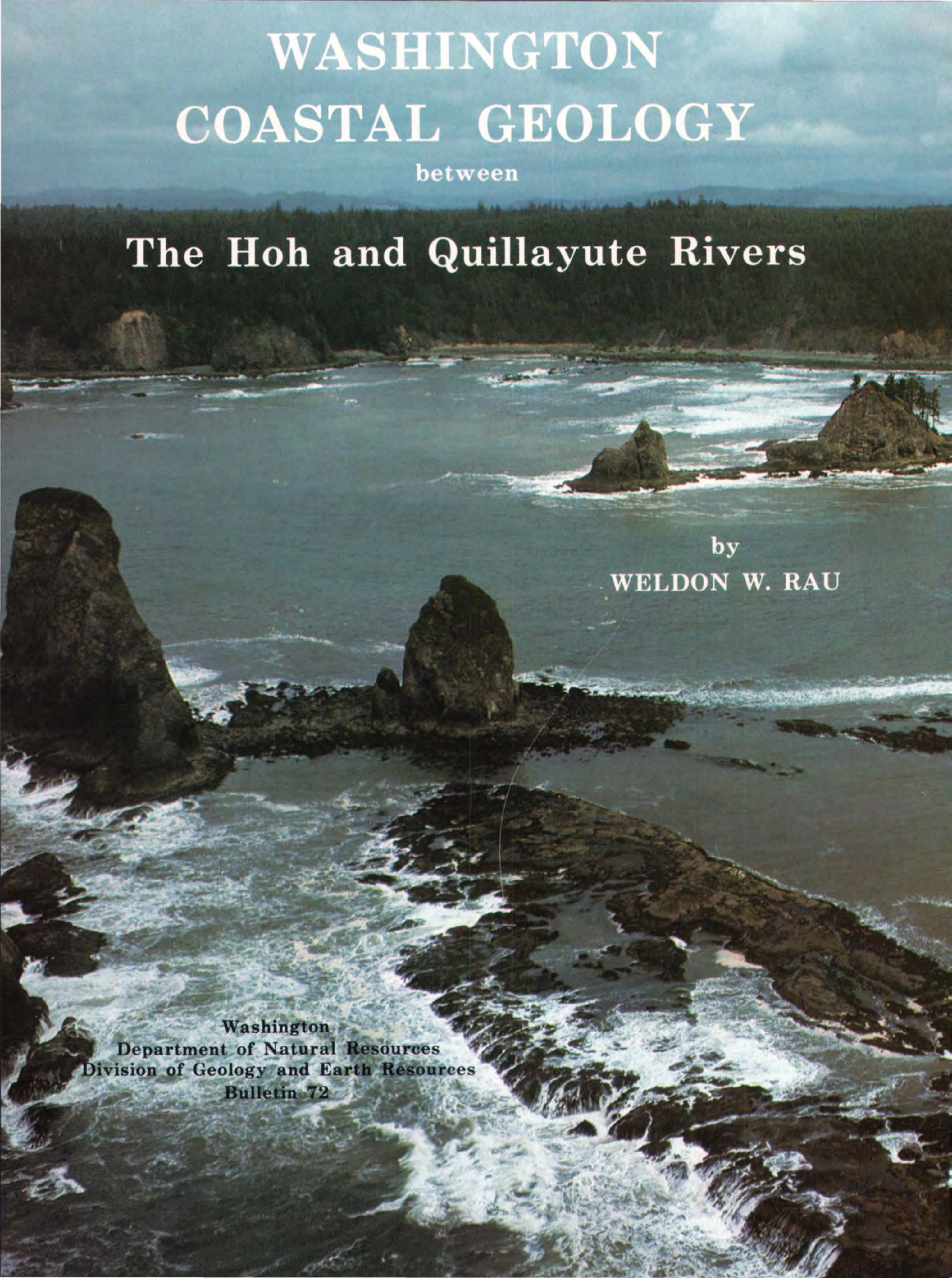


WASHINGTON COASTAL GEOLOGY

between

The Hoh and Quillayute Rivers

by

WELDON W. RAU

Washington
Department of Natural Resources
Division of Geology and Earth Resources
Bulletin 72

FRONT COVER PHOTO

THE GIANTS GRAVEYARD is part of a large group of offshore islets and reefs extending between Toleak Point and Taylor Point. They constitute a segment of the earth's crust composed of massive and stratified sandstones and siltstones known as Hoh rocks. Intense forces and stresses generated by the shifting of the earth's crust over millions of years of time have resulted in complex folding and faulting of these strata.

". . . The whole shore we saild along this forenoon is steep and rocky and entirely lind with a vast number of elevated rocks and islets of different forms and sizes, but the land itself is of a very moderate height coverd with Pines and stretching back with a very gradual acclivity to form an inland ridge of high mountains in which Mount Olympus claimd a just preeminence . . ."

A description of the coastal region between Destruction Island and Cape Flattery, April 29, 1792, by Archibald Menzies, surgeon and naturalist on Vancouver's voyage to the Northwest Coast of America.

LOOKING SOUTHWARD AT TAYLOR POINT from Third Beach with the Giants Graveyard in the distance. Bedrock of Taylor Point and the Giants Graveyard consists of upturned layers of sandstones and conglomerates known as Hoh rocks. Sediments that form these strata were deposited in the sea at least 20 million years ago. Light-colored unconsolidated ice age (Pleistocene) deposits of water-lain sand and gravel and windblown silt rest on a nearly horizontal ancient wave-cut terrace. This surface was carved in Hoh bedrock some 125 thousand years ago when sea level stood higher relative to land than it does today. The "hanging" V-shaped valley from which the small stream flows to form a waterfall has resulted from the more rapid eastward erosion of the land by the sea than downward cutting by the stream.

STATE OF WASHINGTON

DEPARTMENT OF NATURAL RESOURCES

BERT L. COLE, Commissioner of Public Lands
RALPH A. BESWICK, Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES

VAUGHN E. LIVINGSTON, JR., State Geologist

Bulletin No. 72

Washington Coastal Geology
Between
The Hoh and Quillayute Rivers

Part I.—Rock Formations, Geologic Processes, and Events

Part II.—Geologic Observations and Interpretations Along the Coast

A review of geologic processes and events as revealed by the rock formations and deposits of the Washington coast—with historical notes and hiking information.

BY
WELDON W. RAU
Research Geologist

1980

For sale by the Department of Natural Resources, Olympia, Washington

James Island area

PREFACE

An awareness of the many facets of nature is often heightened by a visit to the wilderness coast of Washington. Rock formations of the earth's crust and debris deposits from these formations are not only a major part of, but form the foundation for, the coast's natural setting. Many hikers have, no doubt, wondered about these formations and rock deposits and the processes that formed them. To the geologist, such questions are a challenge. Like the pages in a book, rock strata of the present-day Washington coast reveal to the geologic interpreter an incredible sequence of geologic events that, over epochs of time, has resulted in rocky headlands, offshore sea stacks, and rock debris bluffs.

The purpose of this report is to present the coastal geologic story. Hopefully it will be of interest not only to students of geology but also to those readers with only a general curiosity for natural sciences. The illustrations and accompanying captions alone tell a geologic story that many may find of interest. The text, in two parts, develops the story more fully. Part I deals with the geologic processes and events that have resulted in the forming and distribution of the coastal rock formations. Part II is designed as a beach guide where the geology of individual segments of the coast is discussed starting in the Hoh River area and concluding at La Push.

During the course of field investigations, many historical events were brought to the attention of the author. Some of the more interesting and geologically related appear as historical notes throughout the report. Also, general hiking conditions and trail data are presented in the appropriate sections of Part II.

This report complements Bulletin 66 of the Washington Division of Geology and Earth Resources on the geology of the coastal area south of the Hoh River. Similarly, the present report is an outgrowth of geologic mapping and related research conducted by the author in the coastal area during the past 10 years. These studies have provided basic knowledge about rock types and distribution and geologic structures of the area—data essential to a scientific evaluation of the mineral and petroleum potential of this and adjacent offshore areas. It is the hope of the writer that, as a byproduct of these studies, the present publication will provide the nonscientific reader a useful and enjoyable guide to the geology and related processes of one of Washington's wilderness coastal areas.

ACKNOWLEDGMENTS

The assistance and advice of, and discussions with, numerous professional colleagues have been invaluable to the writing of this report. Many publishd works have served either directly or indirectly as a souce of background material, but due to the nature of this report, not all have been cited specifically. Acknowledgments are here extended to these contributors.

Unpublished studies by the late S. L. Glover, formerly of the Washington Division of Mines and Geology, and a Ph. D. dissertation by R. J. Stewart have been particularly useful sources of basic geologic data. Discussions with, and suggestions from, W. M. Cady, P. D. Snavely, Jr., and R. W. Tabor of the U.S. Geological Survey have been stimulating and helpful. Contributions on macrofossil paleontology by W. O. Addicott of the U.S. Geological Survey are gratefully acknowledged.

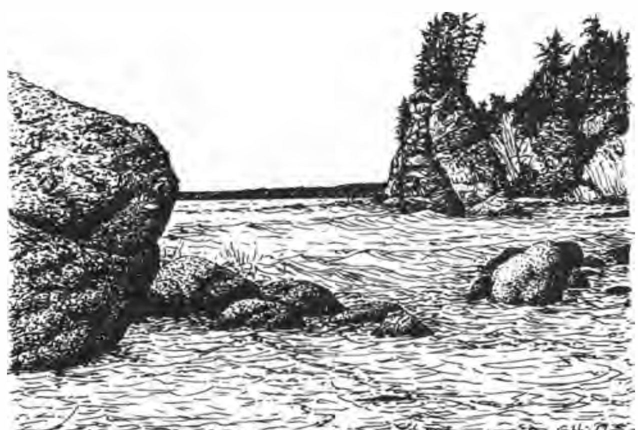
The assistance and cooperation of many individuals of the communities of Forks, La Push, and the Hoh River valley have contributed much to this report. Particular thanks for general and historical information is given to Mr. and Mrs. C. H. Barlow and Mr. and Mrs. John Fletcher of the Hoh River valley.

Gratitude is extended for the cooperation and assistance of many staff members of the Department of Natural Resources Olympic Area Office at Forks, the U.S. Coast Guard Station at La Push, the Olympic National Park Service offices at Port Angeles, Forks, and Mora, and the Quileute Tribal Council at La Push. Helicopter support by the Washington State National Guard for aerial photography is gratefully acknowledged.

Thanks are due to all staff members of the Division of Geology and Earth Resources who assisted in the preparation of this report, particularly Laura Bray for her editorial assistance, and K. G. Ikerd, G. C. Johnson, and M. D. Macleod for their graphic skills. The capable assistance of J. W. Lindberg, J. B. Hall, J. J. Janson, and T. M. Vogel during the summer months at various times throughout the course of this study is gratefully acknowledged.

CONTENTS

HIKING INFORMATION



Secret Cove

ILLUSTRATIONS

Near Mosquito Creek

DISCOVERY AND EXPLORATION*

Early explorers along the Northwest coast of America were primarily concerned with discovery and, to a certain extent, the charting of the coastline. Although largely unaware of geologic processes, these adventurous seamen nevertheless were confronted with the treacherous rocky coast that has resulted from these processes.

The first recorded visits were made by the Spanish—Juan Perez in 1774, and again in 1775 with Bruno Heceta and Bodega y Quadra. During the latter expedition actual landings were made but in an area to the south of the Hoh River. They applied the name "Isla de Dolores" (Island of Sorrow) to the presently named Destruction Island; some believe in memory of an ill-fated encounter nearby with the natives.

Perhaps the first recorded visit by Europeans to any part of the coast between the Hoh and Quillayute Rivers was in the summer of 1787 when the "Imperial Eagle" commanded by Captain Charles Barkley, while on a fur trading expedition, anchored off the mouth of the Hoh River. A small boat was sent ashore to investigate the river, and because the boat never returned, Barkley named the stream Destruction River. This name was first applied to the nearby island the following year by Captain John Meares of the "Adventurer," while also on a trading expedition. Variations, apparently on the original native name for the river, were used in subsequent years (Ohahlat, Hooh, Hooch, Huch, and Hoh).

It was in the vicinity of the Hoh River near Destruction Island, in the spring of 1792, that Captain George Vancouver of the "Discovery" accompanied by the "Chatham" on a voyage of exploration from England, met, by chance, Captain Robert Gray of the "Columbia" out of Boston. Gray had been on a trading expedition and had gained considerable knowledge of the coast as well as the Straits of Juan de Fuca and adjacent waters. He described a large bay and river to the south that hadn't been sighted by Vancouver because of fog and inclement weather. Vancouver, on his return southward, honored Gray and his ship by naming the bay "Grays Harbor" and the river "Columbia."

In the La Push area, one of the earliest records of a probable sighting or contact with what is believed to be the Quileute people was made by John Meares during a trading voyage from China in the "Felice Adventurer," accompanied by the "Iphigenia Nubiana," in the year 1788. Sailing generally southward from Cape Flattery, he describes the following immediately before sighting Destruction Island:

> *. . . but although the village of Queenuitett was obscured from view, we could very plainly discern the town of Queenuitett, which is distant from it about 7 or 8 miles. It is situated on a high perpendicular rock, and is joined by a narrow and impregnable causeway, twenty feet in height, to the mainland, which is an entire forest. With our glasses, we observed a multitude of houses, scattered over the face of the rock.*

A few years later on May 6, 1792, John Boit, a young cadet with Captain Gray, recorded what is believed to have taken place in the La Push area:

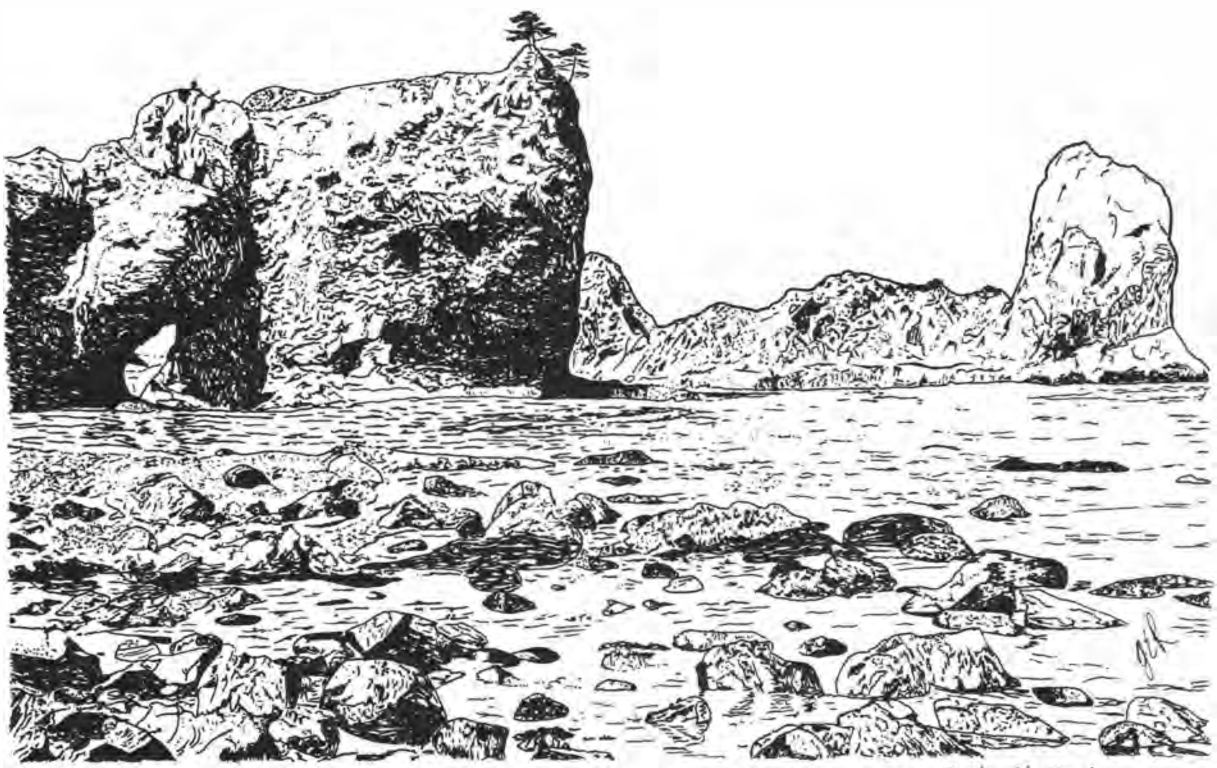
> *. . . Hove too fro some canoes to com up. They brought us fish but no skins, bore off these fellows belong'd to a small village in sight from the Ship, call'd Goliew.*

On May 21, 1792, Boit also recorded:

> *. . . N. latt. 47°51'. Abreast the village Goliu, hove too and purchas'd some Skins from the Natives, then bore off to the north and wt.*

A rock-strewn coastline, where natives took advantage of the sheerness of rock cliff for protection, was the setting for exploration and discovery—a setting that, to a great extent, is the result of geologic processes, some of which began millions of years ago. The following discusses those geologic processes and events responsible for forming the rugged but picturesque present-day north coast of Washington State.

*Source of historical data
Bancroft and Oak, 1884; Howay, 1941; Meany, 1923; Meares, 1790;
Menzies, 1923; Vancouver, 1798.



Teahwit Head

PART I

ROCK FORMATIONS AND GEOLOGIC PROCESSES

GENERAL STATEMENT

Rock formations exposed along the Washington coast tell a fascinating story of complex geologic history. The area between the Hoh River and La Push is no exception. Data recorded in these rocks reveal how and in what environments these strata were formed, millions of years ago, as well as the severe conditions they have since undergone. Because crustal forces of the earth have dealt harshly with some of the rock formations of this area, the geologic history is garbled and can be reconstructed only by piecing together data from individual outcrops. Where the rock record has been completely erased by erosion or has been jumbled by forces within the earth beyond comprehension, geologists can only theorize, basing their concepts on knowledge of the earth's crust in other parts of the world where geologic data is less complex.

ROCK FORMATIONS OF THE EARTH'S CRUST

According to the available data, the oldest rock formations exposed along this part of the Washington coast date back no more than 50 million years. This is relatively young when compared to an age of 4.5 billion years usually calculated for the older rocks of the earth's crust in other areas of the world (fig. 1). During the past 50 million years rock formations of the Washington coast have nevertheless undergone a surprising amount of deformation and alteration.

Rock formations exposed along the Washington coast, particularly between the Hoh and Quillayute Rivers, are largely sedimentary in origin. The sediments (silt, sand, and gravel) that make up these rocks were first deposited on a sea floor millions of years ago in the same way modern sediments, transported by streams from continents to the oceans, accumulate today on the sea floor. Much has happened to these ancient sedimentary deposits since their accumulation, not only because they have become consolidated into rock but because they are found today above sea level and as a part of the continent. Generally, most of these rock formations can be grouped into three major categories—siltstones, sandstones, and conglomerates. These basic terms simply indicate the relative grain size of the individual sediments that make up lithified sedimentary rocks. Silt refers to very fine-grained, essentially mudlike sediment, and sand refers to sandy or sugary size particles similar to sand that accumulates on a beach. Conglomerates are composed of rounded pebbles of various sizes and can be thought of as consolidated gravel. These three types of sedimentary rocks are found associated with each other usually as laminated, thin-to-thick layers or sometimes as very massive individual beds. As sediments accumulate, their weight produces **STATIC PRESSURE** that compacts and solidifies the deeply buried layers. Eventually, with the aid of minerals precipitated from ground water, the deeply buried sediments are lithified into formations and become a part of the earth's crust. Sediments usually accumulate in nearly horizontal layers or beds on the ocean floor. However, as can be seen in many outcrops along the coast, the orientation of bedding in sedimentary rocks is usually far from horizontal. Thus, indications are that forces within the earth, over a period of millions of years, have changed the original orientation of these beds by the gradual processes of **FOLDING** (bending) and **FAULTING** (breaking). These rock strata are therefore steeply tilted or even in overturned positions (fig. 2).

CRUSTAL FORCES

To logically account for the forces responsible for major crustal disturbances and to understand the mechanism or method this force has applied to the rocks of the earth's crust, it is necessary to rely on a relatively new geologic concept known as plate tectonics. Before this idea was developed some 15 or 20 years ago, geologists found it difficult to adequately explain the complex structural relations that are seen in the rock formations of the

MILLIONS OF YEARS AGO	ERA
65	CENOZOIC
230	MESOZOIC
600	PALEOZOIC
4500±	PRECAMBRIAN

MILLIONS OF YEARS AGO	ERA	PERIOD	EPOCH	COASTAL ROCK UNITS AND GEOLOGIC EVENTS
.01	CENOZOIC	QUATERNARY	Recent	Unconsolidated stream, lake, and beach deposits.
.05			Pleistocene	No deposits locally
				Silt, sand, and gravel; deposited by streams from glaciers.
				Marine erosion in coastal area
.10				Gently tilted, semiconsolidated silt, sand, and gravel; deposited by glaciers and streams from glaciers (exposed inland and in areas along coast to the south).
1.5				Uplift and much stream erosion
7.0		TERTIARY	Pliocene	QUINAULT AND QUILLAYUTE FORMATIONS (not exposed locally) Consolidated, stratified, moderately tilted sedimentary rocks, mostly of marine origin. Quinault Formation exposed along the coast to the south; Quillayute Formation exposed in the Quillayute Valley.
15.0			Miocene	Uplift and deformation
22.5				HOH ROCK ASSEMBLAGE Sedimentary rock sequences: Steeply titled and overturned siltstones, sandstones, and conglomerates; originally deposited in a marine basin. Tectonic melange rocks: Chaotically mixed blocks of sedimentary and other rock types in a matrix of softer claystone and broken siltstone; a result of major forces in the earth's crust.
36.0			Oligocene	No coastal rock record
40.0			Eocene	Hard, badly broken, well stratified siltstones and sandstones of marine origin.
45.0				No local rock record
50.0				Badly fractured volcanic rocks interbedded with siltstone beds of marine origin (not exposed locally).
55.0				No local rock record
65.0			Paleocene	No local rock record

GEOLOGIC TIME CHART (fig. 1).

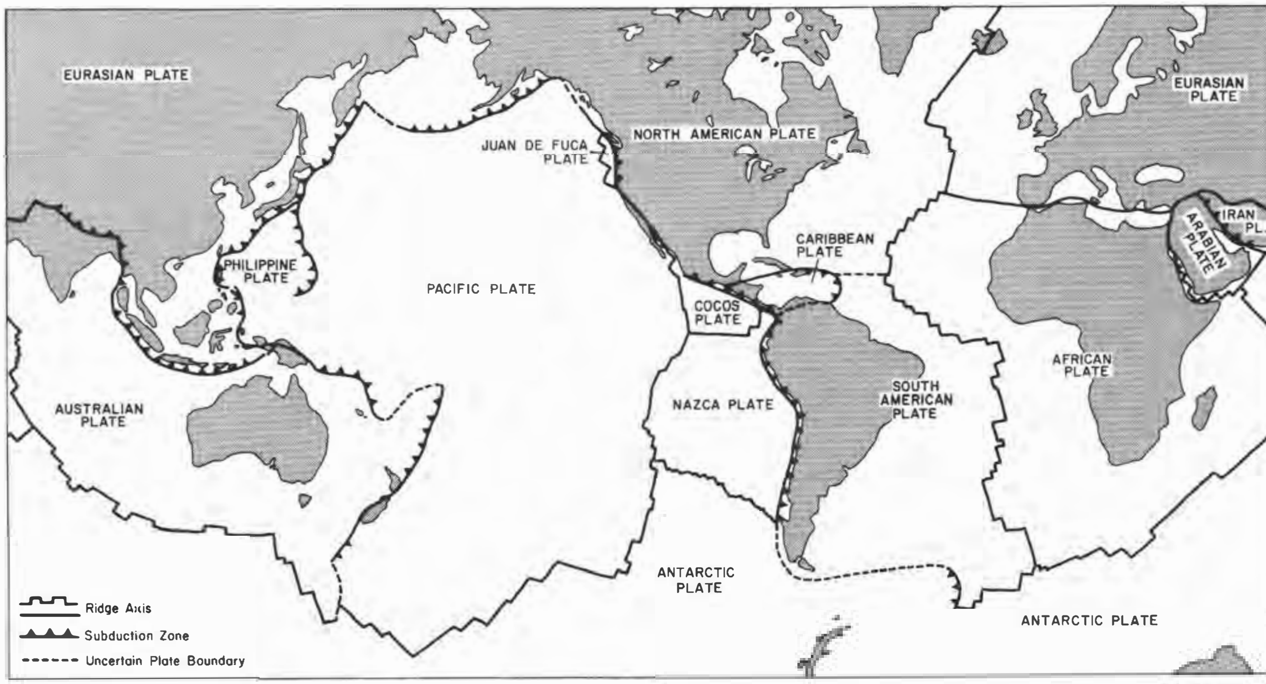
Washington coast and the Olympic Mountains. The application of this concept to the Olympic structures has been discussed in some detail in both professional journals and semipopular reports (Stewart, 1971; Rau, 1973, 1979; Cady, 1975; Tabor, 1975; Tabor and Cady, 1978) and therefore only a brief summary is presented here.

The term **PLATE TECTONICS** refers to the concept that the earth's crust is made up of a series of large, relatively rigid segments or plates (fig. 3) that essentially float on the less rigid or plastic inner part of the earth known as the **MANTLE** (fig. 4). Each plate may maintain a generally constant direction of motion for long periods of time. Although movement of each plate may only be a fraction of an inch each year, over a period of millions of years, many miles of relative motion can take place. Plate motion originates along a mountainous area on the sea floor known as an **OCEANIC RIDGE.** The ridge, in effect, is an elongated vent or crack in the earth's crust where, as the vent opens, magma rises from below to fill the crack, cools, solidifies, and is added to crustal plates on each side of the ridge. As the process is repeated periodically over millions of year, the ocean's volcanic crustal floor appears to move or spread in opposite directions away from the oceanic ridge or crack—thus a closely related term **SEA FLOOR SPREADING** is often applied to this part of the plate tectonic concept. The leading edge of each plate may be hundreds of miles from the oceanic ridge. In such areas the expanding plate is not only in contact with, but is continually moving toward, another plate. To accommodate the continual expansion of the first plate, it usually forces its way beneath the second plate. Eventually rocks of the first plate reach such depths within the earth that they are converted to molten magma by high pressures and temperatures. Areas where one plate moves beneath another are known as **SUBDUCTION ZONES.**

The nature of the force that drives the plates away from the ridge in opposite directions is not entirely known but one theory of explanation is based on convection currents. A simple analogy can be made to a boiling kettle of water where the hottest or least dense water on the bottom rises to the top and forces the cooler, heavier water to the sides of the kettle. If convection currents are functioning within the somewhat plastic inner earth, they may be causing the relatively rigid crustal plates of volcanic rock to continually move away from the oceanic ridge where lighter molten magma rises. The entire system may then be compared to a continuous conveyor belt that slowly, but over a period of millions of years, continues to move in one general direction.

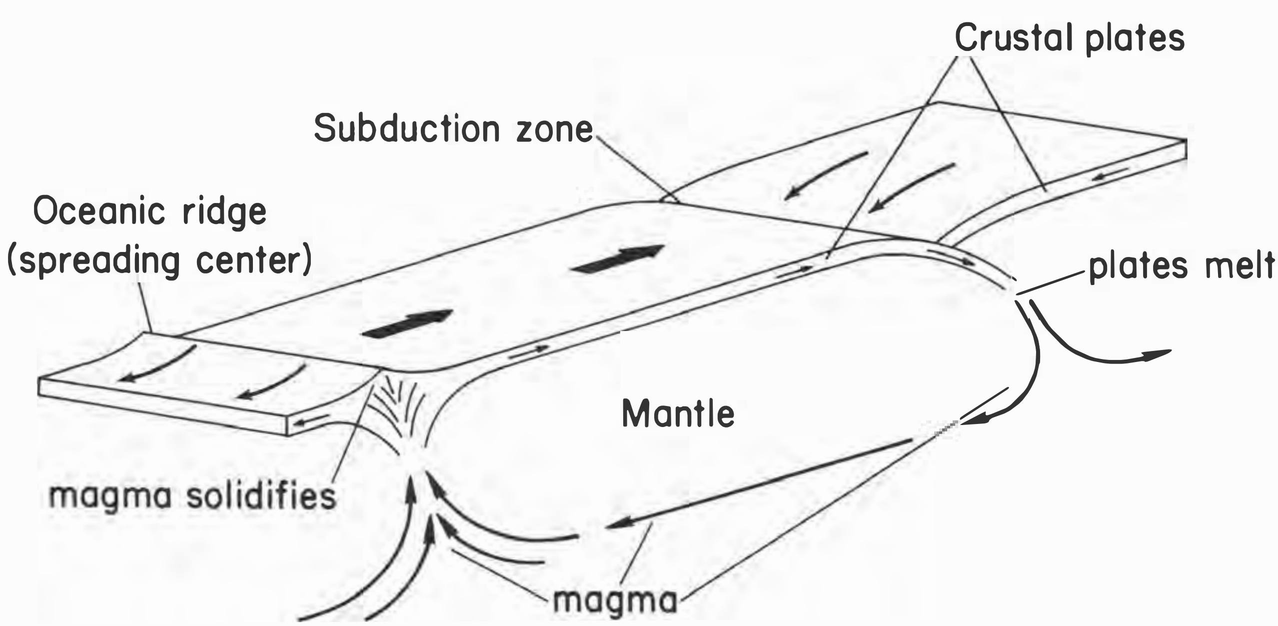
STEEPLY DIPPING, OVERTURNED, well-stratified sedimentary rocks exposed at Strawberry Point (fig. 2).

During all of this time, the seas continually receive sediments that have been transported from the continents by streams. Therefore, in millions of years of time, thousands of feet of sediments (sand, silt, and gravel) can accumulate on the volcanic "conveyor belt" and become consolidated to sedimentary rocks. By the time the oceanic crustal plate reaches the subduction zone, it not only consists of a thick belt of volcanic rock but is blanketed with a considerable thickness of sedimentary strata as well.



Adapted from Dewey, 1972

THE MAJOR PLATE SYSTEM of the world. The earth's crust is believed to be made up of large, rigid plates (fig. 3).



BLOCK DIAGRAM showing the basics of the plate tectonic concept. Molten magma from the mantle rises at the oceanic ridge, cools and solidifies, continually forming a crustal plate. Hundreds to thousands of miles from the ridge the plate moves downward into the mantle at the contact with another plate and melts. The continuous process resembling a large "conveyor belt" moves the crustal plate a few centimeters each year (fig. 4).

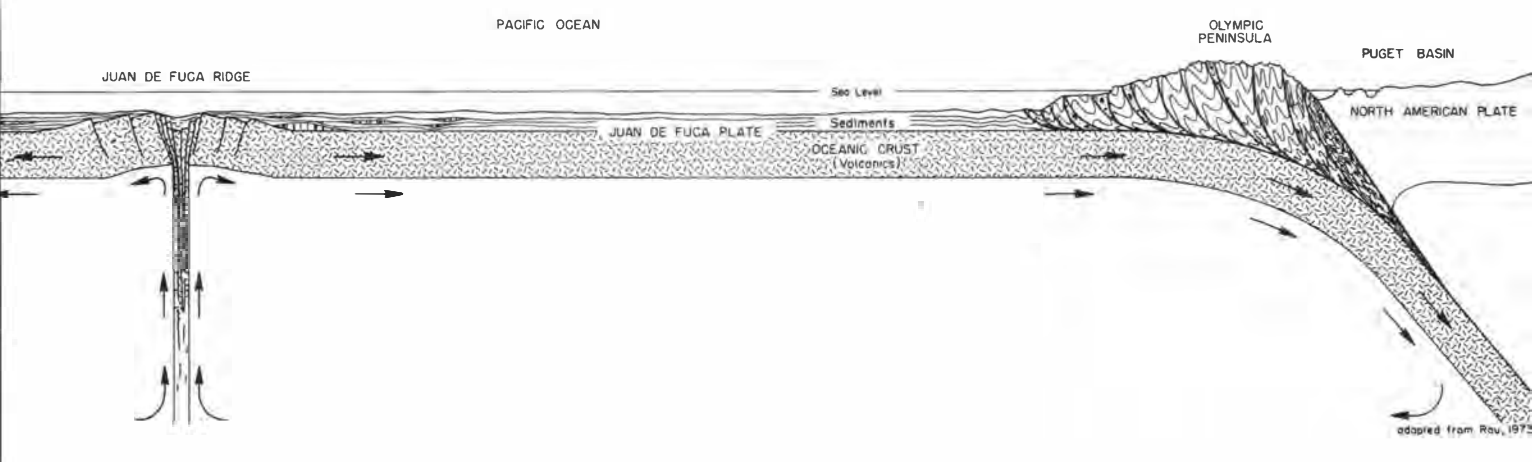
CRUSTAL FORCES AND THE OLYMPIC PENINSULA

Scientists have found that the plate tectonic model may well be applied to the origin of many of the rock formations of the Olympic Peninsula. A northerly trending ridge is known to lie a few hundred miles off the Washington coast. It is referred to as the **JUAN DE FUCA RIDGE** (fig. 5). This ridge has generated the Juan de Fuca plate to the east and the adjacent part of the Pacific plate to the west. According to the concept, the Juan de Fuca plate has been colliding with the North American plate during much of this time. Although normal subduction of the volcanic part of this oceanic plate has taken place over eons of time, much of the sedimentary rock sequence has not been subducted. Instead, it is believed to have been skimmed off, foreshortened by intense folding and faulting, and accreted to the continental plate. **HOH ROCKS** (deep marine sandstones, siltstones, and conglomerates) of the Washington coast and the somewhat altered sedimentary rocks of the Olympic Mountains are believed to be those accreted materials.

HOH ROCK ASSEMBLAGE

SEDIMENTARY ROCK SEQUENCES

The earth's crustal rocks, exposed between the Hoh and Quillayute Rivers, and in many places as far south as Point Grenville, are referred to as the Hoh rock assemblage (Rau, 1973, 1979). As the term assemblage implies, the Hoh rocks are not a single definable rock formation, but are a group of rocks that vary greatly in composition and in geologic age. Many are sequences of siltstones, sandstones, and conglomerates and were originally deposited as sediments in a deep sea basin. These types of Hoh rocks are referred to as **SEDIMENTARY ROCK SEQUENCES.** They make up most of the headland areas and offshore, low-tide reefs along the coast between the Hoh and Quillayute Rivers (fig. 6). The age of these rocks (the geologic time when their sediments were first deposited in the sea) is based on a few fossil collections from widely scattered coastal outcrops. Most of these fossils are the remains of microscopic marine organisms (fig. 7) and others are larger invertebrate marine animals, mainly clams



A DIAGRAMMATIC SECTION showing how the structurally complex rocks of the Olympic Mountains and of the west coastal area may have been formed. Sediments, now lithified to rock, such as the Hoh rocks, have been carried eastward, relative to the continent, on a thick oceanic crust of volcanic rock a few centimeters a year for millions of years. Where the heavier oceanic rocks of the Juan de Fuca plate met the lighter rocks of the North American plate, most of the oceanic rocks moved beneath those of the continent and were dragged into the depths of the earth and converted to magma. However, it is believed some of the materials were not thrust under the continent but were "skimmed off," foreshortened by crumpling and successive underthrusting, piled up, and accreted to the western edge of the North American plate. The present-day Olympic Mountains and complexly folded and faulted Hoh rocks along the coast are believed to represent the rocks of this "pile" (fig. 5).

HOH HEAD, one of the more prominent headlands along the Washington coast, is a thick-bedded sequence of sandstone and is a part of the Hoh rock assemblage (Photo courtesy of the Olympic National Park Service, Port Angeles, Washington) (fig. 6).

and snails. The geologic age that the fossils represent is varied. Some fossils indicate an age as old as a late part of the Eocene Epoch (about 40 million years ago), while others suggest an age as young as a middle part of the Miocene (about 20 million years ago, fig. 1).

TECTONIC MELANGE ROCKS

Hoh rocks exposed in many of the areas between headlands are less resistant to erosion than sedimentary rock sequences of the headlands. The effects of wave action have therefore been greater in these areas; thus coves or reentrances have been formed in the coastline (fig. 8). Examples of such outcrop areas are the bluffs of both Second and Third Beaches, individual coves between Taylor Point and Goodman Creek, and most of the bluffs between Goodman Creek and Hoh Head. Rocks of these areas are easily eroded because they have undergone extreme deformation and are no longer as strong as coherent sequences of sedimentary rocks. Such less competent rock units are a chaotic mixture of various size blocks of siltstones, sandstones, and conglomerates set in a relatively soft or unconsolidated matrix of smaller particles of siltstones, sandstones, and clays (fig. 9). In some areas, blocks of **EXOTIC** rocks or rocks unknown to the sedimentary sequences of Hoh rocks, such as **VOLCANIC** rocks and altered or **METAMORPHIC** rocks, may be found. Areas of highly deformed and mixed rock types are referred to as **TECTONIC MELANGE ZONES** (meaning zones of rock mixtures caused by crustal forces). Melange zones are believed to be places in the earth's crust where there has been extensive faulting or much movement along major cracks. The broken rock materials represent debris developed from movement along these faults. Furthermore some of these zones of faulting are interpreted as having been zones of plate contact. Thus, melange zones are an example of the effects of foreshortening of the sedimentary rock pile by **THRUST FAULTING** rather than by folding of the strata.

Zones of highly fractured rocks are areas in the earth's crust that have been structurally weakened, so pressures that build within the rigid crust are largely relieved in these weakened areas. Thus, in

MICROSCOPIC FOSSILS (Foraminifera) are abundant in sedimentary rocks of marine origin. Because they vary according to where and when they lived, fossil Foraminifera are used in determining time and environment of sedimentation. All specimens are magnified X 25 and are identified below:

1. ***Cassidulina islandica* Nörvang**
2. ***Cassidulina limbata* Cushman and Hughes**
3. ***Cassidulina translucens* Cushman and Hughes**
4. ***Chilostomella* cf. *C. czizeki* Reuss**
5. ***Cassidulina reflexa* Galloway and Wissler**
6. ***Pullenia miocenica* Kleinpell**
7. ***Pullenia* cf. *P. salisburyi* R. E. and K. C. Stewart**
8. ***Globigerina pachyderma* (Ehrenberg)**
9. ***Sphaeroidina bulloides* d'Orbigny**
10. ***Globigerina bulloides* d'Orbigny**
11. ***Globorotalia crassaformis* (Galloway and Wissler)**
12. ***Anomalinoides quinaultensis* Rau**
13. ***Cibicides conoideus* Galloway and Wissler**
14. ***Cibicides fletcheri* Galloway and Wissler**
15. ***Cibicides mckannai* Galloway and Wissler**

(fig. 7)

many zones of tectonic melange, evidence suggests that the broken rock materials have been squeezed upward into, and sometimes through, overlying strata; the resulting structures of such migration of rock materials are referred to as **PIERCEMENT STRUCTURES** or **DIAPIRS** (fig. 10). Many zones of melange rocks exposed along the coast are therefore believed to have been first generated by major faulting, and later structurally modified by various amounts of diapirism (Rau and Grocock, 1974).

DEPOSITS AND PROCESSES OF THE ICE AGE (PLEISTOCENE EPOCH)

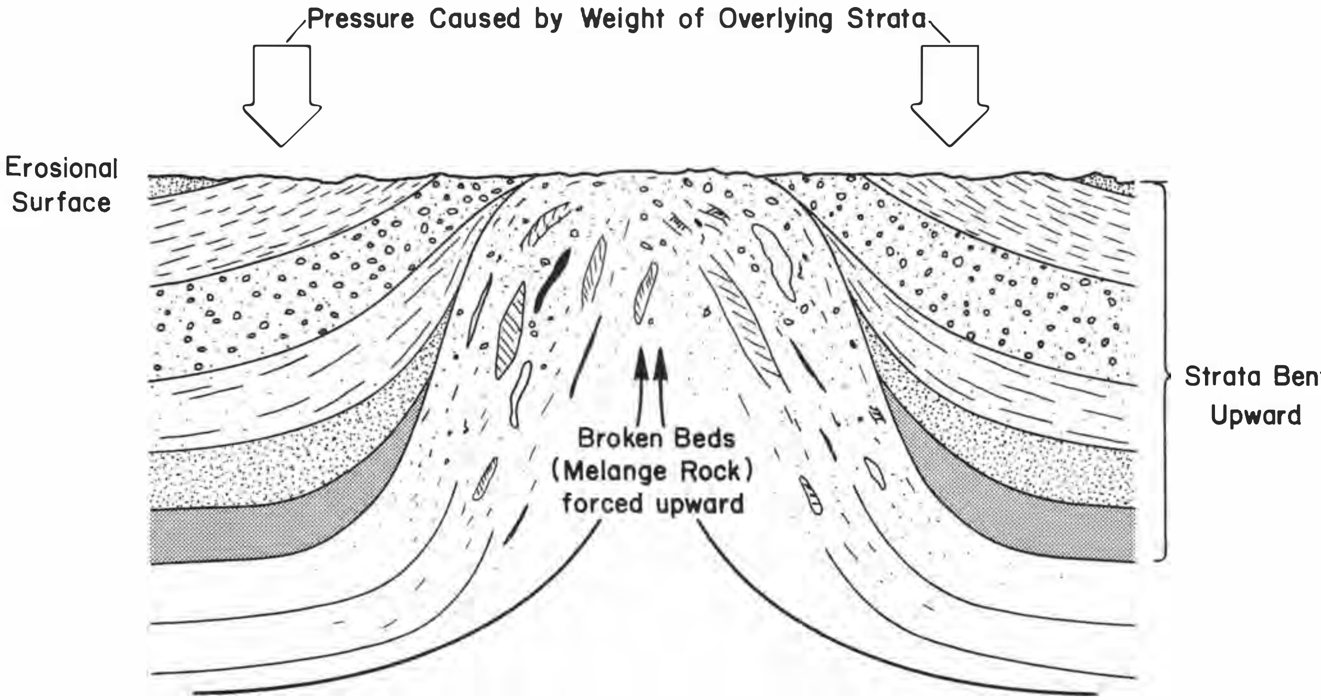
Thick, widespread deposits of unconsolidated sand and gravel blanket much of the Hoh bedrock of inland areas, particularly in and adjacent to the major stream valleys of the Hoh, Quillayute, and Bogachiel Rivers and Goodman Creek. Along the immediate coastal area, such deposits are thinner, less extensive, and are confined largely to areas near the mouth of the Hoh River, Goodman Creek, and the Quillayute River. These deposits are thickest and may best be seen along the coast overlying bedrock sea cliffs and sea stacks between the Quillayute Valley and Taylor Point (fig. 12). Sand and gravel deposits are also present at the mouth of Goodman Creek and, although not very apparent, are also present near the mouth of the Hoh River. These unconsolidated deposits record the activities of the **PLEISTOCENE EPOCH,** generally known as the ice age. Rock debris carved during extensive glaciation of the Olympic Mountains in the past have been transported to the present-day coastal area largely by melt water from glaciers. Some of these rock materials in nearby inland areas are believed to have been deposited directly by ice. These deposits indicate that at one time glaciers stood very near, and perhaps even beyond, the present-day coastline.

The Pleistocene Epoch is confined to approximately the last 1½ million years of geologic time (fig. 1). During the Pleistocene, a relatively short period geologically, the land surface was sculptured into its present-day form. In the Olympic coastal area, glacial ice played an important role in forming the surface of the land, either by direct ice erosion or by deposition of rock debris.

Glaciers advanced and retreated several times to carve the landscape and transport rock debris. Two major events of deposition from glaciers are apparent in the rock record along the coast (fig. 11). Evidence for a major period of erosion by the sea divides these two major deposits. This erosional surface is apparent in many places along the coast. It is manifested by the essentially horizontal trace of an elevated wave-cut terrace at the top of many bedrock outcrops in the sea cliffs (frontispiece). Although usually buried today by younger deposits of sand and gravel, the erosional surface extends inland various distances up to a mile, indicating that the coastline was, at one time during the Pleistocene Epoch, generally farther inland than it is today. Bare, flat-top rocks and sea stacks standing at an approximate elevation of 100 feet are remnants of the old erosional surface (fig. 13). This surface represents an ancient stand of sea

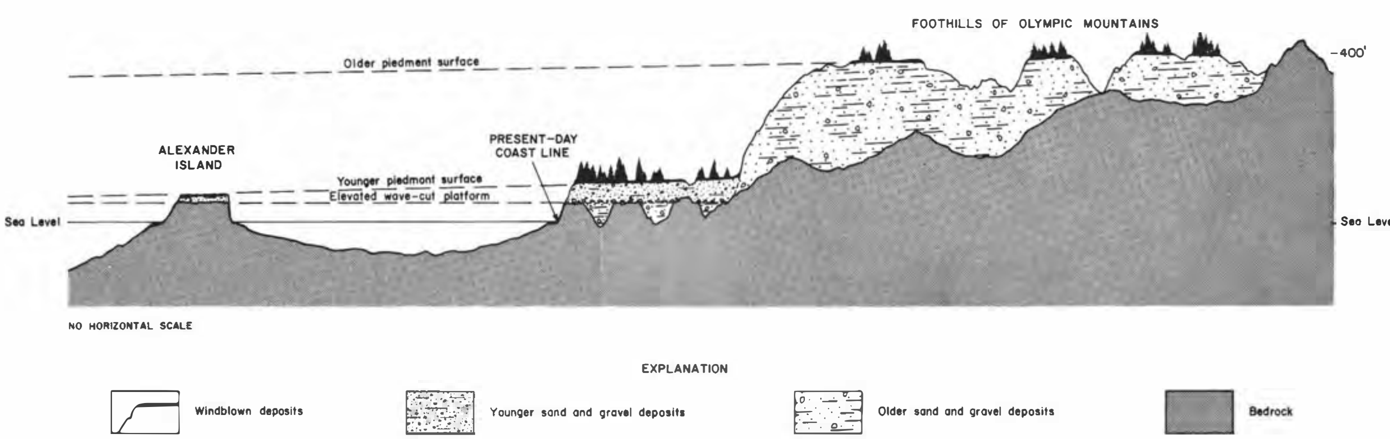
NUMEROUS COVES dot the coastline, often where the easily eroded tectonic melange rocks exist (Photo courtesy of the Olympic National Park Service, Port Angeles, Washington) (fig. 8).

TECTONIC MELANGE ROCKS—A chaotic mixture of sedimentary and other rock type blocks in an unconsolidated matrix of siltstones, sands, and clays (fig. 9).



Piercement Structure Generalized

PIERCEMENT STRUCTURES result when incompetent melange rock is squeezed upward into weak zones of the earth's crust (fig. 10).



IDEALIZED CROSS SECTION showing relations between major Pleistocene deposits and the land surfaces that were formed by periods of either erosion or deposition during the Pleistocene Epoch. Older deposits were thick and extended many miles seaward. Erosion by wave action followed, removing much of these materials from the present-day Continental Shelf. A second and thinner series of sand and gravel was brought down major stream valleys and deposited on the now uplifted wave-cut platform. These younger deposits also extended seaward, but less so than the other deposits. They have been eroded together with bedrock by wave action back to the present-day coastline, leaving Alexander Island as a remnant of the mainland that existed farther west a few thousand years ago. Following the deposition of the younger sand and gravel deposits and probably before much vegetation had developed, windblown silt and sand covered much of the coastal area to a depth of as much as 15 feet (fig. 11).

UNCONSOLIDATED PLEISTOCENE SEDIMENTS rest on the bedrock of Hoh rocks at Quateata. The boundary between the two is the trace of an ancient, now-elevated wave-cut platform (fig. 12).

level when a nearly flat surface was carved by the sea, in the same manner that the sea is carving a somewhat horizontal surface at the lower present-day sea level (fig. 14). In other areas along the coast the ancient erosional surface was carved on older Pleistocene deposits rather than Hoh bedrock. These deposits constitute the older of the two major Pleistocene periods of deposition. The older deposits of sand and gravel, laid down prior to the forming of the elevated wave-cut surface, are thick and widespread in adjacent inland areas, particularly along the valleys of the major drainages (fig. 11). However, in coastal areas they were largely removed by wave action of the Pleistocene sea. The younger deposits are the sand and gravels that rest on top of the elevated wave-cut surface. They are thinner and less extensive than the older deposits (fig. 12).

A third and the youngest of all Pleistocene deposits can be seen as a 3- to 15-foot thickness of light, buff-colored silt and sand at the uppermost part of nearly all sea cliffs and on many sea stacks along the coast (fig. 16). They are thought to be **WINDBLOWN (EOLIAN)** deposits that were laid down during a low stand of sea level at the close of the Pleistocene Epoch. During this time a wide expanse of coastal plain lay bare of vegetation and served as a source area of sediments for transport by the prevailing westerly winds (Rau, 1979). Although these light-colored deposits are very noticeable at the top of most cliffs, a closeup view is accessible along the trail at the top of the descent to Third Beach from Taylor Point (fig. 15).

AGE DATING OF ICE AGE EVENTS

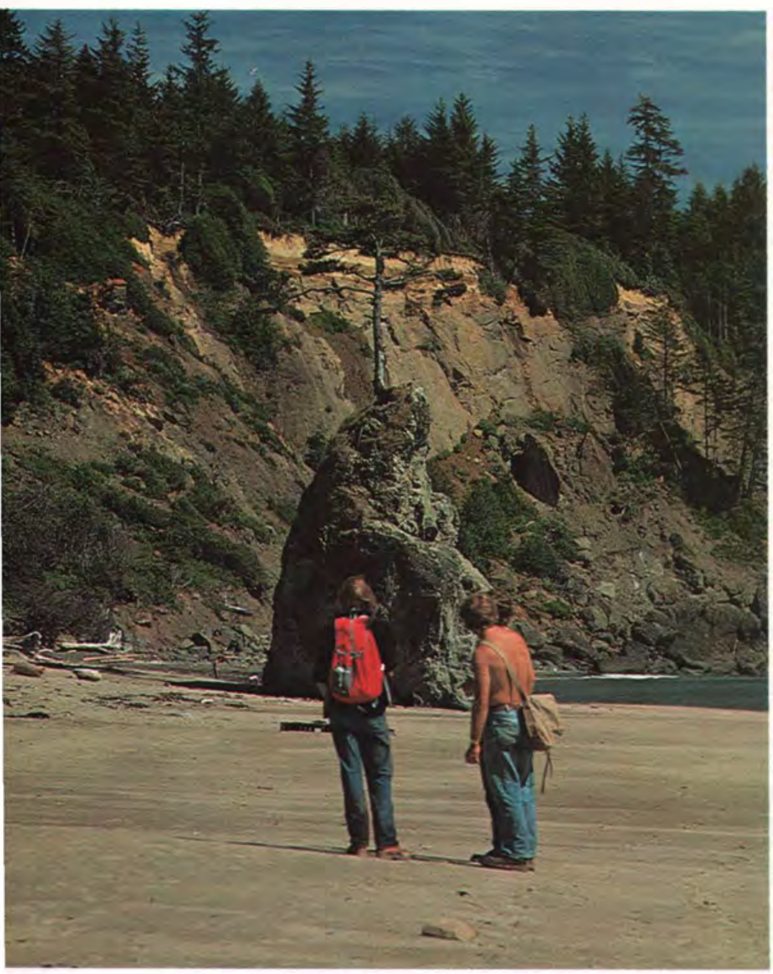
The general sequence of events of erosion and deposition are documented in the rock record; but the actual time when they occurred is not as well established. Based on carbon-14 isotope dating methods, dates can now be calculated to nearly 75,000 years B.P. (before present). On this basis, the oldest date that has been established in coastal Pleistocene deposits is approximately 71,000 years B.P. (Stuiver and others, 1978), a date essentially at the limit of the carbon-14 dating capability. This date was established for materials from 25 feet above the wave-cut terrace level. The actual times when all materials below this level were deposited, as well as when the wave-cut terrace was carved, are not known. It is speculated, however, that the elevated wave-cut terrace may have been formed some 125,000 years ago (Heusser, 1977). Therefore, the maximum age of the extensive Pleistocene deposit that pre-dates this erosional event is not known other than that they were deposited at some earlier date, probably during the 1½ million years of Pleistocene time.

Dates younger than 71,000 years ago have been established for younger Pleistocene coastal and nearby inland deposits. Some of these dates are approximately 59,000, 30,000, and 16,000 years B.P. (Heusser, 1972, 1978). The youngest date based on pollen correlation is about 8,000 years B.P. (Florer, 1978, personal communication). The age was estimated for materials from the uppermost windblown deposits exposed near La Push.

THE FLAT TOP of several bare rock islets in the "Quillayute Needles Group" represents an old elevated sea-level surface (fig. 13).

MODERN WAVE-CUT TERRACE forming south of Jefferson Cove (fig. 14).

A CLOSEUP VIEW OF WINDBLOWN DEPOSITS on top of Taylor Point (fig. 15).



WINDLBOWN DEPOSITS (loess) form the uppermost buff-colored layer on many coastal cliffs as shown here on the north side of Taylor Point (fig. 16).

DRILLING EQUIPMENT in operation along the Hoh River in 1964. No significant petroleum was encountered (fig. 17).

Historical Notes

HOH RIVER AREA

It was not until the latter part of the last century when homesteaders first came to the Hoh River area that it received permanent white settlers. Among them was a Captain J. W. F. Hank who settled in the flat area along the north side of the river very near its mouth. Although this apparently served as his residence until shortly after the turn of the century, he is best known by the settlers for the services he rendered in his 30-foot, two-masted sailing ship, the "Surfduck." He brought settlers as well as much needed supplies not only to the Hoh but to many other nearby rivers between Cape Flattery and the Columbia River (Hult, 1971). His homestead was abandoned about 1903 shortly after he disappeared at sea.

In more recent years the area of Captain Hank's homestead was the site of much geologically related activity. Two periods of petroleum exploration took place in the vicinity of the Jefferson Oil Seep, just north of the mouth of the Hoh River, initially in 1913-14 and again in the 1930's. During the latter period, the area of Captain Hank's homestead became the center of operations known as "Oil City" (fig. 21). Real estate interests became active and much of the flatland and surrounding area was platted into lots, many of which were sold in anticipation of a major oil discovery. The name Oil City may still be seen on road signs and maps of the area. Evidence of this past is marked on the grassy, alder-covered flat by piles of rotting boards from a collapsed building and the rusted remains of a vintage automobile.

Eleven wells were drilled between 1931 and 1937 in the Jefferson Oil Seep area, about 2 miles northwest of the Oil City land development (fig. 18) (Washington Division of Geology and Earth Resources unpublished files). This distance, through the woods, was traversed over a sawed-plank road that can still be traced in part through unlogged areas (fig. 19). Most of the wells of the area, some of which reached depths of several thousand feet, actually did encounter excellent "shows" of oil. As much as 100 barrels a day were claimed at first to be flowing from some of these wells but such quantities soon decreased (Northwest Oil and Gas, 1936). Today, in several casings among tumbled-down wooden derricks and surrounding buildings, small quantities of high gravity (thin) oil continues to accumulate and natural gas still bubbles to the surface (fig. 22).

Although the Jefferson Oil Seep is now a part of the National Park coastal strip where drilling can no longer be conducted, areas outside the park along the lower Hoh River valley continue to interest oil-men. In more recent times a number of wells have been drilled, but none have encountered commercial quantities of petroleum (fig. 17).

DRILLING OPERATIONS of the 1930's near Jefferson Cove where eleven oil test wells were drilled and substantial oil shows were reported (Photo courtesy of Jones Photo Shop, Aberdeen, Washington) (fig. 18).

PART II

GEOLOGIC OBSERVATIONS AND INTERPRETATIONS ALONG THE COAST

HOH RIVER AND VICINITY

Rock formations, from which oil-men, since 1913, have attempted to remove petroleum (see Historical Notes), are exposed in the high sea cliffs and low-tide outcrops between the Hoh River and Hoh Head. All three major sedimentary rock types, siltstone, sandstone, and conglomerate, are present and are part of **SEDIMENTARY ROCK SEQUENCES** of the **HOH ROCK ASSEMBLAGE** (see Part I).

Poorly exposed outcrops of sandstone can be seen along the trail that leads from the parking area to the beach, on the north side of the Hoh River. Landslides are common along the bluff in the vicinity of the mouth of the river (fig. 20). Aside from the obvious slumping of rock debris at the base of the bluff, the extent of this landslide area is marked by a **"DRUNKEN FOREST"** where trees are standing at various angles and many have developed bent trunks in an attempt to grow vertical once again. The slumped material is a jumbled assortment of sandstone and siltstone blocks set in a relatively soft matrix of clay and siltstone fragments. The chaotic nature of these rock materials may appear to be caused by the landslide itself. However, the landslide has only superficially rearranged rocks that have already been intensely deformed and intermixed by the earth's crustal forces (see Part I, Tectonic Melange Rocks). A landslide occurred here because these tectonically jumbled rocks are much less competent than most other rock formations of the area. Landslides, such as this one, and in places even larger ones, are a common sight along much of the coast to the north.

From the mouth of the river northwestward for about a quarter of a mile, no bedrock is exposed because the low bluffs are heavily vegetated and the beach area is blanketed with relatively young deposits of sand and gravel and much driftwood. Beyond this area, bedrock is exposed almost continuously along the beach and in high cliffs that form the headlands south of Jefferson Cove. Rocks of the headlands are also a sequence of Hoh

THE PLANK ROAD that served as access from the Hoh River to the Jefferson Oil Seep area as it looked in the 1930's. Barely recognizable segments of this road can still be traced (Photo courtesy of Jones Photo Shop, Aberdeen, Washington) (fig. 19).

LANDSLIDE DEBRIS near the mouth of the Hoh River. Landslides are common where crustal forces have formed a rock melange (fig. 20).

OIL CITY in the 1930's, near the mouth of the Hoh River, served as the headquarters for drilling operations at the Jefferson Oil Seep area 2 miles to the north (Photo courtesy of Jones Photo Shop, Aberdeen, Washington) (fig. 21).

OIL WELL REMAINS from drilling operations of the 1930's near Hoh Head. Gas still bubbles from, and oil accumulates in, this casing (fig. 22).

sedimentary rocks and consist of massive to thick-bedded sandstone and small to very large irregularly formed lenses of conglomerate. Several landslide areas are present in small coves between the Hoh River and Jefferson Cove.

Structural relations of the Hoh rocks in these headlands are not clearly apparent, mainly because they are massive and are locally folded and faulted. The available data of today suggest that the regional trend or strike of these beds is in a northwest direction, somewhat parallel to the coast; they are tilted or dipping northeastward about 40° from horizontal. Furthermore, evidence indicates that these beds are overturned with their tops facing downward and to the southwest (fig. 24).

Rocks that form the headland area between the Hoh River and Jefferson Cove are mapped as the west limb of a large **ANTICLINAL** structure (upward fold). Most of it lies inland from the coast and occupies about 10 square miles of area (fig. 25). The structural trend of the rock strata along the coast gradually swings inland north of Hoh Head. Hoh sedimentary rock sequences are relatively resistant to erosion and so form headlands and wave-cut terraces. Hence, wave-cut platforms, at approximately low-tide level, extend seaward from the headlands (fig. 14). Resistant erosional remnants of sandstone and conglomerate of this rock sequence are seen in the two major offshore rocks: Middle Rock, with its bifurcated top about three-quarters of a mile immediately west of the mouth of the Hoh River (fig. 26), and the sharply pointed North Rock, nearly 2 miles offshore (fig. 28). Both of these rocks are sandstone. Bedding on North Rock is oriented similar to the regional structure.

JEFFERSON COVE beach from Hoh Head trail (fig. 23).

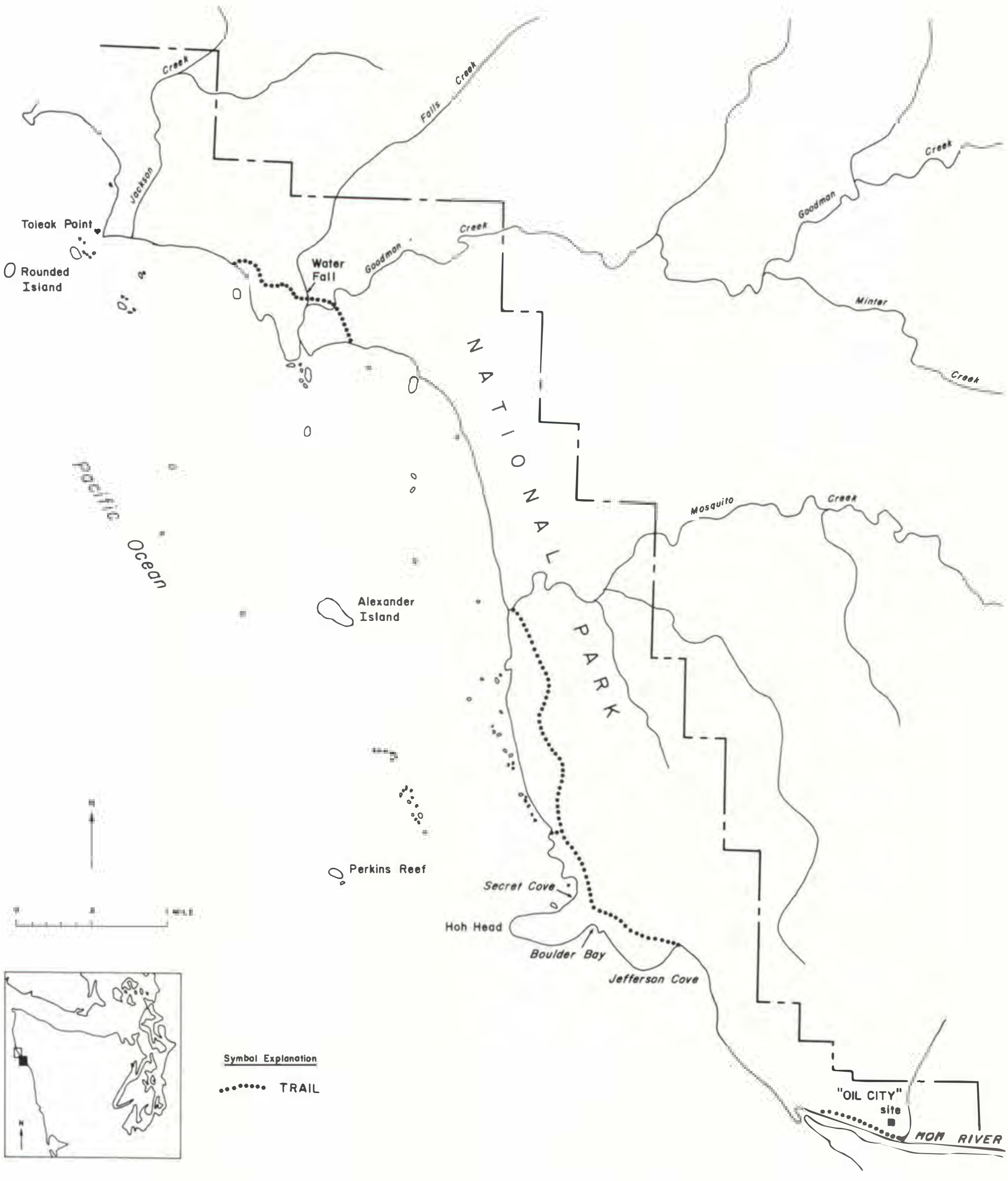
HIKING INFORMATION

HOH RIVER TO MOSQUITO CREEK

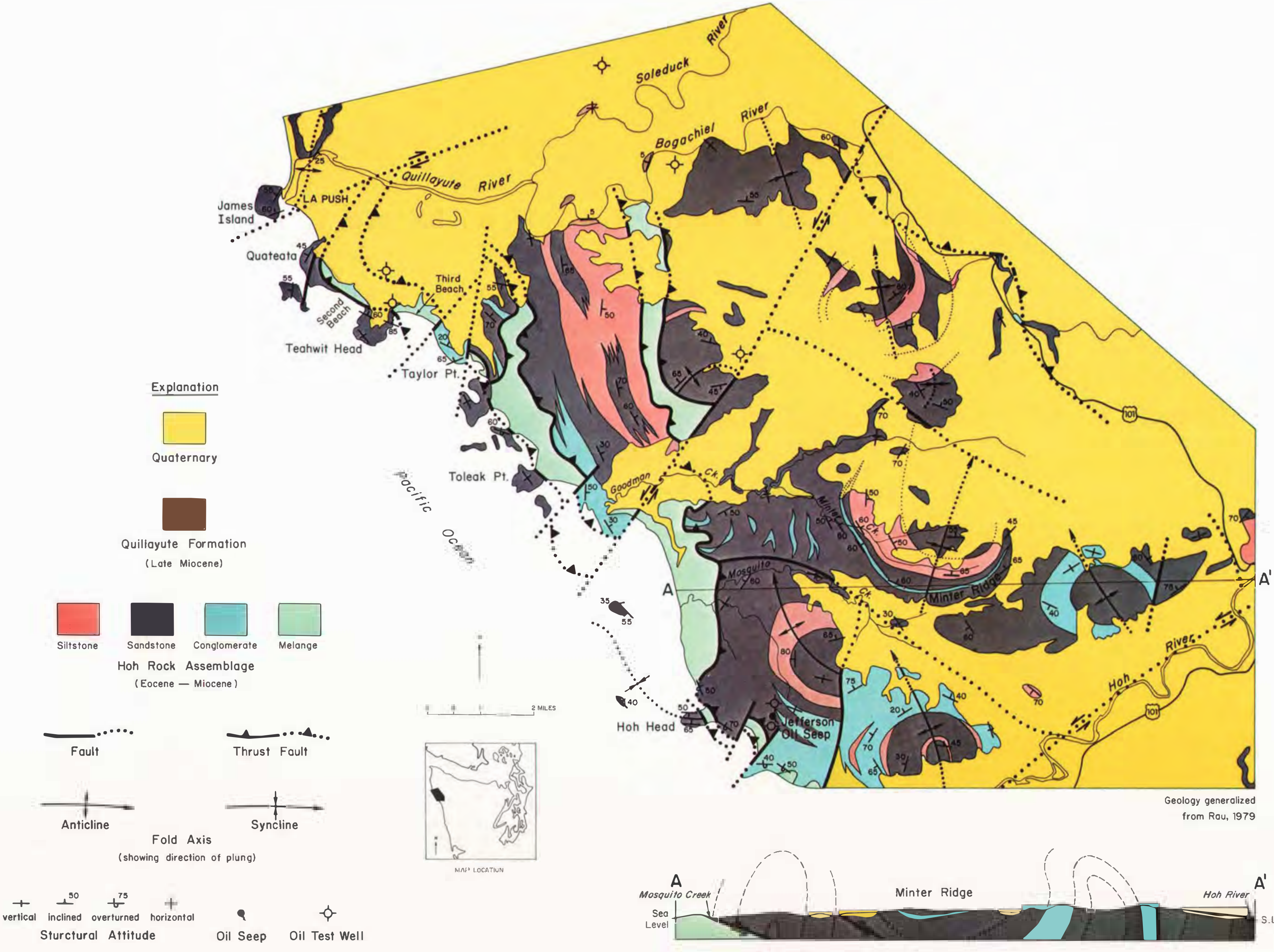
The trail begins at the end of the road on the north side of the Hoh River where, in 1917, Fred Fletcher owned and operated a fish cannery. Along the river a short trail leads to the ocean beach and from there northward for approximately half a mile the beach route is unobstructed. Headlands immediately south of Jefferson Cove are best rounded at low tide, when much of the sandy beach is exposed. In any event, attempts to traverse this area should be restricted to the lower half of any tide. Once around these headlands, the sandy beach of Jefferson Cove provides a pleasant change of pace for half a mile (fig. 23).

The beach ends abruptly at the north end of Jefferson Cove where nearly vertical cliffs of massive sandstone and conglomerate form the prominent headland between the cove and Boulder Bay (fig. 24). For a distance of three-quarters of a mile, the surf pounds directly on the cliffs even at low tide. The route northward is therefore over, rather than around, this major headland. The trail rises steeply and in places over bare outcrops of massive sandstone. In the steepest area, ropes are available to assist in the climb. At the top, the trail continues for 2½ miles through the woods over Hoh Head and along sea cliffs nearly to the mouth of Mosquito Creek.

For the more adventurous, a number of side challenges to the beach could be attempted but without the aid of trails. Among these excursions are Boulder Bay immediately south of Hoh Head, the top of Hoh Head itself, Secret Cove immediately north of Hoh Head, and several small coves farther north (fig. 24). However, the headlands between these small coves can be rounded only during low tide. A trail from the main inland route extends to the beach in the vicinity of the northernmost of these headlands. Northward beyond these headlands for about a mile, a sandy beach stretches unobstructed. Another headland at the north end of the beach can be rounded only at low tide. Unless this headland is reached at a definitely low tide, the inland trail should be used. Several additional small headlands must be rounded or easily climbed before reaching Mosquito Creek (fig. 27).



ROUTE MAP—Hoh River to Toleak Point (fig. 24).

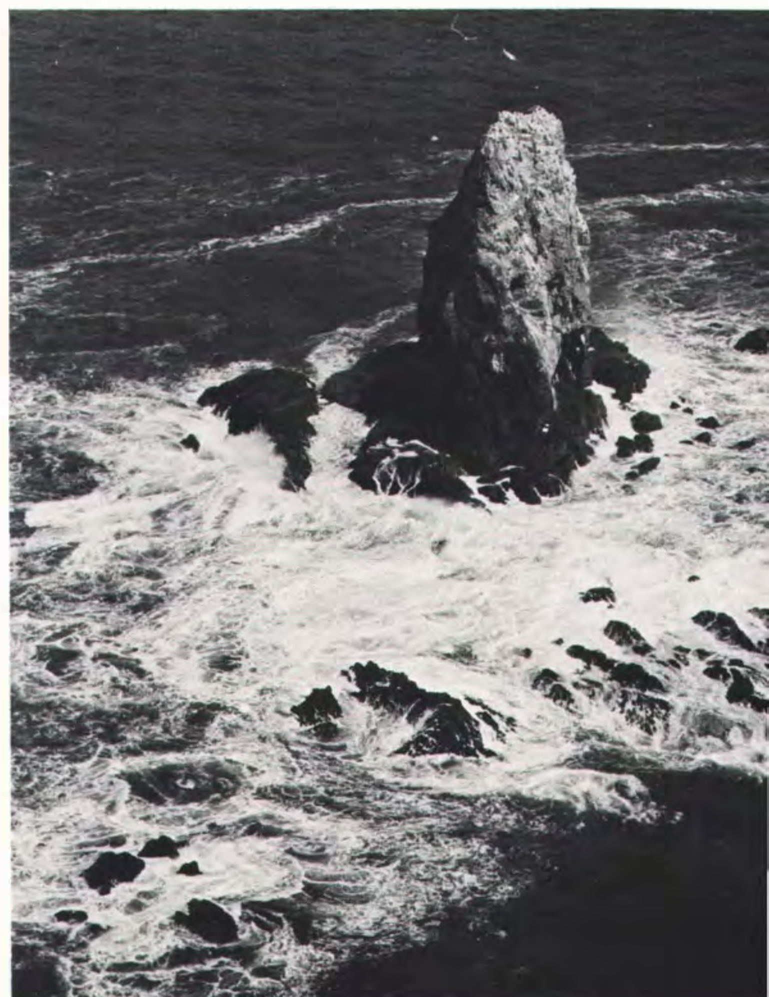


GENERALIZED GEOLOGIC MAP of the area between the Hoh, Quillayute, and Bogachiel Rivers (fig. 25).

MIDDLE ROCK, viewed from the air and offshore, is one of the more prominent rocks near the mouth of the Hoh River. It is an erosional remnant of Hoh sandstone (fig. 26).

Because the rock strata of this area are hard, massive sandstone and conglomerate, they tend to erode into relative large blocks. Thus, the beaches immediately below the cliffs of this area are strewn with exceptionally large boulders. The conglomerate of many of these large boulders is composed of grit- to cobble-size pebbles of various rock types (fig. 29). Sandstone, chert, and siltstone, together with metamorphic and granitic rocks, are the most common. These materials were previously eroded from a mountainous land area, some 25 million years ago. From there they were rapidly transported by streams and thus became well-rounded pebbles to be eventually deposited in a sea. Further transport took place down the slope of the ocean floor where they came to rest in channel-like deposits and in association with massive deposits of sand and some silt.

LOOKING NORTHWARD from the first headland south of Mosquito Creek (fig. 27).



NORTH ROCK, another prominent offshore rock of Hoh sandstone near the Hoh River (fig. 28).

Historical Notes

EARLY OIL TEST

The first petroleum test well to be drilled in the Hoh River country was located a short distance inland from Jefferson Cove. During July of 1913, machinery and other equipment were brought in by barge and landed through the surf. A buoy attached to large anchors 2,000 feet offshore served as a point from which landing operations took place. From there the equipment-laden skow was beached and a steam donkey engine fired up. By means of a steel cable attached to a large stump onshore, the donkey engine dragged itself from the barge, onto the beach. From there it and all other materials were skidded up the cliff and several hundred yards farther inland to the drilling site. The donkey engine was to be used as the major source of power during drilling operations (Aberdeen World, 1913).

Two test wells, Hoh Head Nos. 1 and 2, were both drilled with cable tool equipment to depths of about 1,000 feet. Although substantial amounts of oil and gas were encountered in these wells, they did not prove to be sufficient for commercial use (Washington Division of Geology and Earth Resources unpublished files). However, these findings encouraged the drilling of a number of wells in the 1930's a quarter of a mile to the north of the original Hoh Head wells.

CONGLOMERATE, south of Jefferson Cove, is composed of sandstone, chert, siltstone, and metamorphic and granitic pebbles (fig. 29).

JEFFERSON COVE

The bluffs of Jefferson Cove are a jumbled assortment of sandstone, conglomerate, and siltstone blocks intermixed in a matrix of smaller broken siltstone and claystone fragments. These rocks are similar to the landslide materials exposed near the mouth of the Hoh River. They constitute an excellent example of a **TECTONIC MELANGE,** a term now applied to many rock outcrops of Hoh rocks, both along the coast and inland. As the term implies, this jumbled array in both size and type of rock material forms a mixture or melange of rocks. Tectonic implies crustal deformation—thus, a mixture of rock material resulting from major crustal movements (see Tectonic Melange Rocks, Part I).

The exact nature of the forces or crustal movement that forms rock melanges is not fully known. However, geologists theorize that outcrops, such as those at Jefferson Cove, represent a part of a major fault zone between large segments of the earth's crust. The broken rock materials are believed to be debris developed from movement along these faults. Melange rock zones are structurally weak zones within the earth's crust. In some places these materials respond to pressures somewhat like plastic and are squeezed upward. The resulting structure of such movement of rock material is referred to as a **PIERCEMENT STRUCTURE** or **DIAPIR** (fig. 10). The rock melange of the Jefferson Cove bluffs may have undergone such migration.

On the earth's surface, melange rocks are more easily eroded than sedimentary rock sequences. Thus, along the coast outcrop areas of melange rocks are usually found in coves, such as Jefferson Cove, where the sea has eroded the coastline farther eastward than the headlands. Furthermore, because melange rock are structurally weak, numerous landslides develop where they are exposed.

HOH HEAD AREA

The headland between Jefferson Cove and Boulder Bay is a massive to thick-bedded sandstone and conglomerate sequence and is essentially the same rock type as the headland area to the south of Jefferson Cove. The structural trend or **STRIKE** is similar to the regional northwest strike with steep dips to the northeast. Local variations to this regional trend are common. For example, well-stratified sandstone at the northernmost edge of Jefferson Cove strikes in an east-west direction. This local deviation in strike is believed to have been established when the adjacent melange materials of Jefferson Cove were squeezed upward, thus dragging the resistant sandstone beds parallel to the contact between the two rock types.

At Boulder Bay (fig. 30) on the south side of Hoh Head (fig. 31), melange rocks again are exposed and form a low-lying, sharp saddle-like area between Boulder Bay and Secret Cove to the north. Because these melange rocks are easily eroded, the relatively resistant thick-bedded to massive sandstone of the main body of Hoh Head will eventually become an offshore rock. Hoh Head, although similar in composition to the sandstones of the other headlands of the area, structurally does not conform to the regional northwest trend, but instead strikes in an east-west direction. Strata seen on the south side of Hoh Head are steeply dipping to the north, whereas on the north side they dip steeply south. Thus, sandstone beds of Hoh Head have been folded into a small **SYNCLINE** or downwarp. Evidence of this fold can be seen from off Hoh Head where the actual end view of this folded structure can be visually traced in stratified beds exposed on the extreme western end of the head.

BOULDER BAY on the south side of Hoh Head is well named. Erosion of the massive sandstone of Hoh Head has produced this boulder and cobble strewn beach (fig. 30).

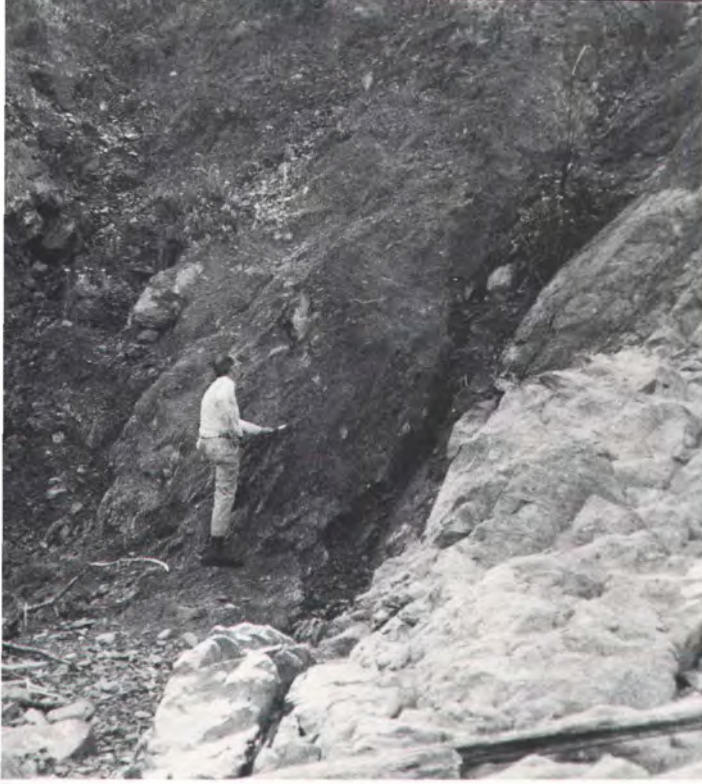
SECRET COVE TO MOSQUITO CREEK

The melange rocks of Secret Cove exposed in the cliffs of the easternmost part of the cove are more extensive than at Boulder Bay. Nearby offshore stacks are also a part of this melange zone representing large resistant blocks of sandstone and conglomerate.

The contact of melange rocks with the sandstone of Hoh Head to the west is well exposed just above the high-tide level at a point a few hundred yards westward from the cove (fig. 32). From here westward, thick, well-bedded sandstone strata of Hoh Head form an extensive low-tide reef trending in a northwest direction. Westward from this outcrop, the bedding trend swings to a nearly east-west direction forming the north limb of the Hoh Head syncline.

Three small headlands lie immediately north of Secret Cove, consisting largely of massive sandstone but well-bedded in places with relatively thin siltstone strata. These headlands are a part of the regional anticline. Evidence from sedimentary features preserved in these rocks indicates that they constitute the west overturned limb of the anticline (fig. 25). Thus, a major geologic structure can be followed generally northward along the coast from the mouth of the Hoh River to these headlands.

HOH HEAD and coastal area to the north (fig. 31).



MELANGE ROCKS OF A MAJOR FAULT ZONE can be seen in contact with Hoh Head sandstone (right) in the Secret Cove area (fig. 32).

varies somewhat from place to place because the earth's crust has warped slightly since Pleistocene time. The buff-colored sediments resting on this surface are unconsolidated sand and silt and are believed to be eolian (windblown) deposits. These sediments mark the last major geologic event of the coastal region, having been deposited some 8,000 years ago, some time after the uplift of the coastal area and the retreat of glacial ice from nearby valleys (see Deposits and Processes of the Ice Age, Part I).

All rocks exposed in the bluffs, headlands, and in low-tide outcrops for the last mile or so northward to Mosquito Creek are a part of a very extensive zone of rock melange. The several small headlands in this area are especially large blocks of massive resistant sandstone; the less competent, badly sheared and broken sandstone and siltstone materials of the melange are exposed in the low-angled bluffs in the small coves that lie between. Broken sandstone constitutes a much greater part of the melange of this area than of that to the south, such as is exposed in Jefferson Cove.

Less resistant melange rocks form the bluffs of each small cove between the three headlands as well as the cliffs for about a mile northward beyond these small headlands. Rock strata are completely disarranged and numerous blocks of sandstone are intermixed with a matrix of broken siltstone and claystone. Resistant blocks of sandstone, not yet worn to sea level by wave action, form many offshore rocks and low-tide reefs. Landslides are particularly prevalent and are made apparent by "drunken forests" and debris flows that extend onto the beach.

At a point about half way along this area of melange outcrop, erosion has exposed a particularly large sandstone block (fig. 33). This block will become a small headland, and then eventually an offshore rock as the less resistant part of the cliff recedes eastward due to coastal erosion. Close inspection will reveal that the top of the sandstone block is nearly flat and that this surface is covered with 5 or 6 feet of buff-colored sediments. The flat surface is a remnant of an ancient terrace that was carved by wave action sometime in the past when sea level stood higher than today. Evidence of this elevated sea-level surface can be seen in many places along the coast. Its height above sea-level

EXCEPTIONALLY LARGE SANDSTONE BLOCK in a Hoh melange outcrop. Its flat top is an erosional remnant of an elevated wave-cut platform (fig. 33).

HIKING INFORMATION

MOSQUITO CREEK TO TOLEAK POINT

For 2 miles northward from Mosquito Creek, the coast can be easily traversed over wide, firm, sandy beaches during low tide; otherwise, during high tide the area is passable over loose sand, gravel and driftwood. The trail leaves the beach about a quarter of a mile east of Goodman Creek where a small sandstone and conglomerate point blocks further passage along the beach during medium and high tides. Furthermore, although during low tide Goodman Creek can be reached from along the beach, it cannot be crossed at its mouth as it flows into the ocean in a deep rock gorge (fig. 34). In addition, the coastline northward from Goodman Creek for about half a mile is mostly a sheer cliff extending into the sea with practically no beach exposed at any time (fig. 35).

The trail ascends from the beach over slumped melange rocks into salal brush, and then into timber for about a third of a mile where it descends to Goodman Creek. The stream level at this point, about half a mile upstream from its mouth, is still affected by the tides. Therefore, crossing during low tide would avoid wading in fairly deep water. The trail is marked on the north side of the gravel bar and from there it follows along the north side of the stream to Falls Creek. This stream receives its name from the picturesque falls located a few hundred feet upstream from its mouth where the water cascades some 50 feet over massive conglomerate rock.

From the mouth of Falls Creek during low tide, Goodman Creek can be easily traversed downstream practically to its mouth. However, the tide level should be watched carefully to avoid having to return in deep water. With luck, sea otter may be seen near the mouth of the stream as they were recently reintroduced to this area. Because the coast is impassable north of the mouth of Goodman Creek, it is necessary to return to Falls Creek to continue northward. The trail northward to the coast crosses Falls Creek near its mouth and continues steeply out of the valley, past several very large cedar trees, and onto a wooded ridge. The trail follows along this ridge for a quarter of a mile or so where it passes several excellent vantage points high above the beach. The descent to the beach is steep in places but should not pose any problem as ropes and steps have been placed in the steepest parts. Once back to sea level about a mile of open beach lies ahead to Toleak Point.

For the last 4 miles of its course to the coast, Goodman Creek flows in a relatively broad valley where it has shifted in places from time to time. A side trip up this valley, along its wandering stream and over the grass-covered valley floor, is a pleasant change from the sandy beaches of the coast. The going is fairly good. A trail may be followed most of the way. The nearest logging road access is about 3 miles upstream from the coast.

GOODMAN CREEK enters the sea through a narrow channel carved in Hoh bedrock. This course was established in overlying Pleistocene deposits. During the slow downward cutting process of the stream, its course was maintained even into the underlying bedrock (fig. 34).

MOSQUITO CREEK

Mosquito Creek, once called *Chah-latt* Creek, drains some 20 square miles that lie between the Hoh River and Goodman Creek to the north (fig. 36). Its three main branches, one from the south, one from the southeast, and the main fork from the northeast, all converge witin a mile of the coast (fig. 24).

For nearly a mile Mosquito Creek flows over a zone of melange rocks before reaching the coast. These rock materials are a continuation of those chaotically arranged rocks seen along the coast both to the south and north of Mosquito Creek (fig. 25). The stream course through this zone is especially crooked and in places nearly doubles back on itself. This course has resulted from the stream cutting down and through an area where large resistant blocks of sandstone occur randomly within the unit of rock melange. A course of least resistance has been taken by the stream around the large sandstone blocks. This melange zone extends inland nearly to the convergence of the middle fork from the southeast with the main branch from the northeast. From this point upstream along both the middle fork and main branch, the stream flows over a bedrock of steeply dipping, bedded sandstone with thin beds of siltstone. These rocks are particularly well exposed in the middle fork where the stream flows generally across the steeply dipping strata. Although they are contorted and steeply dipping and in places even overturned, these rocks are structurally coherent. They constitute a continuation of the strata exposed farther south along the coast that forms the west limb of the anticlinal structure.

CONGLOMERATE, north of Goodman Creek, forms inaccessible cliffs nearly 200 feet in height (fig. 35).

MOSQUITO CREEK drains some 20 square miles that lie between the Hoh River and Goodman Creek (fig. 36).

ALEXANDER ISLAND

Alexander Island, located a mile due west of Mosquito Creek, is the largest offshore rock mass exposed between the Hoh and Quillayute Rivers (fig. 37). This relatively long, narrow flat-topped island is slightly more than a quarter of a mile in length but its greatest width is only about 550 feet, and it stands about 120 feet in height above sea level. Its length is best viewed from the beach in the area between Mosquito Creek and Goodman Creek, and its width is best seen from a point about a mile south of Mosquito Creek. Its nearly flat surface is densely covered with brush of about equal height with the exception of two scrubby trees, one on the south end and the larger near the northern end. The dense bird population has deposited a white coating on much of the rock surface, largely exposed on the west side of the island (fig. 38).

Alexander Island is mostly massive sandstone but with a few stratified beds cropping out in several areas. On the southern end of the island, strata trend in a northwest direction, generally parallel to the length of the island, and dip steeply to the southwest. Bedded sandstones are also exposed on the northern end of the island, but there the trend is nearly east-west with dips moderately to the south.

ALEXANDER ISLAND is the largest offshore rock mass between the Hoh and Quillayute Rivers. It is an erosional remnant of Hoh sandstone. An ancient elevated wave-cut platform is marked by the base of the vegetation. Pleistocene sand and gravel rest on this surface (fig. 37).

SOUTHWEST SIDE OF ALEXANDER ISLAND. The white coating on the rocks is indicative of a large bird population (fig. 38).

The upper surface of bedrock, although capped with some 20-foot thickness of unconsolidated material, is also generally flat. This surface is a remnant of an extensive elevated wave-cut terrace, the trace or actual surface of which may be seen in many places on the mainland and on offshore rock masses. This terrace surface was carved when the sea stood higher relative to the land. The sea also extended farther eastward or inland in places than it does today.

The upper 20 feet of the island is composed of unconsolidated silts, sands, and gravels—materials that were brought from the Olympic Mountains to nearby coastal areas by glacial ice during a late part of the Pleistocene Epoch. These rock materials were further distributed to their present position by melt water from the glaciers. At that time the coastal area was a broad, recently uplifted wave-cut terrace and it extended westward far beyond Alexander Island of today. Over the last few thousand years and since the terrace was blanketed with unconsolidated sediments, the sea, at a lower level, has continued to erode this broad, relatively flat-surfaced land area, moving the coastline slowly eastward to its present position. Alexander Island, with its massive and particularly resistant rock foundation, preserves locally at least the westernmost remnant of this old nearly flat land surface.

MOSQUITO CREEK TO GOODMAN CREEK

The major zone of chaotically arranged melange Hoh rocks, exposed both in Mosquito Creek and along the coast to the south, continues northward for 2 miles to the mouth of Goodman Creek (fig. 25). Along this coastline the instability of melange rock cliffs is demonstrated almost continuously by landslides. Broken and sheared sandstone and some conglomerate dominate the rock type of these outcrops. Resistant blocks of various sizes eroded from the melange are scattered along the beach, and a few very large ones form offshore rocks (back cover photo). One of these blocks, resting on the beach about 1 mile north of Mosquito Creek (fig. 39), is of an unusual composition for the area. It is composed of angular fragments of volcanic and sedimentary rock that have been welded together to form a solid rock mass known as a **BRECCIA.** This rock type differs from a conglomerate by being composed of angular fragments of rock rather than rounded rock pebbles. The largest and most prominent single block exposed along this beach consists of massive sandstone and forms a small nearshore island about three-fourths of a mile south of Goodman Creek (fig. 41).

Historical Notes

GOODMAN CREEK VALLEY

Goodman Creek, once called "Keh-chen-whilt" River (Davidson, 1889), is the major drainage between the Hoh River to the south and the Quillayute River to the north. Together with its tributaries, Goodman Creek drains an area of over 30 square miles extending eastward to the Bogachiel drainage. Falls Creek, a major tributary from the north, descends suddenly into Goodman Creek near its mouth over a 50-foot conglomerate cliff (fig. 40). Minter Creek, also a sizable tributary, drains from the south and east and enters Goodman Creek about 4 miles upstream from the coast.

For the natives and early settlers, Goodman Creek valley served as an avenue of access to the coast from the Bogachiel Valley some 10 miles to the east. Remains of their old trail is still visible in places. Although their buildings are essentially gone, the area is marked by the telltale evidence of large, "high cut" stumps with springboard notches barely visible, together with small patches of second-growth timber growing where a clearing was once made in the virgin forest.

EXOTIC BRECCIA BLOCKS, eroded from the Hoh melange, rest on the beach 1 mile north of Goodman Creek. They are composed of angular fragments of volcanic and sedimentary rocks, a rock type foreign to Hoh sedimentary rock sequence (fig. 39).

FALLS CREEK tumbles over a 50-foot-high conglomerate cliff before merging with Goodman Creek (fig. 40).

SINGLE SANDSTONE BLOCK from tectonic melange forms a small nearshore island three-fourths of a mile south of Goodman Creek (fig. 41).

The broken rock debris exposed along the coast between Jefferson Cove and Goodman Creek forms a north-trending belt that, in places, extends inland nearly a mile (fig. 25). This belt of outcrops is believed to expose a large segment of a major **THRUST FAULT** zone—the contact area between two major segments of the earth's crust, one of which has been thrust beneath the other (Rau, 1979). The melange rocks of the Hoh-Goodman Creek coastal area are therefore believed to be the resulting rock debris formed by the grinding of one crustal plate beneath another (see Tectonic Melange Rocks, Part I).

PICTURESQUE ROCKS of Hoh sandstone and conglomerate off the mouth of Goodman Creek (fig. 42).

GOODMAN CREEK AREA

From Goodman Creek northward for a mile, large outcrops of conglomerate and sandstone form inaccessible sea cliffs some 200 feet in height (fig. 35). A major fault trending northeastward, generally up the Goodman Creek valley, separates these rocks from the melange rocks to the south (fig. 25). Conglomerate and sandstone are also well exposed along the stream course for a short distance inland from the mouth of Goodman Creek (fig. 34) and also form the small offshore rocks and islands at the mouth of this stream (fig. 42). Furthermore, these rock strata trend or strike generally north-northwestward and have been mapped in an inland area northward to the Bogachiel River.

The conglomerates are composed of fairly well-rounded pebbles and cobbles of various rock types including several kinds of igneous rocks, mainly dark-colored basalt and the more crystalline lighter colored, granite-like diorite, together with fragments of white tuff or volcanic ash (fig. 44). Sedimentary rock pebbles are also present including sandstone, siltstone, and limestone nodules. All stones are set in a matrix of fine- to medium-grain sandstone.

Bedrock outcrops are not particularly abundant upstream from the trail crossing, but the few that are present, for a distance of 3 miles, consist largely of melange rocks, similar to those exposed along the coast to the south. Upstream beyond the logging bridge some 3 miles inland, bedrock outcrops are more frequent. Outstanding exposures of massive fractured and recemented sandstone form a very picturesque moss-covered gorge about a mile up the main stream from the bridge and half a mile beyond the confluence of Minter Creek (fig. 43). Other excellent outcrops of Hoh rocks are exposed in Minter Creek, particularly in an area 1½ miles upstream from Goodman Creek. In a distance of 1 mile the stream in this area flows over several thousand feet of steeply upturned rock strata known as the Minter Creek section. These strata can be traced at least 4 miles to the east and for several miles to the north where they cross the main branch of Goodman Creek. They delineate a large steeply plunging **SYNCLINE** (downfold). The structural configuration is mani-

GOODMAN CREEK GORGE, some 3 miles inland, has been carved in massive sandstone of the Hoh sedimentary rock sequence (fig. 43).

fested not only on the geologic map (fig. 25) but the upturned beds of resistant conglomerate and sandstone form a pronounced curved ridge that can be traced on a topographic map as well.

In relatively recent geologic times immediately following the last advance of valley glaciers and during the late part of the Pleistocene Epoch (fig. 1), the floor of Goodman Creek valley stood 100 feet or so higher than it does today. It had been filled during a previous advance and retreat of the glaciers with sand and gravel outwash materials that were carried by melt waters from glaciers. The elevation of the floor of Goodman Creek at that time corresponded approximately with the very apparent flat surface on Alexander Island of today. Since that time the stream has cut downward through this debris either because base level for this stream has been lowered or because the distance to the sea has been shortened by the eastward migration of the coast, thus increasing the stream's rate of flow as well as its eroding power. Remnants of the old higher valley floor level, as well as intermittent levels, are preserved along the present valley and form elevated nearly flat terrace areas. Today, only in places such as the mouth of Goodman Creek (fig. 34), the gorge 4 miles upstream, and occasionally in the sharp river bends has the stream completely cut through the overlying sand and gravel to expose the older Hoh bedrock. In the gorge, bedrock is relatively high and the stream in its downward cutting process reached bedrock relatively soon after the close of the Pleistocene Epoch (fig. 43). Therefore, the stream in this area has had a longer period of time to cut deeply into the bedrock.

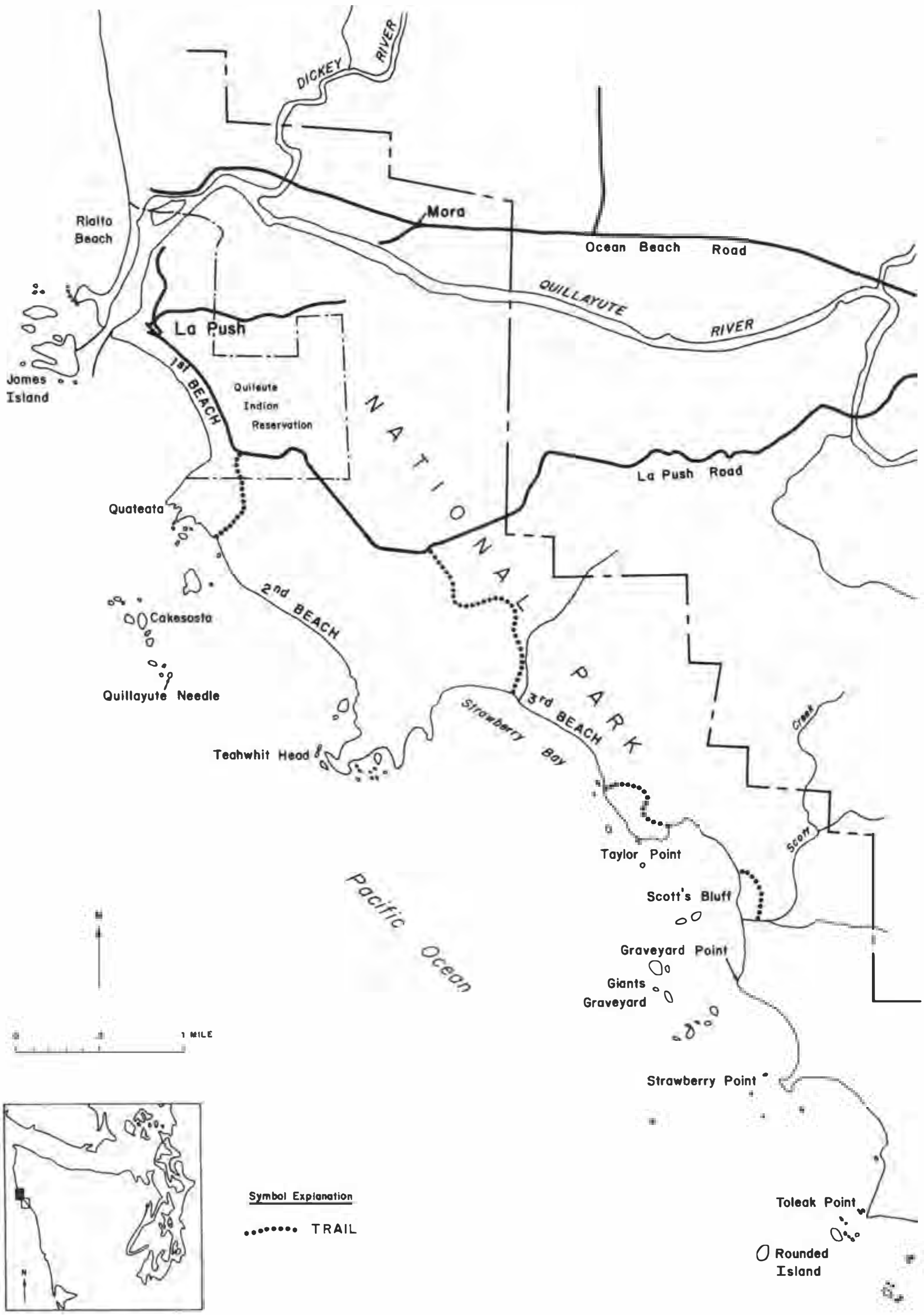
CONGLOMERATE that forms the cliffs north of Goodman Creek (fig. 35) is composed of rounded pebbles and boulders set in a matrix of sandstone. These materials have been cemented together by secondary minerals to form a solid rock mass. The pebbles are of various rock types including dark-colored basalt, light-colored crystalline granitics, sandstone, calcareous siltstone, and fragments of white volcanic ash (fig. 44).

HIKING INFORMATION

TOLEAK POINT TO THIRD BEACH

Open beaches, mostly with hard packed sand at low tide or loose dry sand and gravel at high tide, lie northward of Toleak Point for 1½ miles to Graveyard Point (fig. 45). Several small headlands in this area cannot be rounded during high tides, but if necessary, can be easily climbed over. Once past these headlands, Scott Creek Shelter lies a short distance to the north. Scott's Bluff, immediately north of Scott Creek, restricts beach passage to times of low tide only. However, a trail is available inland around this point, from Scott Creek. Another very small rock point 100 yards south of the beginning of the trail over Taylor Point is also impassable at high tide but is no problem on medium or low tides. A short but steep route behind this point can be climbed.

For a mile the beach at Taylor Point is impassable during all times. Nearly vertical cliffs extend over 150 feet in height above the sea. The well-traveled inland trail rises steeply from the beach. At an elevation of approximately 175 feet above the sea, the trail is relatively level and provides a pleasant walk through the woods for half a mile. Then it descends to cross a major stream valley. Once out of this valley on the north side, the trail passes close to the cliff above the beach, thus an excellent view to the north and west is available from some 200 feet above the sea (fig. 46). The trail descends northward through the woods and then steeply over an open area to sea level at the south end of Third Beach.



ROUTE MAP—Toleak Point to La Push (fig. 45).

Historical Notes

TOLEAK POINT-SCOTT CREEK AREA

Toleak Point, an anglicized Indian name meaning Hole in the Rock Place (Powell, Penn, and others, 1972), is one of the few remaining sites along this part of the coast where evidence of native inhabitants of the past is still apparent. Kitchen middens (concentrations of shell material left by the Indians) erode from the low-lying bluff above the elevated wave-cut bedrock surface (fig. 47). Until the early 1900's two small buildings stood on this surface and Indians were known to bring their canoes through the offshore rocks to land at this point (Davidson, 1889).

Numerous islets and rocks lie off Toleak Point (fig. 48). Rounded Island, the largest and farthest out, is due west of Toleak Point. The intriguing cluster of rocks lying offshore between Strawberry Point and Taylor Point are known as the Giants Graveyard (fig. 49). Although picturesque, it takes very little imagination to visualize how treacherous these rocks would be to a troubled sailing vessel. At least one Spanish ship is believed to have been wrecked in this immediate vicinity, probably in the late 1700's.

In the more recent past this seemingly isolated coastline was more populated than it is today by natives and early settlers, particularly during the latter part of the 1800's. Homesteading brought many people to the Olympic coastal area. Among them was an H. Scott who established his home at the mouth of Scott Creek. Others took up even more remote claims nearby where they made clearings and built modest homes. Evidence of their struggle with nature may be found in the surrounding wooded inland areas. During World War II, Toleak Point was patrolled by a small group of men with dogs.

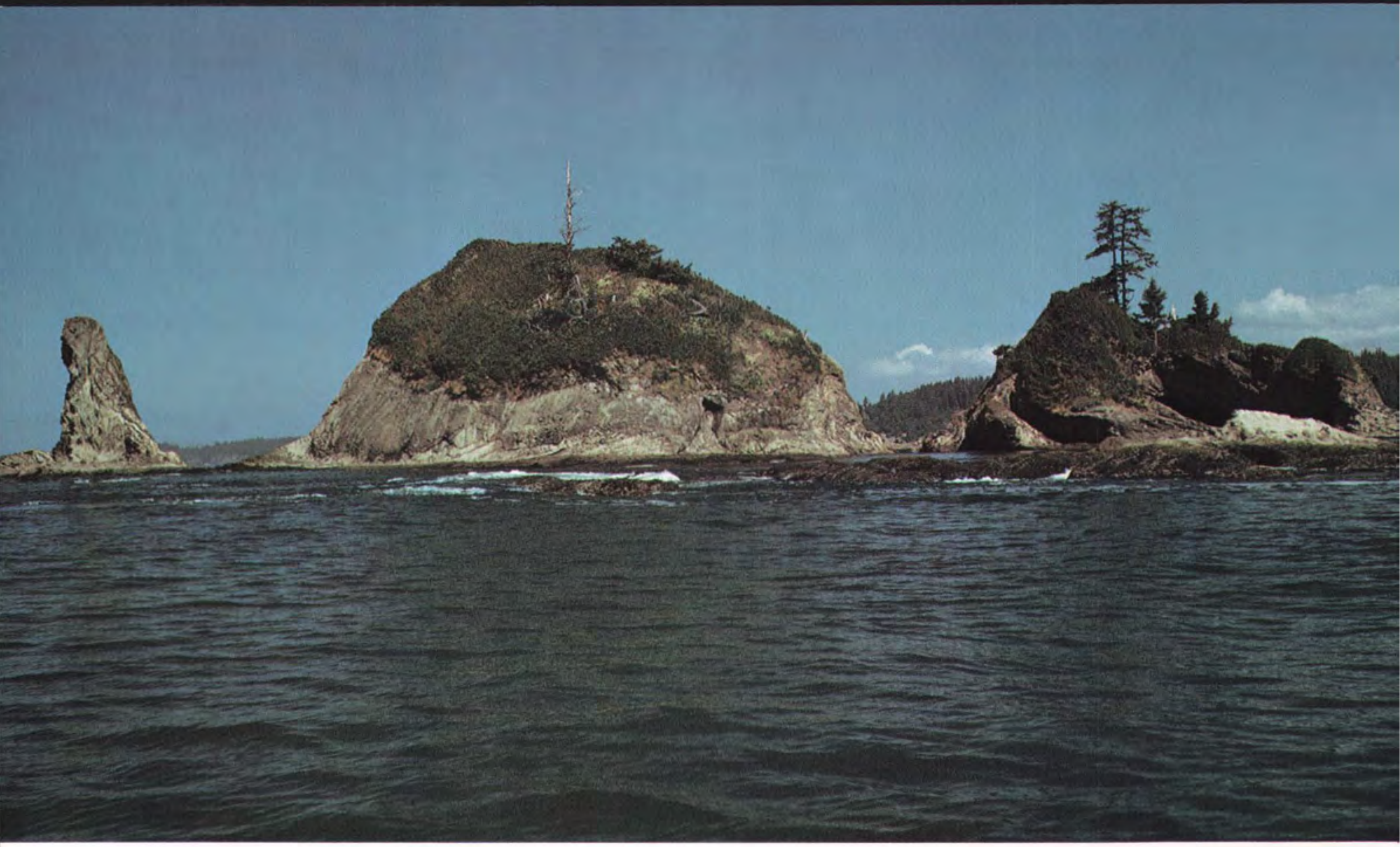
THIRD BEACH, viewed from the top of Taylor Point, is underlain by a major zone of Hoh melange rocks (fig. 46).

TOLEAK POINT TO TAYLOR POINT

Offshore islets, rocks, and reefs extending intermittently from Toleak Point to and including the Giants Graveyard (front cover photo) are composed chiefly of sandstone, but, in places, are stratified with fine-grained siltstone. This stratification reveals that the rocks are steeply tilted and complexly folded with a structural trend striking in a northerly direction somewhat parallel to the coastline. Intense folding and discontinuous or offset bedding resulting from faulting indicates that considerable crustal force and stress have been applied to these rocks. Although these sedimentary rocks generally constitute a coherent sequence of strata, they have nevertheless been greatly rearranged from their original horizontal position. Well-stratified sandstone and siltstone are particularly well exposed at Strawberry Point (fig. 2). They strike northerly and dip steeply to the east. Furthermore, on the basis of sedimentary features preserved in these rocks, it can be determined that the sequence has been rotated beyond vertical to an overturned position with the original bottom side of each bed now facing upward. Several different sedimentary features can be seen in these rocks. However, the most apparent feature is **GRADED BEDDING** or the grading of the size of sand grains from coarse to fine in a single sandstone bed (fig. 50). The top of each bed is always in the direction of the finest grains. At Strawberry Point that direction of grading in the steeply tilted beds is toward the west and slightly downward.

Melange rock debris, similar to that exposed much of the way between Hoh Head and Goodman

KITCHEN MIDDENS, eroding from the terrace surface at Toleak Point, are evidence of native inhabitants of the past (fig. 47).



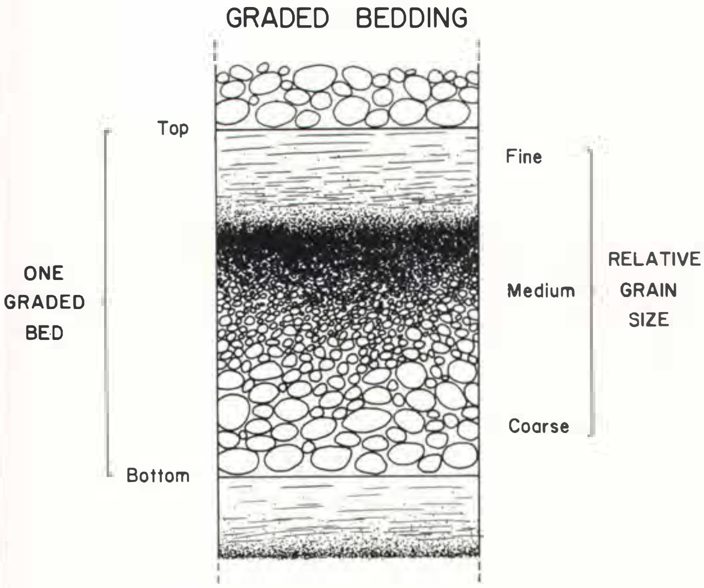
BLOCKS OF MASSIVE SANDSTONE form the many islets and rocks off Toleak Point (fig. 48).

Creek, is also almost continuously exposed in the bluffs between the north end of the Goodman Creek trail and Taylor Point. Countless numbers of large and small sandstone blocks are intermixed in a finer grained siltstone and claystone matrix. Landslide areas are numerous for several miles along essentially continous outcrop. Although the bluff in the cove between Toleak Point and Strawberry Point is mostly vegetated, it too is probably underlain by melange rocks.

Small natural petroleum seeps are common along the Washington coast. Most are associated with melange rocks such as those exposed along this few miles of outcrop. A strong petroleum odor usually can be detected emanating from the cliffs of melange rocks in the area immediately south of the mouth of Jackson Creek.

Deposits of the Pleistocene Epoch are particu-

THE GIANTS GRAVEYARD, viewed from the beach just south of Taylor Point. This group is among the many offshore rocks that extend from Toleak Point to Taylor Point (fig. 49).

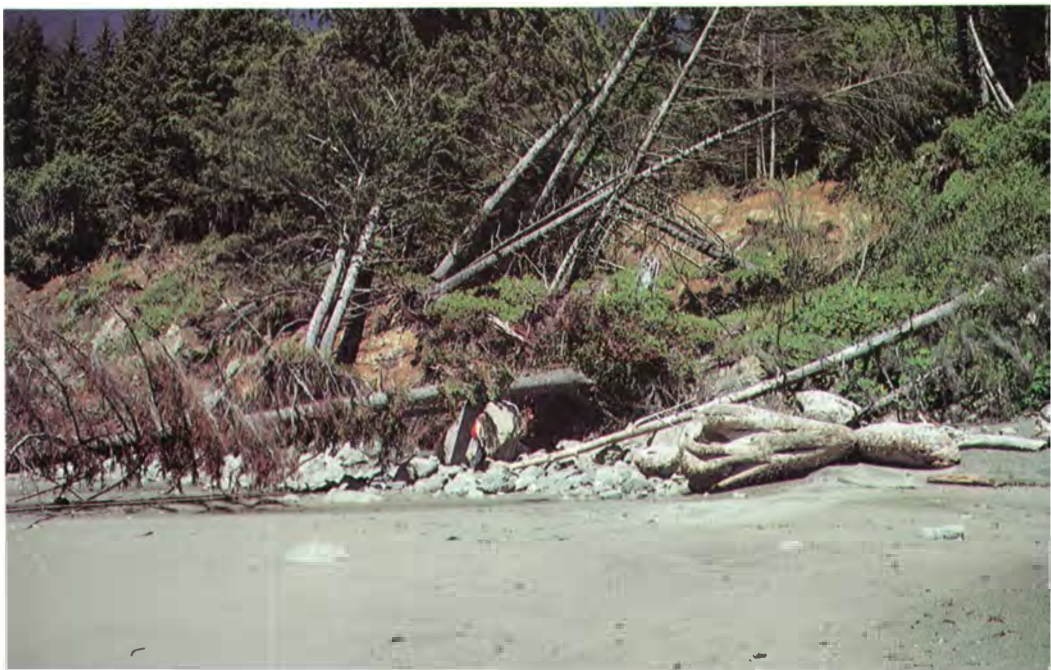


GRADED BEDDING, shown diagrammatically in cross section, is a process of sedimentation that can be used to determine the original top-bottom orientation of an ancient sedimentary sequence seen today as upturned sedimentary rock strata (fig. 50).

larly well exposed in the bluffs between Scott's Bluff and Taylor Point, where they form a cap on the melange bedrock. Landslides are prevalent in this area and have exposed the overlying deposits in **SCARPS** formed behind the landslide debris. In some places Pleistocene material has been carried to the beach as part of the debris slide (fig. 51). Many of the younger deposits consist of laminated silt with carbonized plant and woody material varying in size from branches to logs. These highly organic materials represent deposition of an ancient fresh-water pond or swamp. Although radiocarbon dates are not known from this particular deposit, its stratigraphic position indicates that it represents the latest deposition prior to that of the overlying buff-colored wind-blown deposits. The latter materials are also well exposed here and are thought to have been deposited approximately 8,000 years ago (see Age dating of Ice age events, Part I).

Although the geology of the area extending from a mile south of Toleak Point to Taylor Point appears somewhat monotonous, it nevertheless is an ideal representation of the rock type and structural style that dominates in much of the coastal region of the Olympic Peninsula. As between the Hoh River and Goodman Creek, tectonic melange rocks are exposed in the major part of the bluffs between Toleak Point and Taylor Point. Inland these rocks form a zone approximately a mile wide extending northward generally up the Scott Creek valley (fig. 25). Also, as in the coastal area to the south, this zone is thought to be a large segment of a major fault zone where rock debris has resulted from the thrusting of one segment of the earth's crust beneath another (Rau, 1979). The sandstone and conglomerate beds in the Goodman Creek area and northward into an inland area constitute the upper crustal plate. The offshore rocks extending from the vicinity of Toleak Point to and including the Giants Graveyard area are believed to be part of the contorted strata of the plate beneath. Because this and other coastal fault zones cover relatively wide areas, they are believed to extend downward between plates at a low angle relative to the earth's surface.

A TYPICAL LANDSLIDE commonly occurs where melange rocks are present. Overlying Pleistocene materials north of Scott's Bluff make up most of the debris of this landslide. Undisturbed Pleistocene deposits are visible in the scarp behind the debris (fig. 51).



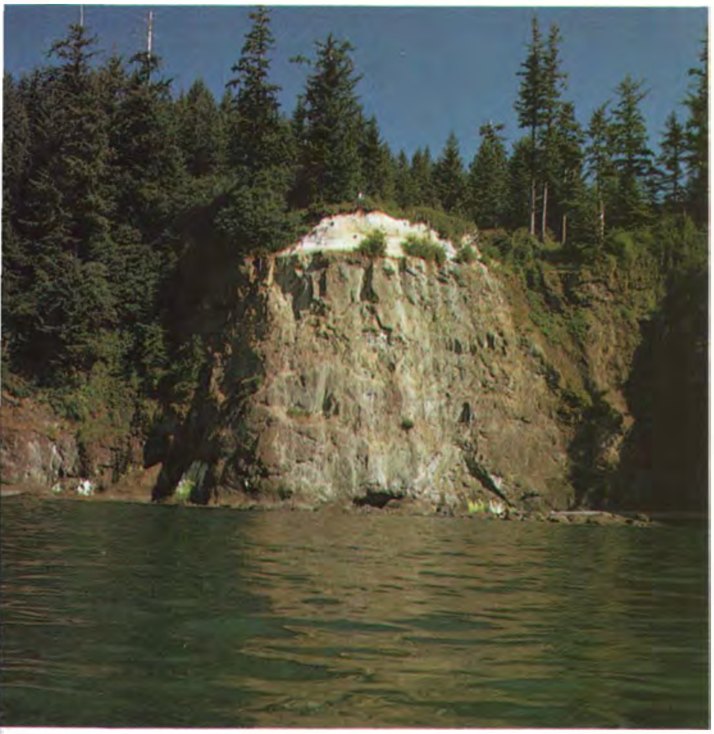
SOUTHEAST SIDE OF TAYLOR POINT. The sandstones and conglomerates of Taylor Point are believed to constitute a faulted segment of a much larger part of the earth's crust (fig. 52).

TAYLOR POINT

Bluffs of melange rocks end abruptly at the southeast side of Taylor Point. This major headland (fig. 52) and its offshore stacks (fig. 53) are composed largely of conglomerate and some massive sandstone—rocks similar to those exposed in the vicinity of Goodman Creek. Taylor Point rocks are believed to constitute a small segment of a much larger part of the earth's crust. They represent some of the strata that are referred to as **HOH ROCK SEDIMENTARY SEQUENCES** (see Part I). The abrupt change from melange rock to a sequence of sedimentary rocks both on the south and north sides of Taylor Point reflects the result of complex northeast strike slip faulting. Strata of Taylor Point have moved southwestwardly relative to adjacent rocks (fig. 25). The contact of these rocks with melange rocks on both the south side and north side of Taylor Point represents the trace of these faults. Although the rock strata of Taylor Point are structurally complex, generally they form a **SYNCLINAL** (downwarp) structure with an axis of folding that trends northwestwardly. A cross-sectional view of this structural feature can be seen from offshore.

Ice age or Pleistocene events are also represented on Taylor Point. The ancient wave-cut terrace, the trace of which is visible in many places along the coast, stands some 150 feet above present-day sea level at Taylor Point (fig. 54). It marks the nearly horizontal contact between conglomerate or sandstone Hoh bedrock and the

AN EROSIONAL REMNANT of massive sandstone off Taylor Point. The notched-like area just above high-tide level has resulted from more rapid weathering where the rock surface is repeatedly dried and then moistened by waves and sea spray (fig. 53).



ICE AGE DEPOSITS rest on an elevated wave-cut terrace at Taylor Point (fig. 54).

overlying unconsolidated silts, sands, and gravels of the Pleistocene Epoch. Particularly good observations of these deposits can be made along the north end of the trail over Taylor Point. The sequence is well exposed in the area where the trail first breaks out of the woods and begins its descent from the top of the cliff to Third Beach. Looking southward, the entire sequence can be viewed (fig. 15). The uppermost 8- to 10-foot thickness of buff-colored sand and silt is believed to be windblown material deposited some 8,000 years ago and represents essentially the latest Pleistocene event in this area. These deposits grade downward into a 10- to 15-foot thickness of well-stratified sand and gravel. They rest on the old wave-cut terrace that was carved on sandstone and conglomerate Hoh bedrock. The trail descends northward along this same sequence of deposits, where it continues downward across the wave-cut terrace and along excellent outcrops and large boulders of Hoh conglomerate and massive sandstone.

THIRD BEACH

The descent from the top of Taylor Point northward to Third Beach crosses the northern fault that separates the Taylor Point rock sequence from another area of melange rocks (fig. 25). Although the actual trace of this fault is not visible, the sudden change from cliffs of conglomerate to slumped deposits of melange debris generally locates the fault contact. Beach travel southeastward from the base of the Taylor Point trail is blocked in a short distance by sheer cliffs of sandstone and conglomerate. However, in that area, an interesting accumulation of large blocks of conglomerate rests at the base of the cliff (fig. 55). The conglomerate of these blocks is similar to the conglomerate of the Goodman Creek area (fig. 44). Well-rounded pebbles and cobbles of sedimentary rocks, such as sandstone and siltstone, are common. Lesser amounts of gray chert, white limestone nodules, granitelike diorite, and dense volcanics, together with various metamorphic (altered) rocks, are also present.

At Third Beach the cliffs of Taylor Point are best viewed a short distance away. Looking back, buff-colored unconsolidated Pleistocene deposits are well displayed, capping massive sandstone and conglomerate Hoh bedrock (frontispiece). A picturesque waterfall can be seen cascading down the cliffs (fig. 56). The V-shaped valley from which it drains has been carved by this stream and abruptly ends at the cliff, thus forming a classic **HANGING VALLEY.** The downward cutting of this stream has not kept pace with coastal erosion and therefore the stream reaches sea level over a final, nearly vertical descent of some 100 feet.

Although the bluffs of Third Beach are largely vegetated, melange rocks are exposed in places

LARGE BLOCKS OF CONGLOMERATE from the cliffs above, rest on the south end of Third Beach (fig. 55).

Historical Notes

EARLY OIL WELL OPERATIONS

One of the earliest geologically related events to take place in the Washington coastal area was the drilling of a petroleum exploration well in the vicinity of Third Beach during the turn of the century. Historical records are in conflict on the exact year of the operations. Some records state that the initial investigations were made in 1898 but actual drilling operations began in the spring of 1899 and were abandoned the same year (Lofgren, 1949). Other records (Landes, 1902; Lupton, 1914) suggest a 1902 date. It may be that the event was not officially recorded until the latter date. Regardless of the exact date, this well, according to all known records, was the first to have been drilled on the Olympic Peninsula.

The site, to this day, is quite evident near the top of the melange rock bluff, no more than an eighth of a mile inland from the north end of Third Beach. Well-rusted machinery, a steam engine (fig. 57) and boiler (fig. 59), together with an assortment of deteriorated drill pipe, lie intertwined among dense underbrush. For years visitors to Third Beach passed by this evidence of man's past mechanical endeavors, a rather startling find in what otherwise appears to be the undisturbed forest. In recent years, the trail to Third Beach has been rerouted and no longer passes the site.

Several known accounts make it clear that the operation was plagued with difficulty. All drilling tools and equipment had to be shipped from San Francisco to Seattle where, together with supplies, they were then transported to the immediate area by tug and barge. The landing of the barge on Third Beach apparently was uncontrolled, completely at the mercy of a strong sea. Reportedly, the barge was totally destroyed, but most machinery, including a donkey engine, was salvaged. The engine was dismantled and backpacked piece by piece to the drill site atop the slippery and somewhat unstable rock melange bluff. Reassembled, the donkey engine was used to drag the remaining machinery and equipment to the site.

Drilling operations were also said to have been wrought with difficulties as the result of a combination of an overbearing operator, uncooperative workers, poor drilling equipment, and unusually difficult drilling conditions in a combination of sandstone conglomerate and incompetent melange rocks. Reports on the total drilling depth are conflicting but state and federal documents suggest a depth of 650 feet may have been reached before "side pressures" became so great that the operation was abandoned. These records also indicate that definite petroleum shows were encountered in the form of strong petroleum odor and rainbow colors on the mud pit (Landes, 1902; Reagan, 1909; Lupton, 1914).

The remains of this ill-fated operation among a maze of underbrush and second-growth timber and a few "high cut stumps" serve as a monument to man's early attempts to recover the resources of this wilderness area.

A WATERFALL viewed from the south end of Third Beach. The abrupt "hanging valley" of the stream is the result of more rapid horizontal erosion by the sea than downward cutting by the stream (fig. 56).

HIKING INFORMATION

THIRD BEACH

Generally, Third Beach can be traversed at almost any tide with only a few places more difficult during extreme high tides. Sheer cliffs of massive sandstone at Teahwhit Head, northwest of Third Beach, make that area completely impassable. Therefore, a formal trail has been provided by the National Park Service from Third Beach to the trail head on the La Push road, a distance of about 1¼ miles. The trail begins in the central part of Third Beach, immediately to the north of a major drainage. This trail is the only formal access to 15 miles of coastal area north of the Hoh River.

along the base of the bluffs and along the beach. Therefore, the entire area between Taylor Point and Teahwhit Head to the northwest is probably underlain by Hoh melange rocks (fig. 46). This zone of tectonic rock melange extends northwestward behind Teahwhit Head and reappears again along Second Beach (fig. 25). Most of the rock debris of these melange deposits are broken sedimentary rocks. However, in the central part of Third Beach, several volcanic blocks are exposed in the bluff and on the nearby beach (fig. 58). Reddish-colored sedimentary **CHERTS** and limey **ARGILLITES** are intermixed with these volcanic rocks. The original source of these volcanic and associated rocks is unknown, but they are similar to volcanic formations in other parts of the Olympic Peninsula. Because no nearby source is known for these volcanic rocks, their presence indicates substantial transport by tectonic action that could occur along a major zone of thrust faulting.

REMAINS OF MACHINERY used during the turn of the century to drill the first exploratory oil well on the Olympic Peninsula lie a short distance inland from the north end of Third Beach (fig. 57).

VOLCANIC BLOCK on Third Beach, an erosional remnant from the Hoh melange. Because this rock type is foreign to the bedrock of the area, its presence suggests transport by major crustal movement (fig. 58).

THIS STEAM BOILER is among the remains of equipment used to drill an exploratory oil well during the turn of the century near Third Beach (fig. 59).

SECOND BEACH, "QUILLAYUTE NEEDLES," AND VICINITY

In many ways the geologic story of Second Beach is similar to that of Third Beach. Melange rocks underlie most of the bluff and beach area whereas the headlands both to the south and north are composed of a sedimentary rock sequence of the Hoh rock assemblage. Structural interpretations suggest that the melange rocks of the bluff and beach are a part of a major zone that extends from the Third Beach area behind Teahwhit Head to the south and continues westward along Second Beach nearly to the headland known as Quateata, where it swings northward (fig. 25). Structural trends suggest that the sedimentary rocks of Teahwhit Head, the "Quillayute Needles," and Quateata are large areas of outcrop of the same sequence of rock strata. Furthermore, these headlands and offshore rocks are thought to constitute another segment of the earth's crust that now lies between two major thrust zones, one of which is represented by the melange rocks of the beach and bluff areas of Second Beach. The contact between melange rocks and the sedimentary rock sequence, although largely concealed, lies between the beach and the "Quillayute Needles," and swings onshore immediately southeast of Quateata to the north and just north of Teahwhit Head to the south.

A large block of volcanic rock rests on the beach immediately seaward from the end of the trail. Volcanic blocks, although rare in local coastal areas, are "exotic" and are found only in melange rock zones. This large volcanic block and other smaller blocks occurring about half a mile to the

A NATURAL ARCH, at the north end of Second Beach, is one of many along the Washington coast. It was formed along a fracture zone in massive sandstone (fig. 60).

HIKING INFORMATION

SECOND BEACH AND VICINITY

Second Beach is accessible by a formal National Park Service trail about three-quarters of a mile in length from the La Push highway to the northern end of the beach (fig. 45). The beach may be traversed a short distance northward where, at low tide, nearby offshore rocks are exposed. A long narrow headland, where a natural arch has been carved, marks the limits of the passable area (fig. 60). It extends the farthest of several fingerlike projections that form the major headland of Quateata. The origin and meaning of Quateata is apparently unknown, but it is pronounced Qw'aatilla by the Quileute people (Powell, Penn, and others, 1972).

One and a half miles of beach stretch southward along melange rock bluffs from the formal trail. During low tide, the rocky massive sandstone shores of the north side of Teahwhit Head may be traversed to its westernmost point (fig. 61). It was from atop this high narrow point that Coast Guardsmen in 1943 rescued 51 crewmen from the wrecked freighter *Lamut* (see Historical note on Teahwhit Head Shipwreck).

south are composed of angular fragments of volcanic rock and some sedimentary rocks that are welded together to form a breccia. White veins of calcite are scattered throughout and represent a period of secondary mineralization that filled fractures once present within the rock mass.

The rock strata of Quateata can be examined in part from Second Beach, particularly at low tide. Most of these strata, as well as those of the "Quillayute Needles" and Teahwhit Head to the south, are massive sandstone. However, bedded siltstone and sandstone are exposed in the small cove just beyond the first passable headland to the north from the trail. The contorted and broken bedding of the rock strata of this outcrop (fig. 63) spectacularly demonstrates the considerable effect of crustal forces on rock formations.

As a result of **DIFFERENTIAL EROSION,** an arch or slotlike feature has been formed in the impassable headland to the northwest (fig. 60).

TEAHWHIT HEAD, between Second Beach and Third Beach, is mostly sandstone. These sedimentary rocks are believed to be a large outcrop of a segment of the earth's crust that lies between two major fault zones (Photo courtesy of the Olympic National Park Service, Port Angeles, Washington) (fig. 61).

Historical Notes

SHIPWRECK AT TEAHWHIT HEAD

Teahwhit Head (according to Davidson, 1889, Te-ah'whit means "leg" in Chinook jargon), a major irregular headland with high sheer cliffs, craggy seaward projections, and offshore rocks, forms an impassable barrier between Second and Third Beaches (fig. 61). This large outcrop area of Hoh rocks is only one of many treacherous rock outcrop areas along the Washington coast where ships have met their fate.

In the spring of 1943, the Russian freighter "Lamut" with a crew of 52 men and women bound for Vladivostok from Puget Sound, encountered a violent storm and went aground between offshore rocks and the sheer cliffs of Teahwhit Head (fig. 62). Accounts attribute the successful rescue that followed to the gallantry, courage, and ingenuity of the men of the U.S. Coast Guard. Because storm conditions prevented a rescue by sea, Coast Guardsmen made their way through several miles of dense underbrush of the coastal forest to reach the knife-edge cliff high above the wreck. It is said that the ridge was so narrow that it had to be literally straddled. Finding that immediate action must be taken or the Russian crew would perish, the rescuers ingeniously tied shoe laces together to form the initial line to the ship. The ship's crew then attached a heavier line which the rescuers hoisted to the top of the cliff and secured. With the exception of one woman, who was lost in an overturned lifeboat when the ship's crew attempted to abandon ship, all remaining 51 members of the crew were rescued. One by one, both men and women climbed upward on the nearly vertical line, dangling over a churning chasm below to a precarious perch, then to safety from Teahwhit Head (Gibbs, 1962).

A SHIPWRECK in 1943 among the treacherous rocks of Teahwhit Head. Crew members of the Russian freighter *Lamut* were rescued by members of the U.S. Coast Guard from the knife-edge cliff above the wreck (Photo courtesy of the U.S. Coast Guard, Seattle, Washington) (fig. 62).

CONTORTED BEDDING in stratified siltstone and sandstone exposed in a small cove at the north end of Second Beach. This outcrop vividly displays the effects of crustal forces through prolonged periods of geologic time (fig. 63).

Fracturing across this massive sandstone headland has weakened the rock thus allowing the process of erosion to carve an opening in this narrow headland. Another example of **DIFFERENTIAL WEATHERING** has resulted in the honeycomblike structure that is particularly well developed on the surface of the headland to the southeast of the cove (fig. 64). Although the massive sandstone of this small headland appears uniform, it has an unequal weakness to weathering, thus a **FRETTED** surface has developed.

Southward, in several places, red-colored sands occur on the beach (fig. 65). They usually are prevalent in the vicinity of the trail near small drainages or seeps that flow onto the beach from the bluff. The red coloring of these sands is caused by concentrations of tiny crystals of the relatively heavy red mineral **GARNET.** Black sand grains of the iron-rich mineral **MAGNETITE** are frequently found associated with the red garnet sands because they too are a heavy mineral. These **HEAVY MINERALS** were originally in the Pleistocene or ice age deposits that cap bedrock in this area. They have since been eroded from the Pleistocene deposits and brought to the beach by streams where, because they are relatively heavy, they have been concentrated along the beach by wave action.

The massive sandstone stacks and islets of the "Quillayute Needles" lie directly west of Second Beach and therefore are best viewed from this area (fig. 66). Although modern-day "sea-level platforms" are developed along almost all coastal areas, they are particularly well formed at the base of these offshore rocks. The feature is best observed when the tide is low. It appears as a nearly flat surface skirting most rock masses slightly below the high-tide level. Because bedrock is periodically dampened and dried at this level by fluctuating sea level, its surface is weakened and therefore more easily eroded by the wave action than the continuously damp surface below this level. Furthermore, some stacks are even slightly undercut at or just above the level of the platform (fig. 53). At this level the process of erosion is

FRETTED SANDSTONE SURFACE. Sandstone surfaces that are dampened by sea spray and dried periodically can become delicately weathered. Slight variations in the resistance to erosion within the sandstone results in a honeycomblike surface structure (fig. 64).

Historical Notes

THE "QUILLAYUTE NEEDLES"

The Quillayute Needle is perhaps the most spectacularly shaped of all the massive sandstone rocks and islets that lie immediately west of the north end of Second Beach. As the southernmost of the group, its needlelike spine rises some 85 feet above sea level and is no more than 35 feet in diameter at the base (fig. 67). Because the name is so vividily descriptive, the entire group of offshore rocks and islets has informally become known as the "Quillayute Needles" (fig. 66).

Other terms are recorded as having been applied to some of the islets and places within the group. Early records (Davidson, 1889) refer to the outermost large islet as ***HUNTINGTON ISLAND*** *and describe it as ". . . about 180 yards in extent with nearly vertical sides, flat top, and bare . . ." However, the top of the outermost of these large islets is noticeably sloped. The origin of this name may have been from that of C. A. Huntington, an Indian agent at Neah Bay during the 1870's. More recent data (Alcorn and Alcorn, 1976) state that the Quileute people know the largest and "slanted" islet as Dhuo-Yuat-Zach-Tah, meaning* ***BIRD ROCK.*** *Assuming that "slanting" refers to the islet's top, the description best fits what earlier records refer to as Huntington Island.*

The term ***CAKESOSTA*** *is an official place on maps and charts, and according to historians (Powell, Penn, and others, 1972), Kikc'ostal, in the Quileute language refers to* ***CANOE LANDING PLACE.*** *It is not clear if the name is for a general place among the islets or if it possibly refers to the large islet immediately east of Huntington Island or Bird Rock.*

RED BEACH SANDS contain tiny crystals of the relatively heavy material GARNET. They have been eroded by streams from ice age deposits exposed in upper part of the bluffs nearby and concentrated on the beach by wave action (fig. 65).

sometimes more effective than all other parts of the rock exposed to subaerial weathering.

The ancient and now-elevated, wave-cut sea-level platform, carved during the Pleistocene Epoch, is also well displayed on several islets off Second Beach by flat top surfaces. The trace of this surface can be seen in many other places along the coast, as on Alexander island, (fig. 37) and along many coastal bluffs. In most of these places, the actual surface is covered with a varying thickness of Pleistocene material. However, the "Quillayute Needles" are essentially bare of such surficial material and the surface viewed here is the actual elevated wave-cut terrace, estimated to have been formed some 125,000 years ago (see Deposits and Processes of the Ice Age, Part I).

Although partially covered in places with vegetation, melange rocks are almost continuously exposed southward to the massive sandstone cliffs of Teahwhit Head. The bluffs in the southern part of Second Beach are composed largely of incompetent siltstone blocks rather than blocks of sandstone; thus landslides are particularly prevalent in that area.

The sudden change from bluffs of slumped melange rocks to cliffs of massive sandstone to the south marks the trace of the fault that separates melange rocks of Second Beach from the sedimentary rock sequence of Teahwhit Head, "Quillayute Needles," and Quateata (fig. 25). A major thickness of this sequence is accessible for examination at low tide along the northwest shores of Teahwhit Head (fig. 61). Most of these rocks are highly fractured massive sandstone (fig. 69). Several thin zones of bedded siltstone and sandstone indicate that the sequence is nearly vertical and trending northwest toward the adjacent bay.

Several archlike features have also been eroded in the Teahwhit Head area. Here again, as at Quateata to the north, they are developed along weakened fracture zones in massive sandstone. The first of these to be encountered southward from Second Beach is a tunnel-like passage through a massive sandstone knob (fig. 69) that lies a short distance seaward from the main cliffs. This tunnel may be reached and examined at low tide. A typical arch has also developed on the westernmost accessible point of Teahwhit Head. As Teahwhit Head is very largely massive sandstone and highly fractured, erosion has developed a very irregular headland with fingerlike, knife-edged projections, irregularly shaped reentrances, and elongated nearby offshore stacks. The northwest structural trend of the sedimentary rocks of Teahwhit Head is grossly reflected by several northwest-trending projections and elongate offshore stacks.

"THE QUILLAYUTE NEEDLES," off Second Beach, are massive sandstone erosional remnants of a major Hoh sedimentary rock sequence. Note, most stacks and islets are skirted by a sea-level erosional platform at a height just below the high-tide level (fig. 66).

THE QUILLAYUTE NEEDLE, a sandstone spinelike erosional remnant off Second Beach, rises some 85 feet above sea level (fig. 67).

Historical Notes

JAMES ISLAND

Traditions, legends, and recorded history relate many fascinating early events in the lives of the Quileute people, some of which directly or indirectly are related to geology. Outstanding among the stories about their way of life is their use of James Island as a very efficient fort against their enemies. James Island, said to have been named after a tribesman, James Howe, originally was called Ah-kah-lahkt (meaning way up there or on top of the hill; Alcorn and Alcorn, 1976). Conflict between the Quileutes and the Makahs to the north apparently began several hundred years ago and lasted for at least 100 years. With only one precarious route to the nearly 5-acre flat surface, James Island served as a natural fort for the Quileutes (fig. 68). Food grown on the island and water from springs served much of their needs. Hot water and large boulders thrown over the side were important weapons used by the Quileute and the sheer walls, 180 feet high, mostly of Hoh sandstone, afforded excellent protection. Geology and rock formations, therefore played an important role in the well being of the Quileute people.

JAMES ISLAND, a large near-shore outcrop of massive sandstone with sheer walls and a flat top, once served as a natural fort for the Quileute people (fig. 68).

MASSIVE FRACTURED SANDSTONE forms an erosional remnant on the western shore of Teahwhit Head. Differential erosion has accentuated the fracture pattern on this outcrop (fig. 69).

FIRST BEACH, JAMES ISLAND, AND VICINITY

The bedrock of First Beach is largely concealed with unconsolidated deposits brought to the area during Pleistocene and Recent times by the Quillayute River and its tributaries. Hoh bedrock is exposed only at the headland of Quateata to the south (fig. 70), and James Island and nearby islands to the north (fig. 73). The bedrock of Quateata, as discussed under the section on Second Beach, is believed to be a part of a sedimentary rock sequence that includes the rocks exposed both at the "Quillayute Needles" and Teahwhit Head to the south (fig. 25). Hoh strata of the James Island area trend northward beneath the concealed area of the river and breakwater to the Rialto Beach area. There, these strata underlie a north-trending ridge where they are exposed in places along the road to Rialto Beach and in ravines of that area. Because a major fault is thought to extend northeastward somewhere through the First Beach area, the James Island-Rialto Beach sequence of sedimentary rocks are believed to be structurally distinct from those of Quateata and other areas to the south.

THE HEADLAND OF QUATEATA as viewed from First Beach. The steeply sloping surface developed on the undisturbed western portion of this headland is an expression of the structural trend of the sandstone and conglomerate strata that form this headland. Pleistocene deposits capping bedrock are well exposed in the quarried area to the left (fig. 70).

Historical Notes

EARLY CONTACTS WITH WHITE MEN

Although no date has been established, the first white men to have made contact with the Quileutes were survivors with Spanish-sounding names from a ship wrecked on nearby offshore rocks (Hobucket, 1934). The Quileutes are said to have referred to the shipwrecked people as the "drifting white race." Because they had never seen white people before and because the white men came from the ocean, the Quileutes thought the ocean was their only home. As the story goes, the shipwrecked crew stayed with the Quileutes for many years. Then finally, they left, headed south, never to be heard from again.

Another shipwreck is thought to have had a French-speaking crew. The event must have taken place during the early days of steamships as the ship was described as a "side-wheeler." The location of the wreck apparently was in the immediate area of La Push. It is said to have been loaded with merchandise, food, and several chests of gold coins. The value of the gold coins was not revealed to the Quileutes, so they simply allowed them to sink in the sand. Later these shipwrecked people left the area and headed south. They, too, were never heard from again (Hobucket, 1934). The French word "la bouche," meaning mouth, may be the origin of the name "La Push," perhaps as a descriptive reference by the French visitors to the mouth of the Quillayute River.

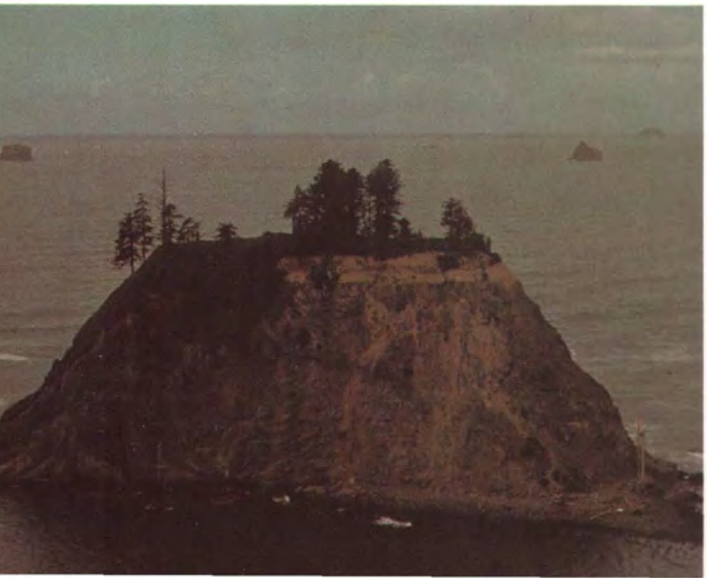
THE INNER BAY OF JAMES ISLAND. The horseshoe-shape of the island has resulted from differential erosion by wave action. A thin, steeply dipping siltstone bed extending westward through the bay area has eroded more rapidly than the adjacent sandstone of the island (fig. 71).

The headland of Quateata is largely massive sandstone; but stratification is apparent in places where it clearly indicates that the beds are dipping steeply to the northwest and strike to the northeast. This structural trend is reflected well on the headland surface to the west of the quarried area where the natural surface is essentially a **DIP SLOPE** surface (fig. 70). Furthermore, the several northeast-trending fingerlike bays and projections that form Quateata distinctly reflect structural lineation manifested by differential erosion of the sedimentary rocks of this headland. The northeast structural trend at Quateata, as well as the east trend on James Island, is most likely the result of drag caused by **STRIKE SLIP** movement on the fault extending through the First Beach area (fig. 25).

Pleistocene deposits are also well displayed in the quarried area (fig. 70). Orange-colored outwash sand and gravel that was deposited by streams from glaciers during the Pleistocene Epoch rests on the now-elevated Pleistocene sea-level surface. Wind-blown, buff-colored silt and sand that blankets much of the coastal area is well-displayed in the uppermost part of this outcrop (fig. 12). These materials are estimated to have been deposited some 8,000 years ago (see Deposits of the Ice Age, Part I).

The bedrock of James Island and nearby islets is largely massive sandstone. Stratification is rare but

"LITTLE JAMES ISLAND" is the northernmost islet of the James Island group. Its gravel-covered, flat-top surface exemplifies Pleistocene deposition on an ancient elevated wave-cut surface (fig. 72).

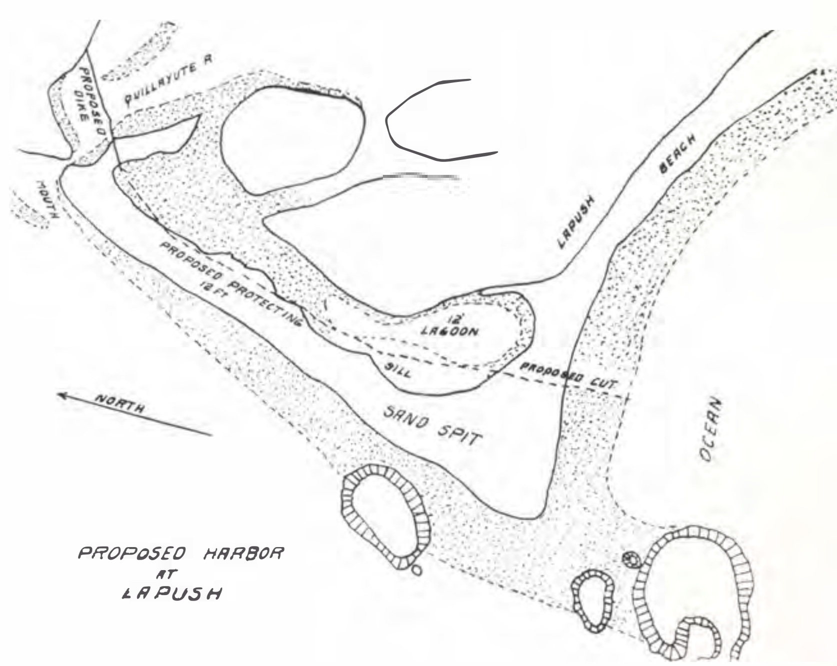


JAMES ISLAND and surrounding islets viewed from the north. Today the Quillayute River is guided by a dike and a jetty so that it enters the sea along the southeast side of James Island (fig. 73).

Historical Notes

LA PUSH HARBOR

Records of more recent and geologically related events reveal how the Quillayute River has entered the sea at various locations through the years. Documents (U.S. Army Corps of Engineers, 1950) state that in 1876 the mouth of the river, approximately at its present location (fig. 73), was closed by a log jam, and the river broke through the sand spit at its upper end to form a new outlet (the area now occupied by the picnic area at Rialto Beach). By 1911, the mouth of the river had migrated southward on the spit and sometime later it moved to its present location. A sketch of the La Push area in a 1909 publication (Reagan, 1909) verifies that at the time only a lagoon existed where the La Push harbor is today, and that the river entered the sea in the Rialto Beach area (fig. 74). It was not until 1931 that the U.S. Army Corps of Engineers constructed a dependable harbor at La Push by completing a dike extending from the existing sand spit to James Island and a jetty on the opposite side of the river. Periodic repairs of the installations followed through the years with a major restoration in 1946. In the 1950's the channel and basin were deepened and the jetty on the east side of the river's mouth was raised to a height of 15 feet above low-tide level. Materials for the dike and jetty were quarried from the Hoh sandstone and conglomerate exposed on the north side of Quateata at the south end of First Beach. A quarry was also opened in Hoh sandstone on the east side of the northernmost islet of the James Island group, "Little James Island" (fig. 72).



LA PUSH HARBOR AREA, 1909. The Quillayute River has entered the sea at various locations through the years. This 1909 sketch map shows that its mouth was then in the vicinity of the present-day picnic area at Rialto Beach (Reagan, 1909) (fig. 74).

may be observed in several places on the main island and also on the northernmost island of the group. The horseshoe shape of James Island (fig. 71) is a structurally controlled feature and is the result of differential erosion by wave action. A thin, relatively soft siltstone strata, dipping steeply northward and trending eastwardly through the central area of the island, has eroded more rapidly relative to the massive sandstone of the rest of the island. The result, over thousands of years, has been elongate reentrant or the inner bay of the island.

Like Quateata, James Island and some of the surrounding islets are also capped with Pleistocene deposits of sand, gravel, and wind-blown sediments. The trace of the Pleistocene elevated wave-cut terrace upon which the deposits rest is particularly well exposed on the northernmost island—"Little James Island" (fig. 72).

Secret Cove

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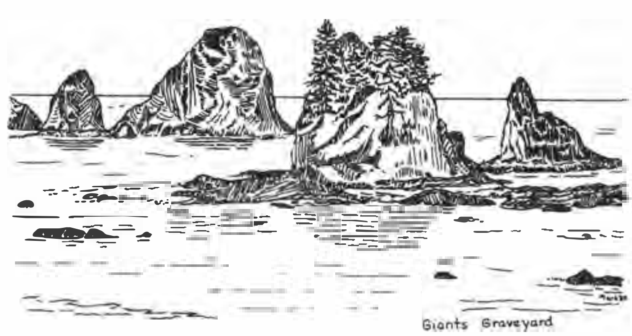

BACK COVER PHOTO

THIS JAGGED ROCK projecting from the sea near Alexander Island is one of many sandstone blocks strewn along the Washington coast. Due to its greater resistance, it remains as an erosional remnant from a mixture or melange of broken rock material from a major fault zone of the earth's crust.