget Sound area Indexes of Hydrographic Surveys may be had based on the following charts: No. 6300, sheets 1 and 2; no. 6380, sheets 1 and 2; no. 6450, sheets 1 and 2; no. 6460, sheets 1 and 2. An analysis has been made of the period in which the Hydrographic Surveys were made and is presented on Fig. 9-1.



123°
122° 45'
122° 15'
48° 15'
48°
47° 45'
47° 30'
47° 15'
123° 15'
WHIDBEY ISLAND
CAMANO ISLAND
BAINBRIDGE ISLAND
VASHON ISLAND
HARTSTENE ISLAND
FOX I.
McNEIL
ANDERSON I.
N
LEGEND
PERIODS IN WHICH SURVEYS WERE MADE
1951
1945 - 1948
1940 - 1943
1939
1934 - 1937
1926 - 1927
1917 - 1920
1902
1890
1884 - 1888
1880 - 1883
1876
PUGET SOUND
LOCATION OF MOST RECENT HYDROGRAPHIC SURVEYS
SOURCE — U.S. COAST AND GEODETIC SURVEY, INDEX CHARTS TO HYDROGRAPHIC SURVEYS OF PUGET SOUND.

PERIOD OF SURVEY. The oldest survey on which current charts are being based in 1878. This area lies north of Seattle between Edwards Point and Useless Bay. Hood Canal, part of Admiralty Inlet, Saratoga Passage, and Port Susan were surveyed between 1884 and 1886. The entire area south of Point Jefferson (including Port Orchard) was surveyed during the period 1934 to 1937, while the approaches to Admiralty Inlet were surveyed in the period 1940 to 1943.

Topographic Surveys

A topographic survey of the shore line is made at the time of each hydrographic survey. Using a scale of 1:5,000 or 1:10,000 good detail of shore line features and the beaches may be found.

Reliability of Measurements

The mean high water line is delineated by the topographer during his traverse along the shore line. Since this is a tidal plane, the topographer must estimate this position--not difficult on abrupt shores, but requiring knowledge of stage of tide on low gradient beaches and tide flats. Topographic requirements on shore line traverse call for closures not to exceed 4 meters in a mile between control stations for sheet scales 1/20,000 or larger, and 8 meters to a mile for sheet scales smaller than 1/20,000. The accuracy of any point on the mean high water line (charted shore line) depends upon spacing of control in the area, shore line topography, the residual evidence on the shore of this line and the skill of the topographers. Captain Pierce of the Coast and Geodetic Survey estimates that 5 meters would be an average for the error from the true position on Puget Sound (U. S. Department of Commerce Coast and Geodetic Survey 1953a).

Instructions on basic hydrographic surveys call for the hydrographer, where possible, to delineate the zero depth curve (mean lower low water). This requires sounding at high water with a tide sufficient to provide for water under the keel of the sounding boat and sea conditions suitable for sounding in shoal depths. This has not been practicable in all areas of Puget Sound and Alaskan waters because of rocks, reefs, etc., and usual surf and breakers prevalent along the coasts (U. S. Department of Commerce Coast and Geodetic Survey 1953a).

Depth contouring may be reliably accurate in Puget Sound because of the steep slopes of the basin.

BATHYMETRY

Puget Sound is one of the deepest salt water basin areas in the United States. Depths of 600 to 800 feet prevail in the northern section, while south of the Tacoma Narrows, near the head waters, 300 feet is more typical. Occasionally deep holes occur in either section which may be illustrated by the depth of 930 feet off Point Jefferson in the northern section and the 546-foot hole near McNeil Island in the southern section. Such conditions are analogous to the topography of the adjacent land areas. See section on Geography: Description of Area.

Sills, Basins, and Mud Flats

Puget Sound may be divided into four general sections which are partly isolated by vertical or lateral constrictions. The main basin extends from a 240-foot threshold sill at the confluence of Admiralty Inlet with the Strait of Juan de Fuca, south to a 180-foot sill at the Tacoma Narrows. The section south of the narrows consists of a primary basin in excess of 500 feet in depth with many branching channels and inlets.

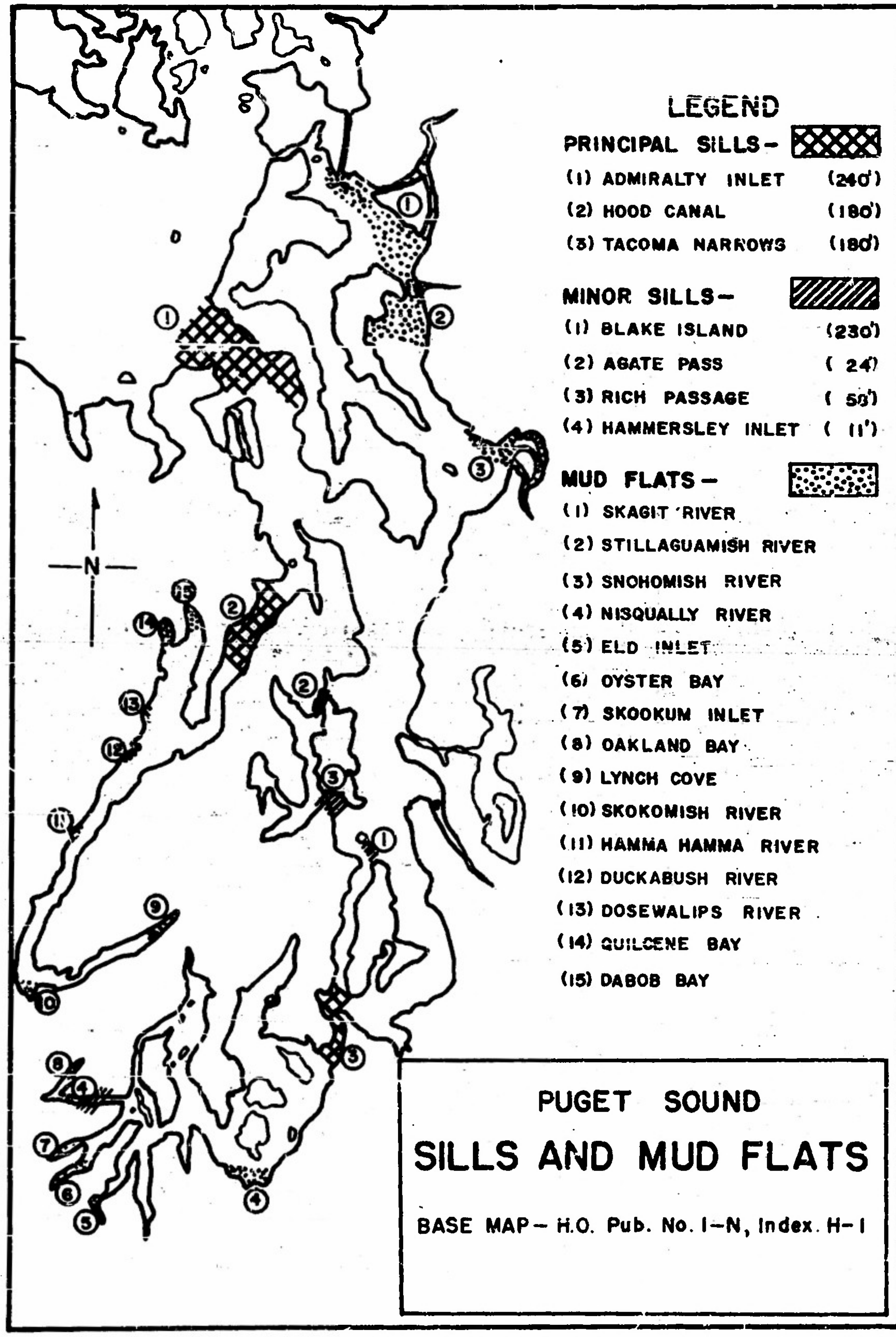
Hood Canal, averaging about two miles in width and having a depth of 600 feet, extends about 50 nautical miles southwest from Admiralty Inlet and is partly separated from it by a 180-foot sill.

The fourth section extends with diminishing depth from Possession Sound, about 25 nautical miles from the entrance to Admiralty Inlet, north through Skagit Bay to Deception Pass. The Pass is a very restricted channel about 200 yards wide and 96 feet in depth (in the constricted portion) connecting with the Strait of Juan de Fuca (see Fig. 9-3).

Several minor sills set off smaller areas from the main water bodies. Figure 9-2 shows the sill areas for Puget Sound. Also shown are mud flats which occur in the delta regions of major rivers. These areas are usually bare at low water.

Depth Analysis

The average depth of Puget Sound (volume/area) is 205 feet. The mean depth of 56 unit area divisions from the maximum depth of 56 unit area divisions of Puget Sound is 390 feet. The variation in depths exemplifies the "deeps" as being restricted holes. The shoal and tide flat areas adjacent to river deltas offset the few 900-foot holes. An analysis of Fig. 9-6, a curve showing accumulated volume versus depth, will show other relationships.



LEGEND
PRINCIPAL SILLS -
(1) ADMIRALTY INLET (240')
(2) HOOD CANAL (180')
(3) TACOMA NARROWS (180')
MINOR SILLS -
(1) BLAKE ISLAND (230')
(2) AGATE PASS (24')
(3) RICH PASSAGE (50')
(4) HAMMERSLEY INLET (11')
MUD FLATS -
(1) SKAGIT RIVER
(2) STILLAGUAMISH RIVER
(3) SNOHOMISH RIVER
(4) NISQUALLY RIVER
(5) ELD INLET
(6) OYSTER BAY
(7) SKOOKUM INLET
(8) OAKLAND BAY
(9) LYNCH COVE
(10) SKOKOMISH RIVER
(11) HAMMA HAMMA RIVER
(12) DUCKABUSH RIVER
(13) DOSEWALIPS RIVER
(14) QUILCENE BAY
(15) DABOB BAY
N
PUGET SOUND
SILLS AND MUD FLATS
BASE MAP – H.O. Pub. No. 1–N, Index. H-1

Fig. 9-2


PUGET SOUND
BOTTOM CONTOURS
BASE CHART — COMPOSITE OF U.S. COAST AND GEODETIC SURVEY CHARTS 6450 AND 6380.
Nautical Miles
SHEET 1 OF 3
NOTE — CONTOURS FROM SOUNDINGS ON BASE CHARTS
Contour interval is 10 fathoms
Datum is mean lower low water
LOCATION MAP

Fig 9-3 (1)

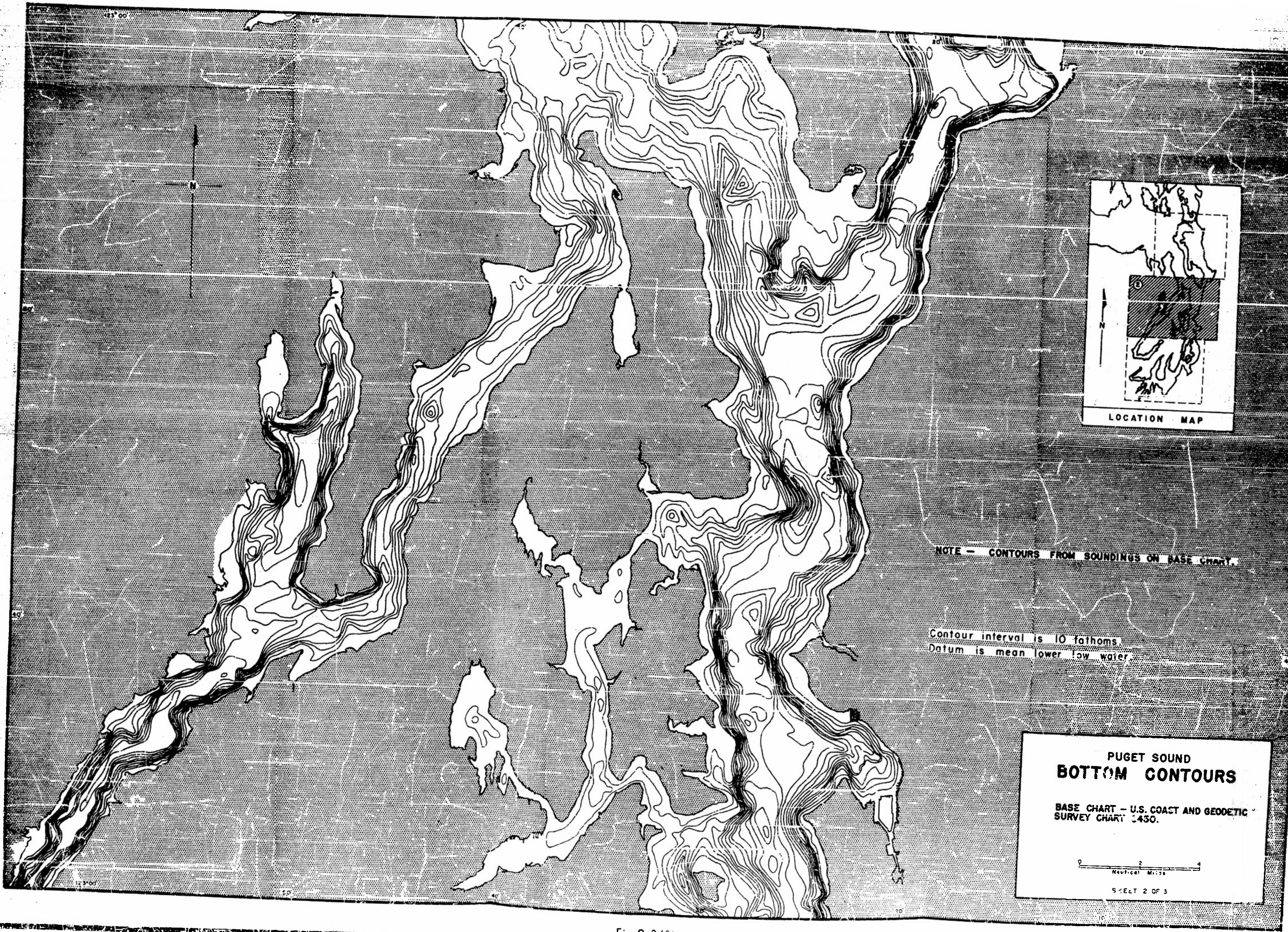

LOCATION MAP
N
NOTE — CONTOURS FROM SOUNDINGS ON BASE CHART.
Contour interval is 10 fathoms.
Datum is mean lower low water.
PUGET SOUND
BOTTOM CONTOURS
BASE CHART – U.S. COAST AND GEODETIC SURVEY CHART 6450.
Nautical Miles
SHEET 2 OF 3

Fig. 9-3(2)

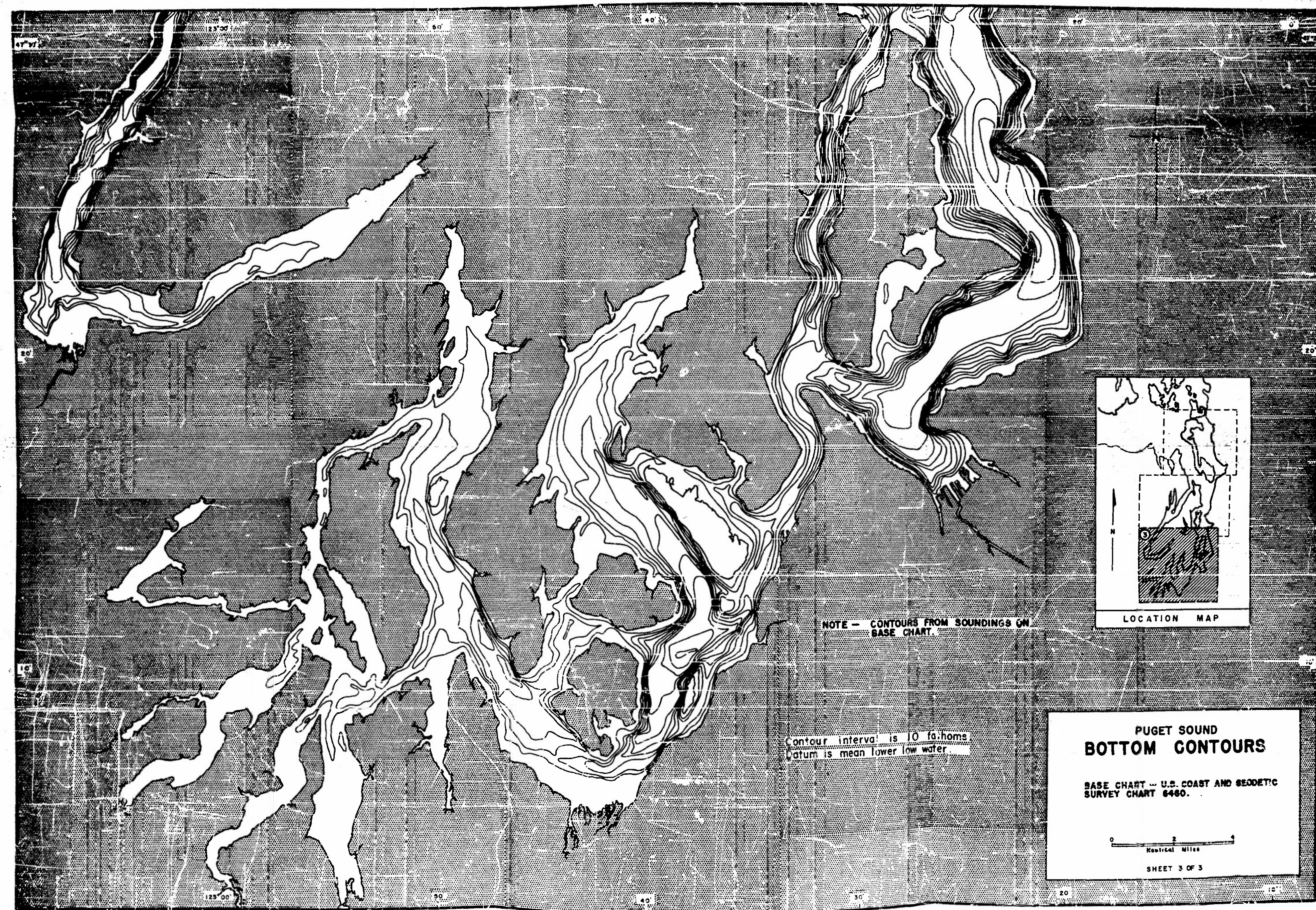

PUGET SOUND
BOTTOM CONTOURS
BASE CHART – U.S. COAST AND GEODETIC SURVEY CHART 6460.
0 2 4
Nautical Miles
SHEET 3 OF 3
LOCATION MAP
NOTE – CONTOURS FROM SOUNDINGS ON BASE CHART.
Contour interval is 10 fathoms
Datum is mean lower low water.
123°00'
50'
40'
30'
20'
10'
47°30'

Fig 9-3(3)

In an area where unknown rates and locations of sedimentation are prevailing, the bottom depth configuration may be expected to change with each new Hydrographic Survey. See section on Geology: Deep Filling and Location of Areas of Most Recent Bathymetric Surveys, this section.

Changes in bottom configuration are known to take place with violent earthquake shocks. See section on Seismology: Earthquakes of Intensity VIII.

Cable and Pipeline Areas

Examination of Fig. 9-4 will show the extent to which Puget Sound is traversed by major commercial submarine cables and pipes. Generally they are located in deep water with the shore terminations posted with an appropriate marker. The locations of cables likely to be disturbed by drags and anchors are marked on the Coast and Geodetic Survey charts.

AREA AND VOLUME ANALYSIS

The total area of Puget Sound (as delineated in the section on Geography) at Mean High Water is 767.6 square nautical miles. The total volume of Puget Sound is 26.5 cubic nautical miles. The volume of water within the tidal prism (MHW-MLLW) is 1.27 cubic nautical miles.

Puget Sound, shown in Fig. 9-5, has been divided into five sections: A. Admiralty Inlet, B. Puget Sound (central part), C. The Narrows and south, D. Hood Canal, and E. Possession Sound and north. Volume and area analysis are presented in Tables 9-1 and 9-2. Figure 9-6 shows accumulated volume versus depth of Puget Sound.

Data in final preparation at the Department of Oceanography, University of Washington, includes the entire Puget Sound area as analyzed in 57 geographic divisions--each a complete unit and the aggregate totals and sub-totals to be presented as reference tables (McLellan 1953).

Accuracy of Measurements

The area values are considered reliable to four significant figures and the values for the volume are reliable to three significant figures.

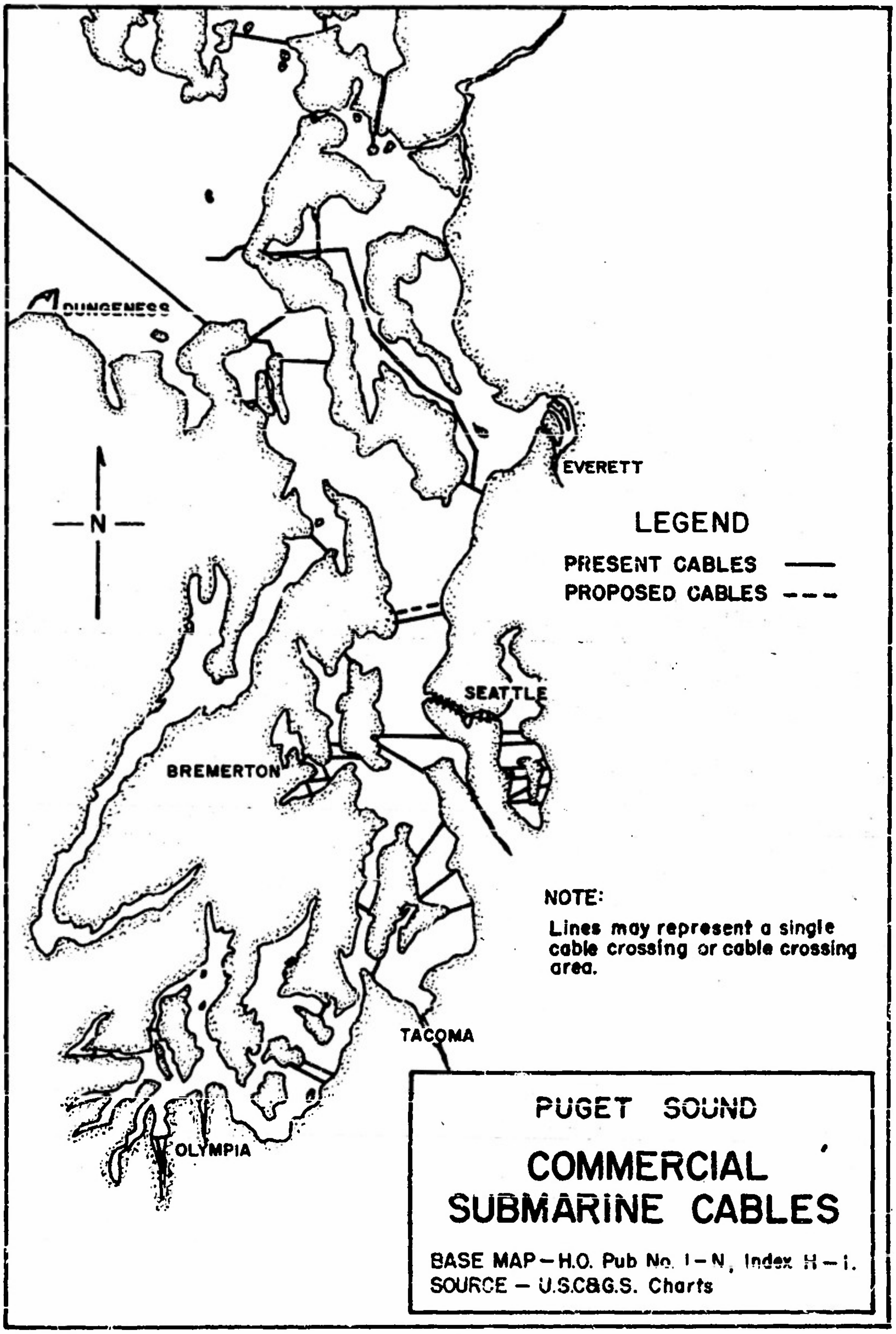

DUNGENESS
EVERETT
N
LEGEND
PRESENT CABLES
PROPOSED CABLES
SEATTLE
BREMERTON
NOTE:
Lines may represent a single cable crossing or cable crossing area.
TACOMA
OLYMPIA
PUGET SOUND
COMMERCIAL SUBMARINE CABLES
BASE MAP — H.O. Pub No. 1 — N, Index H — 1.
SOURCE — U.S.C&G.S. Charts

Fig. 9-4

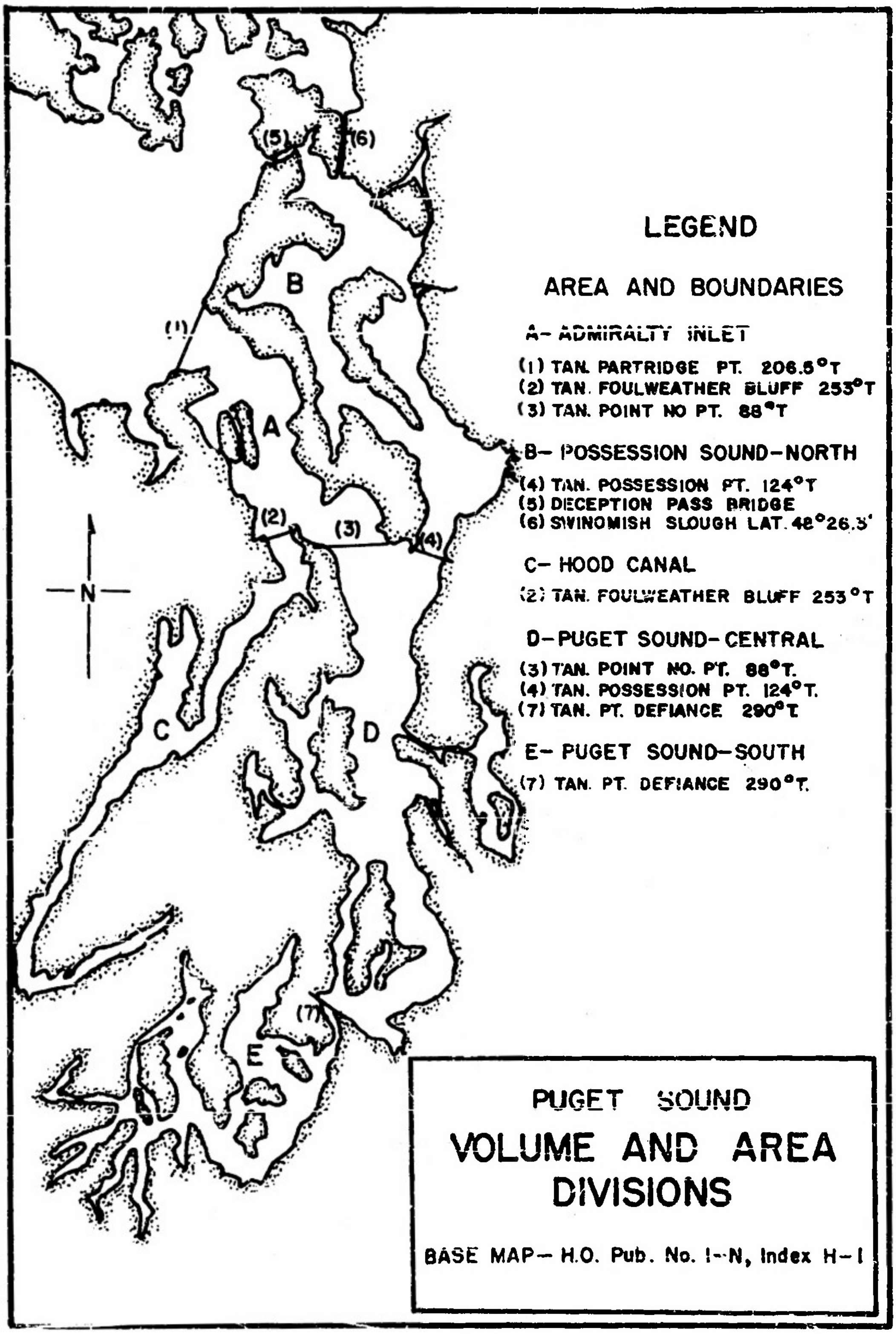

LEGEND
AREA AND BOUNDARIES
A- ADMIRALTY INLET
(1) TAN. PARTRIDGE PT. 206.5°T
(2) TAN. FOULWEATHER BLUFF 253°T
(3) TAN. POINT NO PT. 88°T
B- POSSESSION SOUND-NORTH
(4) TAN. POSSESSION PT. 124°T
(5) DECEPTION PASS BRIDGE
(6) SWINOMISH SLOUGH LAT. 48°26.5'
C- HOOD CANAL
(2) TAN. FOULWEATHER BLUFF 253°T
D-PUGET SOUND-CENTRAL
(3) TAN. POINT NO. PT. 88°T.
(4) TAN. POSSESSION PT. 124°T.
(7) TAN. PT. DEFIANCE 290°T
E- PUGET SOUND-SOUTH
(7) TAN. PT. DEFIANCE 290°T.
PUGET SOUND
VOLUME AND AREA DIVISIONS
BASE MAP- H.O. Pub. No. 1-N, Index H-1
N
A
B
C
D
E

Fig. 9-5

TABLE 9-1. Area Analysis [In square nautical miles].

DEPTH [In fathoms]	GEOGRAPHIC AREAS* A. Admiralty Inlet	B. Puget Sound center section	C. The Narrows and south	D. Hood Canal	E. Possession Sound and north	Total
MHW	115.3	223.5	130.7	113.2	184.9	767.6
MLLW	109.6	209.6	111.7	101.2	147.0	679.1
3	102.6	195.0	92.32	91.87	111.5	593.3
10	86.05	168.5	64.27	78.30	92.02	489.1
20	65.03	146.9	42.87	64.97	72.56	392.3
30	50.85	131.2	26.36	52.42	60.19	321.0
40	32.55	118.8	15.85	42.46	49.32	259.5
50	21.36	108.5	10.55	33.13	38.53	212.1
60	11.02	97.66	6.96	24.27	25.86	165.8
70	4.31	88.42	4.45	16.62	14.18	128.0
80	1.82	79.18	2.48	10.22	10.03	103.7
90	0.93	66.44	0.88	4.51	5.34	78.10
100	0.22	42.01	0.11	0.39	1.28	44.01
110	0.01	20.06			0.48	20.55
120		8.06			0.08	8.14
130		2.80				2.80
140		0.29				0.29
150		0.02				0.02
Max. Depth	112	155	103	102	123	155
Mean Tide	1.44	1.78	2.11	1.75	1.76	1.76

*See Figure 9-4 for map.

Table modified from McLellan 1953.

Note: MHW - Mean High Water
MLLW - Mean Lower Low Water
Mean Tide - Difference between MHW and MLLW

TABLE 9-2. Volume Analysis [In cubic nautical miles].

DEPTH [In fathoms]	GEOGRAPHIC AREAS* A. Admiralty Inlet	B. Puget Sound center section	C. The Narrows and south	D. Hood Canal	E. Possession Sound and north	Total
MHW-MLLW	0.157	0.383	0.265	0.179	0.287	1.27
MLLW-10	0.971	1.87	0.833	0.877	1.07	5.62
10-20	0.743	1.57	0.527	0.717	0.811	4.36
20-30	0.579	1.38	0.328	0.584	0.659	3.54
30-40	0.419	1.25	0.205	0.474	0.548	2.89
40-50	0.260	1.13	0.129	0.376	0.449	2.35
50-60	0.159	1.03	0.0845	0.285	0.323	1.88
60-70	0.0741	0.925	0.0542	0.204	0.190	1.45
70-80	0.0274	0.832	0.0323	0.132	0.119	1.14
80-90	0.0126	0.735	0.0171	0.0744	0.076	0.915
90-100	0.00512	0.550	0.00416	0.0214	0.028	0.609
100-110	0.00112	0.302		0.00048	0.00300	0.312
110-120		0.128			0.00272	0.131
120-130		0.0472				0.0472
130-140		0.0133				0.0133
140-150		0.00240				0.00240
Total	3.41	12.1	2.49	3.92	4.57	26.5

*See Figure 9-4 for map.

Table modified from McLellan 1953.

Note: See Table 9-1 for Maximum Depth and Mean Tide.
MHW - Mean High Water
MLLW - Mean Lower Low Water

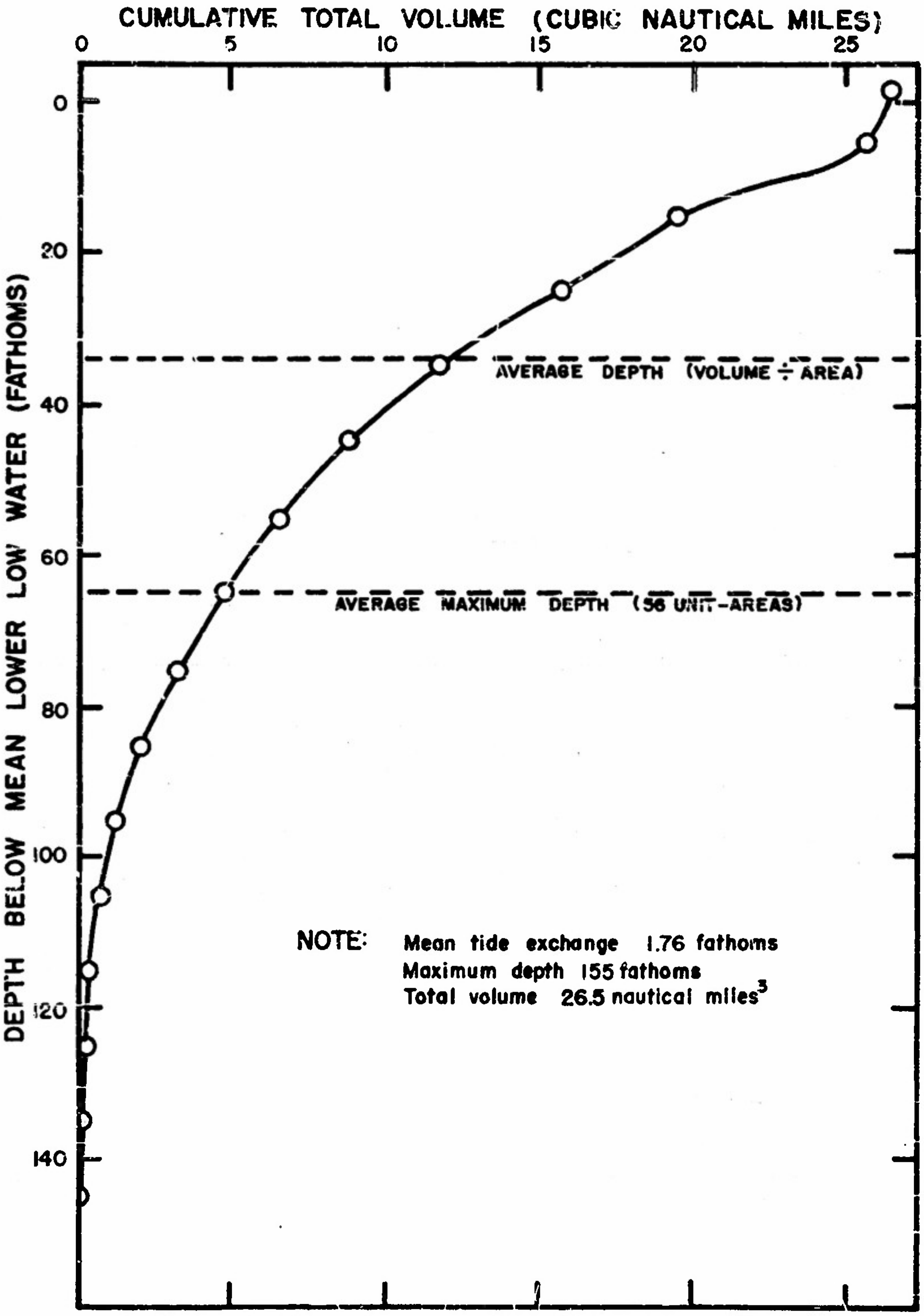

CUMULATIVE TOTAL VOLUME (CUBIC NAUTICAL MILES)
0
5
10
15
20
25
DEPTH BELOW MEAN LOWER LOW WATER (FATHOMS)
0
20
40
60
80
100
120
140
AVERAGE DEPTH (VOLUME ÷ AREA)
AVERAGE MAXIMUM DEPTH (56 UNIT-AREAS)
NOTE: Mean tide exchange 1.76 fathoms
Maximum depth 155 fathoms
Total volume 26.5 nautical miles³

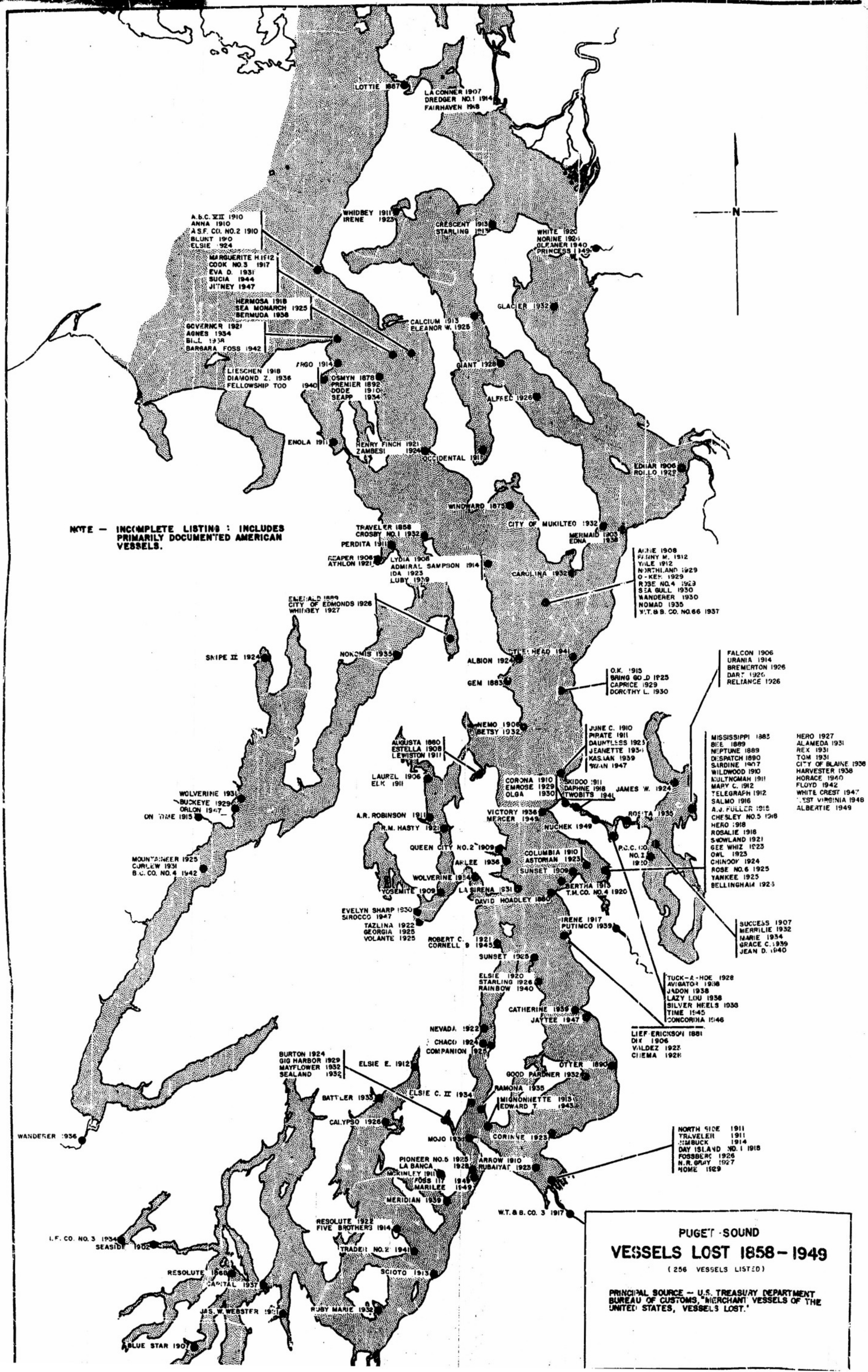
Fig. 9-6

SHIPWRECKS

A comprehensive analysis of locations and causes of wrecks (marine disasters of any cause) within the Puget Sound area would be extremely time-consuming. The various marine histories list almost every boat and ship that has sailed within the area and their ultimate disposition. The most readily accessible information is contained in the annual publication "Merchant Vessels of the United States," list of American vessels lost (U. S. Treasury Department Bureau of Customs Annual). This publication lists only American vessels lost after 1902. For a list of vessels from all nations lost prior to 1895, refer to "Lewis and Dryden's Marine History of the Pacific Northwest" (Wright 1895).

Appendix 9-A and Fig. 9-7 show characteristic areas, locations, and statistics of those vessels lost that were encountered in this preliminary survey.

Fig. 9-7



PUGET SOUND

VESSELS LOST 1858 – 1949

(256 VESSELS LISTED)

PRINCIPAL SOURCE — U.S. TREASURY DEPARTMENT BUREAU OF CUSTOMS, "MERCHANT VESSELS OF THE UNITED STATES, VESSELS LOST."

Appendix 9-A

SHIPWRECKS WITHIN THE BOUNDARIES OF PUGET SOUND
256 Vessels Listed
(See Fig. 9-6)

Vessels whose names are listed on the following pages have been reported to the Bureau of Customs as actual total loss and are classified in the column headed NATURE as follows:

FOUNDERED: Casualties due to leaking or capsizing of vessels including vessels running aground, striking rocks, reefs, bars, etc.
STRANDED: Casualties due to vessels running aground, rocks, reefs, bars, etc.
COLLIDED: Casualties involving collisions between two or more vessels but not between a vessel and any other object.
BURNED: Casualties due to fire.

The rig abbreviations used in describing vessels are as follows:

Bk. - bark	Sch. - schooner
Brg. - barge	Scw. - scow
Ga.s. - gas screw	St.p. - steam side wheel
Ga.y. - gas yacht	St.s. - steam screw
Ol.s. - oil screw	St.w. - steam stern screw

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
Steam	St.s.	Traveler	-	5	Foundered	1858	Off Foulweather Bluff
Steam	St.s.	Resolute	-	6	Explosion	1868	Squaxon Island Passage
Sail	Bk.	Windward	782	-	Stranded	1875	Useless Bay
Sail	Bk.	Osmyn	-	3	Collided	1878	Near Point Marrowstone
Steam	St.s.	Augusta	-	-	Burned	1880	Port Madison
Sail	Bk.	David Hoadley	984	-	Stranded	1880	Point Williams
Steam	St.s.	Lief Erickson	-	7	Burned	1881	Off Alki Point
Steam	St.p.	Gem	-	5	Burned	1883	Off Apple Tree Cove
Steam	St.s.	Mississippi	-	1	Stranded	1883	Seattle
Steam	St.s.	Lottie	-	-	Stranded	1887	Deception Pass
Steam	St.s.	Bee	-	-	Burned	1889	Seattle
Sail	Bk.	Emerald	1134	-	Burned	1889	Port Gamble
Steam	St.s.	Neptune	-	-	Burned	1889	Seattle
Steam	St.s.	Despatch	-	-	Burned	1890	Seattle
Steam	St.s.	Otter	-	-	Collided	1890	Near Des Moines
Steam	St.s.	Premier	-	2	Collided	1892	Near Marrowstone Point

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
Steam	St.s.	Seaside	31	0	Stranded	1902	Hammersley Inlet
Steam	Ga.s.	Mermaid	9	0	Burned	1903	Mukilteo
Steam	St.s.	Dix	130	45	Collided	1906	Alki Point
UR	Scw.	Edgar	15	0	Foundered	1906	Everett
Steam	St.s.	Falcon	74	0	Burned	1906	Houghton
Steam	St.s.	Laurel	16	0	Burned	1906	Keyport
Steam	St.s.	Nemo	9	0	Burned	1906	Jefferson Point
Sail	Bk.	Reaper	1468	0	Burned	1906	Port Ludlow
Steam	St.s.	Blue Star	32	0	Burned	1907	Eld Inlet
Steam	St.s.	La Conner	297	0	Burned	1907	La Conner
UR	Scw.	Sardine	11	0	Burned	1907	West Seattle
Steam	St.s.	Success	13	0	Foundered	1907	Lake Washington
Steam	St.s.	Acme	31	0	Burned	1908	Puget Sound
Steam	St.s.	Estella	27	0	Burned	1908	Port Madison
Sail	Sch.	Lydia	39	2	Collided	1908	Point No Point
UR	Scw.	Queen City No. 2	46	0	Stranded	1909	Bainbridge Island, Eagle Harbor
Steam	Ga.s.	Sunset	13	0	Burned	1909	Duwamish Head
Steam	St.p.	Yosemite	1319	0	Stranded	1909	Port Orchard Narrows
UR	Scw.	A.B.C. VIII	18	0	Broke from mooring	1910	Point Partridge
UR	Brg.	Anna	47	0	Foundered	1910	Point Partridge
Steam	Ga.s.	Arrow	9	1	Collided	1910	Commencement Bay
UR	Scw.	A.S.F. CO. No. 2	24	0	Broke from mooring	1910	Point Partridge
UR	Brg.	Blunt	96	0	Foundered	1910	Point Partridge
Steam	Ga.s.	Columbia	14	1	Collided	1910	Elliott Bay
Steam	Ga.s.	Corona	13	0	Burned	1910	Salmon Bay
Steam	St.s.	Dode	215	0	Stranded	1910	Marrowstone Point
Steam	Ga.s.	June C.	15	0	Burned	1910	Meadow Point
Steam	St.s.	Wildwood	80	0	Burned	1910	Seattle
Steam	St.s.	A. R. Robinson	36	0	Burned	1911	Brownsville
Steam	St.s.	Elk	25	0	Burned	1911	Keyport
Steam	St.s.	Enola	26	0	Burned	1911	Hadlock
Steam	Ga.s.	Lewiston	11	0	Burned	1911	Port Madison
Steam	St.s.	McKinley	66	0	Burned	1911	Wellochet Bay
Steam	St.p.	Multnomah	312	0	Collided	1911	Seattle
Steam	Ga.s.	North Side	9	0	Burned	1911	Tacoma
Steam	Ga.s.	Occidental	22	0	Burned	1911	Holmes Harbor
Steam	St.s.	Perdita	286	0	Burned	1911	Ludlow Rocks
Steam	Ga.s.	Pirate	11	0	Burned	1911	Meadow Point
Steam	Ga.s.	Skidoo	9	0	Burned	1911	Ballard

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
Steam	Ga.s.	Traveler	8	0	Burned	1911	Tacoma
Steam	St.s.	Whidbey	192	2	Burned	1911	Oak Harbor
Steam	Ga.s.	Elsie E.	14	0	Struck dock	1912	Burley Lagoon
Steam	Ga.y.	Fanny M.	25	0	Burned	1912	Puget Sound
Steam	Ga.y.	Marguerite H.	31	0	Burned	1912	Near Whidbey Island
Steam	Ga.s.	Mary C.	13	0	Burned	1912	Seattle
Steam	St.p.	Telegraph	386	0	Collided	1912	Seattle
Steam	Ga.s.	Yale	14	0	Burned	1912	Puget Sound
Steam	Ga.s.	Bertha	34	0	Burned	1913	At West Seattle
Steam	St.s.	Calcium	51	0	Burned	1913	Camano
Steam	Ga.s.	Crescent	9	0	Burned	1913	Utsalady
Steam	Ga.s.	LaPaloma	13	0	Burned	1913	Seattle
Steam	Ga.s.	Mignonnette	14	0	Burned	1913	Dalco Point, Admiralty Inlet
Steam	Ga.s.	Scioto	11	0	Burned	1913	Steilacoom
Steam	Ga.s.	Starling	13	0	Burned	1913	Utsalady
Steam	St.s.	Admiral Sampson	262	12	Collided	1914	Off Point No Point
Steam	St.s.	Argo	65	0	Collided	1914	At Point Hudson
Steam	St.p.	Dredger No. 1	282	0	Burned	1914	Near La Conner
Gas	Ga.s.	Five Brothers	14	0	Burned	1914	Gertrude
Steam	Ga.s.	Jimbuck	13	0	Collided	1914	Tacoma
Steam	St.s.	Urania	93	0	Burned	1914	Houghton
UR	Scw.	O.K.	20	0	Stranded	1915	Richmond Beach
Motor	Ga.y.	On Time	28	0	Burned	1915	Duckabush River
Motor	Ga.s.	Salmo	14	0	Burned	1916	Seattle
UR	Scw.	Cook No. 3	19	0	Stranded	1917	Whidbey Island
Steam	St.p.	Irene	105	0	Foundered	1917	Duwamish River
UR	Scw.	W.T. and B.Co.3	194	0	Foundered	1917	Puyallup River
Sail	Sch.	A. J. Fuller	1848	0	Collided	1918	Seattle
UR	Scw.	Chesley No. 5	46	0	Foundered	1918	Seattle
Gas	Ga.s.	Daphne	14	0	Burned	1918	Ballard
UR	Scw.	Day Island No. 1	6	0	Broke from mooring	1918	Tacoma
Steam	St.p.	Fairhaven	337	0	Burned	1918	La Conner
Gas	Ga.s.	Hermosa	11	0	Burned	1918	Admiralty Inlet
Steam	St.s.	Hero	21	0	Foundered	1918	Seattle
UR	Scw.	Lieschen	6	0	Stranded	1918	Port Townsend Beach
Steam	St.s.	Rosalie	318	0	Burned	1918	East Waterway, Seattle
Gas	Ga.s.	Elsie	7	0	Struck Obstruction	1920	Vashon Island

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
UR	Scw.	P.C.C.Co. No. II	79	0	Foundered	1920	Madison Park
UR	Scw.	T.M.Co. No. 4	65	0	Burned	1920	West Seattle
Motor	Ga.s.	White	14	0	Foundered	1920	Skagit River
Steam	St.s.	Athlon	157	0	Stranded	1921	Port Ludlow
Steam	St.s.	Governor	5474	0	Collided	1921	Near Point Wilson
Gas	Ga.s.	Henry Finch	29	0	Burned	1921	N.W. of Bush Point
Gas	Ga.s.	Jas. W. Webster	16	0	Burned	1921	Henderson Inlet
Gas	Ga.s.	R. M. Hasty	11	0	Burned	1921	Fletcher Bay
Gas	Ga.s.	Robert C.	25	0	Burned	1921	Harper
Gas	Ga.s.	Snowland	31	0	Burned	1921	Seattle
Gas	Ga.s.	Nevada	35	0	Burned	1922	Near Olalla
Gas	Ga.s.	Resolute	46	0	Burned	1922	Gertrude
Gas	Ga.s.	Tazlina	13	0	Foundered	1922	Port Orchard
Steam	St.s.	Astorian	255	0	Collided	1923	Near Smiths Cove, Elliott Bay
Gas	Ga.s.	Corinne	15	0	Burned	1923	Off Dash Point
Steam	St.s.	Dauntless	127	0	Foundered	1923	Meadow Point
Motor	Ga.s.	Gee Whiz	9	0	Collided	1923	Seattle
Gas	Ga.s.	Ida	10	0	Collided	1923	Point No Point
Gas	Ga.s.	Irene	7	0	Foundered	1923	Oak Harbor
Motor	Ga.s.	Mary Ann	7	0	Burned	1923	Olympia
Motor	Ga.s.	Owl	15	0	Foundered	1923	Seattle
Gas	Ga.s.	Rubaiyat	88	4	Foundered	1923	Tacoma Harbor
Gas	Ga.s.	Valdez	13	0	Foundered	1923	South Seattle
Motor	Ga.s.	Albion	86	0	Burned	1924	Apple Tree Pt.
Steam	St.s.	Burton	97	0	Burned	1924	Gig Harbor
Motor	Ga.s.	Chaco	104	0	Burned	1924	Colvos Pass
UR	Brg.	Chinook	167	0	Foundered	1924	Seattle
Motor	Ga.y.	Elsie	64	0	Stranded	1924	Partridge Pt.
Gas	Ga.s.	James W.	8	0	Burned	1924	Sand Point, Seattle
Steam	St.s.	Norine	13	0	Stranded	1924	Skagit River
Gas	Ga.s.	Snipe II	7	0	Burned	1924	Quilcene
Gas	Ga.y.	Zambesi	21	0	Burned	1924	Bush Point, Puget Sound
Motor	Ga.s.	Bring Gold	18	0	Burned	1925	Richmond Beach
Motor	Ga.s.	Companion	37	0	Burned	1925	Lisbeula
Motor	Ga.s.	Eleanor W.	123	0	Burned	1925	Point Lowell, Camano Island
Steam	St.s.	Georgia	70	1	Explosion	1925	Port Orchard
Steam	St.s.	Mountaineer	57	0	Stranded	1925	Hood Canal
UR	Scw.	Pioneer No. 5	273	0	Foundered	1925	Point Evans, Tacoma

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
UR	Scw.	Rose No. 6	11	0	Foundered	1925	Seattle
Steam	St.s.	Sea Monarch	471	0	Collided	1925	Admiralty Inlet
Motor	Ga.s.	Sunset	16	0	Burned	1925	Vashon Heights
Motor	Ga.s.	Volante	15	0	Burned	1925	Port Orchard
Motor	Ga.s.	Yankee	7	0	Foundered	1925	Seattle
Motor	Ga.s.	Alfred	17	0	Burned	1926	Saratoga Passage
Motor	Ga.s.	Bellingham	21	0	Burned	1926	Seattle
Steam	St.s.	Bremerton	191	0	Burned	1926	Houghton
Motor	Ga.s.	Calypso	13	0	Burned	1926	Raft Island
Motor	Ga.s.	City of Edmonds	49	0	Burned	1926	Port Gamble
Steam	St.s.	Dart	74	0	Burned	1926	Houghton
Motor	Ga.s.	Fossberg	15	0	Foundered	1926	Tacoma
Steam	St.s.	Reliance	98	0	Burned	1926	Houghton
Steam	St.s.	Starling	17	0	Foundered	1926	Cove, Vashon Is.
Motor	Ga.s.	Hero	7	0	Foundered	1927	Seattle
Motor	Ga.s.	N. R. Gray	16	0	Burned	1927	Tacoma
Motor	Ga.s.	Whidbey	48	0	Burned	1927	Port Gamble
Motor	Ol.s.	Chema	13	0	Burned	1928	Alki Point
Motor	Ga.s.	Giant	19	0	Burned	1928	Lowell Point
Motor	Ga.s.	La Banca	11	0	Burned	1928	Point Evans
Motor	Ga.s.	Tuck-a-hoe	37	0	Burned	1928	Lake Union
Steam	St.s.	Buckeye	47	0	Burned	1929	Pleasant Harbor
Motor	Ga.s.	Caprice	13	0	Foundered	1929	Richmond Beach
Steam	St.s.	Emrose	67	0	Collided	1929	Salmon Bay
Steam	St.s.	Gig Harbor	159	0	Burned	1929	Gig Harbor
Motor	Ga.s.	Nome	10	0	Stranded	1929	Tacoma
Motor	Ga.s.	Northland	39	1	Collided	1929	Puget Sound
Motor	Ga.s.	O-Keh	11	0	Burned	1929	Puget Sound
Motor	Ga.s.	Rollo	19	0	Burned	1929	Everett
UR	Scw.	Rose No. 4	85	0	Foundered	1929	Puget Sound
Motor	Ga.s.	Evelyn Sharp	14	0	Burned	1930	Bremerton
Motor	Ol.s	Dorothy L.	21	0	Burned	1930	Richmond Beach
Motor	Ga.s.	Olga	13	0	Burned	1930	Salmon Bay
Motor	Ga.s.	Sea Gull	8	0	Foundered	1930	Puget Sound
Motor	Ga.y.	Wanderer	11	0	Burned	1930	Puget Sound
Steam	St.s.	Alameda	3158	0	Burned	1931	Seattle
Motor	Ga.s.	Curlew	11	0	Burned	1931	Hood Canal
Motor	Ga.s.	Eva D.	12	0	Foundered	1931	Whidbey Island
Motor	Ol.s.	La Sirena	16	0	Stranded	1931	Restoration Point
Motor	Ga.s.	Rex	9	1	Burned	1931	Seattle
-	Scw.	Tom	134	0	Burned	1931	Seattle
Motor	Ga.s.	Wolverine	12	0	Burned	1931	Brinnon
Motor	Ga.s.	Beauclaire	39	0	Burned	1932	Olympia
Motor	Ga.s.	Betsy	8	0	Stranded	1932	Jefferson Point
Motor	Ga.y.	Carolina	18	0	Burned	1932	Off Possession Point

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
Steam	St.s.	City of Mukilteo	150	0	Burned	1932	Columbia Beach
Motor	Ol.s.	Crosby No. 1	14	0	Burned	1932	Foulweather Bluff
Motor	Ga.s.	Glacier	47	0	Burned	1932	Port Susan Bay
Motor	Ga.s.	Good Partner	36	0	Burned	1932	Robinson Point
Motor	Ga.s.	Mayflower	37	0	Burned	1932	Gig Harbor
Motor	Ga.y.	Merrilie	13	0	Burned	1932	Lake Washington
Steam	St.s.	Ruby Marie	11	0	Burned	1932	Vega
Motor	Ga.s.	Sealand	39	0	Burned	1932	Gig Harbor
Motor	Ga.s.	Battler	12	0	Burned	1933	Huge Creek
Motor	Ga.s.	Agnes	20	5	Foundered	1934	Point Wilson
Motor	Ga.s.	Elsie C. II	12	0	Burned	1934	Off Sunrise Beach, Tacoma
UR	Scw.	I. F. Co. No. 3	43	0	Foundered	1934	Shingle Mill Dock, Shelton
Motor	Ga.s.	Jeanette	9	0	Foundered	1934	Off Meadow Point
Motor	Ga.s.	Marie	12	0	Stranded	1934	Lake Washington, Seattle
Motor	Ga.s.	Seapp	16	0	Foundered	1934	Marrowstone Point
Motor	Ga.s.	Wolverine	17	0	Stranded	1934	Pleasant Beach
Motor	Ga.y.	Nokomis	14	0	Burned	1935	On Beach at Lofall
Motor	Ga.s.	Nomad	19	0	Burned	1935	Puget Sound
Motor	Ga.s.	Ramona	13	0	Burned	1935	Spring Beach
Motor	Ga.y.	Rosita	10	0	Collided	1935	Foot University Way, Seattle
Motor	Ga.y.	Arlee	19	0	Burned	1936	Creosote
Motor	Ga.s.	Diamond Z.	33	0	Burned	1936	Glen Cove, Port Townsend Bay
Motor	Ga.s.	Victory	10	0	Stranded	1936	West Point, Whidbey Island
Motor	Ga.s.	Wanderer	7	0	Foundered	1936	Skokomish River
Motor	Ol.s.	Capital	148	0	Burned	1937	In Dana Passage near Brisco Pt., Puget Sound
UR	Scw.	W.T. and B. Co. No. 66	339	0	Burned	1937	Puget Sound
Motor	Ga.s.	Avigator	12	0	Burned	1938	Lake Union, Seattle
Motor	Ol.s	Bermuda	14	0	Foundered	1938	1/2 Mi.S. Skagit Head, Admiralty Inlet
UR	Scw.	Bill	10	0	Stranded	1938	Off Point Wilson

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
Motor	Ga.s.	City of Blaine	37	0	Collided	1938	Seattle
Motor	Ol.s.	Edna	9	0	Collided	1938	Mukilteo
Steam	St.w.	Harvester	638	0	Collided	1938	Seattle
Motor	Ga.s.	Jadon	8	0	Burned	1938	Lake Union, Seattle
Motor	Ga.s.	Lazy Lou	10	0	Burned	1938	Lake Union, Seattle
Motor	Ga.s.	Mojo	15	0	Burned	1938	Point Defiance, Tacoma
Motor	Ga.y.	Silver Heels	20	0	Foundered	1938	Lake Union, Seattle
Motor	Ga.s.	Catherine	15	0	Foundered	1939	2 1/2 miles S. Pulley Point
Motor	Ga.s.	Grace C.	7	0	Collided	1939	Lake Washington
-	Ga.s.	Kasaan	42	0	Burned	1939	Halfway between Richmond Beach and Meadow Point
Motor	Ga.s.	Luby	20	0	Burned	1939	Off Point No Point
Motor	Ga.s.	Meridian	38	0	Burned	1939	Point Fosdic, Tacoma
Motor	Ga.s.	Putimco	10	0	Burned	1939	Duwamish River, Seattle
Motor	Ga.s.	Fellowship Too	7	0	Burned	1940	3 mi. out toward Oak Bay Channel, Port Townsend Bay
Steam	St.w.	Gleaner	422	0	Stranded	1940	Skagit River
UR	Scw.	Horace	253	0	Foundered	1940	Seattle
-	Ga.s.	Jean D.	9	-	Burned	1940	Cozy Cove, Lake Washington, Seattle
Motor	Ga.s.	Rainbow	7	0	Foundered	1940	Racoma Beach, Vashon Island
-	Ol.s.	Steelhead	35	-	Foundered	1941	Edmonds
-	Scw.	Trader No. 2	31	-	Stranded	1941	McNeil Island
-	Ga.s.	Twobits	8	0	Burned	1941	Ballard, Seattle
-	Ol.s.	Barbara Foss	34	-	Burned	1942	Between Point Wilson and Partridge Point
-	Scw.	B.C. Co. No. 4	12	-	Foundered	1942	Hood Canal
-	Ba.s.	Floyd	12	-	Burned	1942	Seattle
-	Ga.y.	Edward T.	20	-	Burned	1943	Off Dalco Point
-	Ga.s.	Sucia	10	-	Stranded	1944	Whidbey Island

TYPE	RIG	NAME OF VESSEL	GROSS TONNAGE	LIVES LOST	NATURE	DATE	PLACE
-	Scw.	Cornell 9	231	-	Burned	1945	Harper
-	Ga.s.	Time	10	-	Foundered	1945	Lake Union, Seattle
-	Ga.s.	Concordia	11	-	Foundered	1946	Lake Union, Seattle
-	Ga.s.	Jaytee	15	-	Burned	1947	3 mi. off Three Tree Point
-	Brg.	Jitney	896	-	Stranded	1947	Whidbey Island
-	Ga.s.	Orlon	12	-	Foundered	1947	Pleasant Harbor, Hood Canal
-	Ga.s.	Sirocco	16	-	Burned	1947	Bremerton
-	Ga.s.	Swan	8	-	Burned	1947	1/2 mi. off Meadow Point
-	Ga.s.	White Crest	38	-	Burned	1947	Seattle
-	Ga.s.	West Virginia	14	-	Stranded	1948	Seattle Harbor
-	Ga.s.	Albertie	7	-	Burned	1949	Seattle
-	Scw.	Foss 117	376	-	Foundered	1949	Tacoma Narrows Bridge
-	Ga.s.	Marilee	14	-	Burned	1949	Tacoma Narrows
-	Ol.s.	Mercer	35	-	Foundered	1949	1 mi. S. West Point Light
-	Ol.s	Nuchek	169	-	Burned	1949	Lake Washington Ship Canal
-	Ga.s.	Princess	15	-	Burned	1949	Skagit River

Table modified from Merchant Vessels of the United States (U. S. Treasury Department Bureau of Customs Annual) and Lewis and Dryden's Marine History of the Pacific Northwest (Wright 1895).

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