THE COLUMBIA RIVER DISCHARGE AREA
OF THE NORTHEAST PACIFIC OCEAN
A LITERATURE SURVEY
by
George C. Anderson, Clifford A. Barnes,
Thomas F. Budinger, Cuthbert M. Love,
and Dean A. McManus

U. S. Atomic Energy Commission
Contract No. AT(45-1)-1385
Reference M61-25
July 1961

SEATTLE 5, WASHINGTON
Columbia River Drainage Basin and Adjacent Sea
FOREWORD

This literature survey has been prepared in connection with the research program entitled "Columbia River Effects in the Northeast Pacific". It is intended as a work paper to provide a listing of references pertinent to the oceanography of the geographical area which either is influenced by the effluent of the Columbia River or whose waters might appreciably influence the movement and mixing of this effluent. Broadly, the entire North Pacific Ocean, as well as the drainage system of the Columbia River and of nearby rivers, are involved to some extent; and the subject matter appropriately should cover many aspects of physical, chemical, biological and geological oceanography. Practically, it has been necessary to restrict the area considered and subject matter to that of primary importance for the initial pursuit of field work. The existing literature has been reviewed and references on the local oceanographic regime have been compiled. In addition, a number of selected references on river load, flow rates and drainage basin environment of the upstream area have been included to establish the general characteristics of the river. By intent, only a limited number of general references are included.

In arrangement, the text is divided into three main sections which treat, in order, the physical and chemical oceanography, the biological oceanography and the geological oceanography. Each section abstracts pertinent aspects of the current status of knowledge in the subject subfields. Specific reference is made in the text to a few selected entries in the bibliography which follows each section. The entries in the section bibliographies are arranged in the general sequence of the subheadings in the text. There is some duplication of entries between sections in a few cases where the subject matter is relevant to different subfields.

Most of the references in the physical and biological sections are annotated, whereas a number in the geological section are listed without annotation. Some of the latter pertain to current and continuing work not adequately evaluated, and in some cases unpublished.

Only summary consideration has been given to the Columbia River upstream from the estuary and to material having little apparent bearing on the oceanography of the river effluent. No attempt has been made to relate the knowledge in the major disciplines to radioactive waste disposal, and references pertaining specifically to radiation chemistry for the most part have been excluded. This literature survey should be regarded as the initial installment of a continuing study to which additional references will be added as the study progresses. It should not be regarded in any sense as a published or completed document.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRONTISPICE</td>
<td>ii</td>
</tr>
<tr>
<td>FOREWORD</td>
<td>iii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>SECTION I: PHYSICAL OCEANOGRAPHY</td>
<td>2</td>
</tr>
<tr>
<td>HYDROLOGY AND METEOROLOGY</td>
<td>3</td>
</tr>
<tr>
<td>Hydrology</td>
<td>3</td>
</tr>
<tr>
<td>Precipitation and Evaporation</td>
<td>4</td>
</tr>
<tr>
<td>Wind</td>
<td>4</td>
</tr>
<tr>
<td>Wind Effect on the Sea</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICAL OCEANOGRAPHY</td>
<td>6</td>
</tr>
<tr>
<td>Offshore Water Structure</td>
<td>6</td>
</tr>
<tr>
<td>Coastal Water Structure</td>
<td>6</td>
</tr>
<tr>
<td>Ocean Circulation</td>
<td>7</td>
</tr>
<tr>
<td>Tidal Currents</td>
<td>8</td>
</tr>
<tr>
<td>Estuarine Circulation</td>
<td>9</td>
</tr>
<tr>
<td>CHEMICAL OCEANOGRAPHY</td>
<td>10</td>
</tr>
<tr>
<td>General</td>
<td>10</td>
</tr>
<tr>
<td>Dissolved Solids</td>
<td>10</td>
</tr>
<tr>
<td>Oxygen</td>
<td>10</td>
</tr>
<tr>
<td>Phosphate</td>
<td>11</td>
</tr>
<tr>
<td>Silicon</td>
<td>11</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>12</td>
</tr>
</tbody>
</table>
INTRODUCTION

This literature survey is a step in a general program directed towards a better understanding of the seaward distributary system of the Columbia River, an understanding which is necessary for determining the ultimate disposition of materials transported by the river. No major river emptying into the sea has been completely mapped from its mouth to its seaward detectable terminus. Conventional river studies have ended at the river mouth or in a more or less confined estuary in an arm of the sea immediately downstream. Studies of somewhat diluted sea water in coastal areas have been concerned with the overall water and salt budgets and the interaction of fresh water and sea water along a broad front. Only near the river mouth has water from a particular river been distinguished uniquely from that of other rivers as well as from the ambient sea.

The water from the Columbia extends from the river mouth as a surface plume in which the salinity increases downstream. With salinity as a guide its course can be tracked more than 300 miles in the Northeast Pacific Ocean, and its water is detectable over an area approaching 100,000 square miles in extent. As dilution of the sea can come from precipitation and from general runoff, low salinity alone does not identify water from a particular river. The addition of fresh water is only one of many important influences of a river on the sea. Dissolved inorganic and organic substances also are carried to the sea. Certain of these enter into the biological cycle of the ocean. Some are precipitated on contact with sea water and together with the suspended material carried by the river contribute to the near- and offshore sediments. Thus the river can affect the physics, chemistry, biology and geology of the sea. The various ways in which this might occur and the extent to which and area over which it will be manifested are unknown. A base is needed for evaluating the river's influence on the ocean environment. It is the authors' intent that the assembled bibliography serve as a reference base from which the study of the Columbia River effects in the Northeast Pacific Ocean can begin.
SECTION I: PHYSICAL OCEANOGRAPHY
HYDROLOGY AND METEOROLOGY

Hydrology

The Columbia River drains a basin of 259,000 square miles lying mostly in the Pacific Northwest of the United States. The remainder is in the province of British Columbia in Canada. Eighty-five percent, or about 220,000 square miles, is within the United States and constitutes about 7 percent of the Nation's area or twice the area of the British Isles. The basin includes nearly all of Idaho, most of Washington and Oregon, the western part of Montana, smaller areas in Wyoming and Nevada, and the northwestern tip of Utah (c.f. frontispiece). The headwaters of the main stem of this river are in a mountain lake of British Columbia 2,650 feet above sea level. After flowing 1,465 miles through Canada the river enters the United States near the northeast corner of Washington and discharges into the Pacific Ocean through a broad estuary at the coast boundary between Oregon and Washington. The largest tributary is the Snake River. West of the Cascades and downstream from the gaging station near The Dalles, the tributaries of major importance are the Cowlitz River from the north and the Willamette River from the south. The Columbia is somewhat more than 1,200 miles long.

The mean annual discharge of the Columbia River is 243,000 cubic feet per second (over 174 million acre-feet per year). This represents 91 percent of the total gaged discharge into the Pacific Ocean south of the Strait of Juan de Fuca to and including the Umpqua River (43°40' N), or about 79 percent of the total discharge to but excluding San Francisco Bay. If the Strait of Juan de Fuca and San Francisco Bay discharges are included the Columbia accounts for approximately 52 percent of the total. However, these figures tend to be misleading because the seasonal discharge varies widely with source. The Columbia River discharge reaches a maximum in June whereas the combined discharge of the coastal rivers south to the Umpqua reaches a maximum of about 80,000 cfs during the months of December, January and February when the Columbia River discharge is near its minimum of about 153,000 cfs. During these winter months the Columbia River contributes about 66 percent, and in September when the discharge of the coastal rivers is at a minimum, 98 percent of the total discharge. The month of maximum coastal runoff is usually February during which 25 times more freshwater is discharged than during September. The above discharge rates are somewhat low because the lower reaches of the Columbia and Coastal rivers are not gaged. The ungaged area is probably about 10 percent of the coastal watershed. (U. S. Geological Survey, 1952-1960, 1955a; U. S. Geol. Survey Water Resources Division, Tacoma, 1955).

Note should be made of the numerous dams constructed across the Columbia River and its tributaries during the last 20 years (U. S. Department of the Interior, 1947) and the effect these dams have had on river flow and sediment transport.

The role of ground water is believed to be of little importance from the oceanographic standpoint. But the level fluctuation, dissolved-solids composition, and circulation of ground water is an important problem along the reaches of the River particularly in the lowland areas. Studies in the Willamette-Puget Lowland and in the alluvium of most of the larger coastal valleys have shown an abundance of ground water.
Precipitation and Evaporation

The mean annual precipitation in the coastal and immediate off-shore areas of the Northeast Pacific Ocean influenced by the Columbia River discharge is estimated to exceed 120 cm/year. Precipitation exceeds evaporation and essentially the entire ocean area under consideration is one of net dilution, the surplus of precipitation being least in the west and south and increasing to a maximum of more than 90 cm/year off the coast of British Columbia and southeastern Alaska. South of the Columbia River the surplus decreases to near zero at San Francisco Bay (Jacobs, 1951). The precipitation over the Columbia River drainage basin and contiguous coastal drainage basins is as variable as the topography. In the Columbia River Basin alone, the yearly average can vary from less than 20 to over 300 centimeters depending on the location. The mountainous areas receive generally heavy precipitation, much of it in the form of snow. The plateaus lying in the rain shadow of the Cascade Mountains receive little precipitation of any kind. More information is needed on precipitation and evaporation at sea; however, the routine observations as made by the Weather Bureau are adequate for use in considering the gross water budget.

Wind

The seasonal cycle of winds over the Northeast Pacific Ocean is largely determined by the circulation about the North Pacific high-pressure area and the Aleutian low-pressure area. In the summer, the high-pressure area occupies a mean position centered approximately at 40°N, 150°W and favors predominantly northwest and north winds over the coastal areas of Oregon and Washington. In winter, the high-pressure area moves south and east to a mean position at about 30°N, 130°W. At the same time the Aleutian low moves south from the Bering Sea to about 52°N, 180°W and increases in extent and intensity until it effectively dominates the circulation of the Northeast Pacific. The resulting winds are frequently of gale force and range in direction from southeast at the coast to southwest in the offshore region.

Although general wind information may suffice for a gross consideration of the circulation, detailed measurements along the coast and over the effluent waters of the Columbia are wholly inadequate.

Wind Effect on the Sea

The effect of wind in driving and mixing fresh water discharged into the open ocean is one of the most important phenomena to consider in assessing the distribution of Columbia River effluent. The interaction between wind and a water surface has been a subject of considerable theoretical investigation and controversy. An adequate account of this interaction has yet to emerge. There are two facets of this interaction: wave generation (Jeffreys, 1925; Ellison, 1956; Miles, 1960) and wind drift current formation (Van Dorn, 1952; Munk, 1955). Both topics have been approached from different but not necessarily contradictory viewpoints. Although the literature is replete with theoretical discussions on wave formation and drift currents these do not provide a basis for adequately predicting the wind influence on the drift and set of the Columbia Plume. Seemingly, without first investigating the basic processes
involved in the generation of drift currents, any attempt to evaluate the wind effect on the Columbia River plume would be open to some question; however, voluminous observations of wind waves (Groen and Dorrestein, 1958) and wind currents (Haight, 1942) furnish a basis for empirical equations which will permit a rough estimate of wind effect and serve as a model for guiding studies in the effluent plume. The velocity of the surface current is a function of the stress of the wind and the eddy viscosity. The difference in viscosity between the fresh water layer and the underlying sea water will reflect a differential movement between the surface and some depth, which will be larger than the differential movement between the surface and the same depth for areas not covered by the plume. Little is known of this phenomenon.
PHYSICAL OCEANOGRAPHY

Offshore Water Structure

The Northeast Pacific Ocean area affected in measurable degree by the Columbia River runoff extends from the Washington coast south past 40°N and westward at that latitude as far as 250 miles offshore in the summer. During the winter the area affected is poorly defined. This area as well as the whole Northeast Pacific Ocean is characterized by the presence of three distinct zones or water layers. These zones are the result of excess precipitation, fresh water runoff from the Columbia River and coastal drainage, wind mixing, and other less well understood or known causes. The mechanisms whereby these zones are established have not been adequately described. The upper surface zone outside the river plume is about 90 meters thick and is characterized by a small increase in salinity with depth but a large decrease in temperature. Below this is a boundary zone or halocline wherein temperature remains relatively constant while the salinity increases rapidly with depth (Tully, 1957; Fleming, 1958; Dodimead, 1960). The halocline varies in thickness between 60 and 100 meters, and its base is identified throughout the region by a constant salinity of 33.8 °/oo.

Immediately below the surface the mass field is characterized by a shallow zone of uniform density; then a layer of increasing density associated with decreasing temperature. In the summer there is usually a thin constant density layer immediately above the top of the halocline. Throughout the halocline the density increases with depth. The lower zone which extends from the bottom of the halocline to the abyss is characterized by a gradual increase in density with depth.

In the offshore region the vertical salinity gradients are small at all times but tend to be greater in summer than in winter. The summer gradients are brought about by advection and high precipitation, and are preserved under conditions of strong thermal stability. The excess of precipitation over evaporation is greater in the winter than in the summer, but there is diminished stratification because the cooling of surface waters reduces the thermal stability and therefore enhances the effectiveness of mixing by the strong winter winds.

Coastal Water Structure

The general structure described above obtains both in the offshore and coastal regions; however, in the latter the characteristics of the upper zone are modified by the processes of tidal mixing and coastal runoff. Low salinity water of the coastal region has been observed as far south as 40°N where it extended as a tongue from the Columbia mouth with its extremity separated from the coast by more saline water. The low salinity belt north of the Columbia appears to be continuous along the entire coast into the Gulf of Alaska. The relation and influence of this low salinity water on the ocean dynamics have not been adequately studied. The influence of the Columbia and coastal river discharges is certainly great. Conversely,
the influence of the ocean systems and winds on this effluent is considerable. Very little is known of the behavior of river water at sea from either the theoretical or descriptive viewpoints.

The local appearance of relatively cold saline water along the coasts of Washington and Oregon during summer has been attributed to upwelling. When the surface waters are moved offshore by winds from the northwest, some of the water deficit is replaced by deeper water (Sverdrup, 1938). This upwelled water is relatively cold and saline and has a high phosphate and a low oxygen concentration. Where ample runoff continuously replaces surface water as it is transported seaward by winds, upwelled water presumably will be blanketed by less saline water and not break through to the surface. Thus it might appear only occasionally in areas covered by effluent from the Columbia River or from the Strait of Juan de Fuca. Between the strait and the Columbia and along most of the Oregon coast south of the Columbia, local runoff in summer is seldom sufficient to entirely blanket the upwelled water. Upwelled water apparently comes from depths of less than 300 meters (Sverdrup, 1938; Doe, 1955). Better documentation is needed for the times at which upwelling occurs in particular localities, the intensity of upwelling, and the period required for upwelled water to attain the surface characteristics of ambient water. In winter predominantly southerly winds drive surface water inshore and maintain a region of low rather than high salinity all along the coast.

Ocean Circulation

In the region off the coasts of Washington and Oregon the major water movement is that of the southerly-setting California Current. During the summer, flow is toward the south in both the nearshore and offshore regions but in the winter the nearshore flow is toward the north while the offshore current sets to the south. The westwind drift of the North Pacific sets eastward and upon approaching the North American continent diverges well offshore near 45°N, the northern arm feeding a gyral in the Gulf of Alaska. A southern arm turns southward to form the California Current. The latitude at which this apparent split occurs varies with longitude and at 140°W is approximately 50°N in summer and about 43°N in winter. Off the Washington and Oregon coasts in winter, the Davidson Current feeds water northward inshore. This entire area is characterized by weak and poorly defined currents which are easily influenced by temporally changing wind patterns and local bathymetric irregularities. The current drift as computed from the dynamic topography of the sea surface (Barnes and Paquette, 1954; Doe, 1955; Fleming, 1955) is small, with average values of the order of 5 cm/sec or less and maxima up to 20 cm/sec (10 miles per day) in spring and summer. The speed at 300 meters is half that at the surface. The principal characteristics of movement as shown by drift bottle studies (Thompson and Van Cleve, 1936; Dodimead, 1958; Reid, 1960) corroborate the pattern depicted by the dynamic topography.

In the absence of wind and background ocean circulation, one would expect the Columbia River water, in response to geostrophic forces, to extend in a plume northward from the river mouth. However, in summer and autumn wind and current carry the plume of water having a salinity less than 32.0 °/oo and a temperature somewhat higher than that of the ambient water over 200 miles to the southwest. This southwestward movement of relatively fresh
water at this period of year is in agreement with both the southerly set of
the local oceanic circulation and southerly directed winds. During winter,
the northward setting Davidson Current coupled with southerly winds and low
runoff favor a northward transport of Columbia River water but the circulation
is poorly defined.

Sverdrup (1947) has shown that the main features of mass transport in
the eastern equatorial Pacific can be derived from the average wind stress
distribution. This work is supported by that of Reid (1948), Stommel (1948)
and Munk (1950) and indicates that the total steady-state transport of mass
and accompanying currents depends primarily on the curl of the wind stress
components acting on the surface of the ocean. This steady-state model of
mass transport has been applied to extensive calculations of transports in
the North Pacific Ocean for the years 1955, 1956, 1957, 1958 (Fofonoff, N. P.,
1960). Charts of the monthly mass transports are being prepared on a
continuing basis (Fofonoff and Froess, 1960). Fofonoff (1954) has shown
that it is not possible to account for the observed features of an ocean
current in terms of wind stress alone although this is the predominant force.
The arguments of Sverdrup and other investigators have ignored thermodynamic
processes and lateral friction. From Fofonoff's work it appears that an
adequate understanding of the ocean circulation cannot be achieved until the
baroclinic structure of the ocean can be interpreted quantitatively in terms
of suitable mathematical models which include thermodynamic processes. It
appears possible that an analysis of the relationship between the wind stress
and the prevailing currents in the Columbia River effluent area, with consideration
of the local boundary condition will provide an insight into this system. The
relationship between wind and water movement will be a powerful tool for a
theoretical examination of the conditions which would be expected in winter
and summer if the Columbia River did not exist.

**Tidal Currents**

The tidal currents contribute to the flushing of estuaries, accelerate
the mixing of river and sea water, and are directly related to processes of
erosion and deposition of sedimentary material. These are known at particular
locations in navigational waters as in the approaches to ports and at the
mouths of coastal systems emptying into the sea (various U. S. Coast and
Geodetic Survey publications). Too few measurements have been made far
enough from land influence to establish the true strengths and patterns of
tidal currents which exist over the shelf area off the Washington and Oregon
coasts. Some observations have been made on Cobb Seamount (300 miles off
the Willapa Harbor) in which tidal components can be detected (Barnes
and Paquette, 1957) but these are incomplete. The Pacific Oceanographic Group
of Canada is now making some current measurements on the shelf off Vancouver
Island. Direct current measurements in a time series are needed for the
surface, mid-depths and the bottom across the shelf off and flanking the
Columbia River, and also at the bottoms of the local depressions crossing
the slope, such as the Astoria Canyon.
Estuarine Circulation

The Columbia River from the head of tidewater to the river mouth is a rather narrowly confined positive type estuary for which the runoff at all times greatly exceeds the evaporation. The circulation upstream from the mouth varies primarily with the stage of river runoff but is influenced by tide, wind and the configuration of the river bed (National Marine Consultants, 1961). During flood tide, a wedge of salt water intrudes at the mouth of the river and extends a variable distance up the river near the bottom. Above this deeper salt water wedge an upper layer transports seaward some salt picked up from the lower layer and a net amount of fresh water somewhat less than the average fresh water drainage. During ebb, water-level falls and water leaves the channel at an accelerated rate as a displacement flow in response to the hydrostatic force. The river water in the estuary becomes somewhat enriched in salt as it moves downstream over the salt water wedge, and the enrichment continues as the river plume moves seaward from the coast. Eventually the plume no longer can be distinguished from the ambient ocean water. Outside the entrance bar the river effluent moves as a surface brackish layer with 180° of lateral freedom. The movement and mixing of this water is influenced by the local oceanic circulation, tidal currents of the shelf and slope, winds and waves. The upper layer transports seaward a net amount of fresh water equal to the river runoff. At the same time its salt concentration is increasing, so there must be a net transfer of salt from the lower to the upper layer in the estuary (Tully, 1949; Pritchard, 1952), and also in the open sea (Tully and Barber, 1961). This occurs by salt diffusion and by entrainment of relatively high salinity water from the lower layer. Lateral mixing also occurs but the mechanisms of the mixing processes are poorly known. Existing theories require observational verification some of which is available from model studies (Rouse and Dodu, 1955; Cromwell, 1960). An evaluation of the mixing processes is vital to the distribution of the Columbia River water and its dissolved constituents.
CHEMICAL OCEANOGRAPHY

General

The composition of the dissolved constituents in the Columbia River system changes from that characteristic of the upstream drainage to that dominated by the sea beyond the river mouth. Major constituents common to both the ocean and the river are so highly concentrated in sea water that the individual constituents offer little promise over salinity as a tool for tracing the Columbia River seaward. Distinctive substances of potential use as tracers are the radioactive isotopes carried by the river, and perhaps some of the naturally occurring trace elements or organic compounds. These constituents, all of which occur in low concentration, would be involved to an unknown extent in the flocculation which occurs in the estuary. Moreover, they probably enter into the biological cycle to an extent that any cogent evaluation of river effects would require more knowledge of the local food chain than now exists. The general composition of the Columbia River is known from the records of the U. S. Geological Survey, and that of the North Pacific from various oceanographic studies.

Dissolved Solids

The annual contribution of dissolved solids by the Columbia River drainage is 19 million metric tons. This is equivalent to about 20 percent of that carried by the Mississippi River. The concentration of the dissolved solids in the Columbia River is approximately one thousandth that of the North Pacific Ocean into which it flows. The relative composition of sea salts differs from that of fresh water salts and the composition of the latter varies from one river to another. The major cations of the sea listed in order of decreasing concentration are: sodium, magnesium, calcium, potassium, silicon; whereas, the Columbia River cations in order of decreasing concentration are: calcium, silicon, sodium, magnesium, potassium. The major anions listed in order of decreasing concentration for the sea are: chloride, sulfate, carbonate; whereas, for the Columbia River the order is: carbonate, sulfate, chloride.

The specific conductance for the surface ocean water of this region is about 0.03 (ohm·cm)^{-1}; whereas that of the Columbia River water is about 10^{-4}(ohm·cm)^{-1}. At a given temperature the conductivity of both river and sea water increase with an increase in the amount of dissolved solids.

Oxygen

In the surface layers of the North Pacific Ocean the concentration of dissolved oxygen is at approximately its saturation value due to aeration and the photosynthesis of plants. Below the euphotic zone the concentration decreases in response to respiration and decay. The maximum value in terms of saturation generally occurs at depths between 25 and 50 meters. Below this depth there is a steady decrease to a minimum value of under 5 percent in saturation at about 750 meters and then a gradual increase. This condition obtains in both coastal and offshore regions.
Phosphate

Phosphate, one of the principal nutrients of the sea, is found in higher concentrations in the North Pacific than in either the Atlantic or Indian Ocean. The maximum values occur well below the surface and usually at a greater depth than that of the oxygen minimum. Values greater than one microgram atom per liter are found at the surface north of 45°N, increasing to values as great as 3 μg-atom/l at a depth of 200 meters. Over the Northeastern Pacific Ocean the horizontal distribution of phosphate at 100 meters depth and the horizontal distribution of zooplankton are very much alike (Reid, 1958). Inshore, an abundance of plankton is apparently associated with areas of upwelled water. The concentration of phosphate in fresh water is relatively low, frequently less than one percent of that of the coastal sea water.

Silicon

The vertical distribution of silicon increases from about 10 microgram-atoms per liter at the surface to values near 200 microgram-atoms per liter in the abyss. The Columbia River water contains an average concentration of 200 μg-at/l. If not obscured by the effects of biological activity, the discharge of this relatively high silicon content water might significantly affect the surface silicon distribution of the coastal waters.
## BIBLIOGRAPHY

<table>
<thead>
<tr>
<th>Topic</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYDROLOGY AND METEOROLOGY</td>
<td>13</td>
</tr>
<tr>
<td>A. HYDROLOGY</td>
<td>13</td>
</tr>
<tr>
<td>B. METEOROLOGY AND WIND EFFECT</td>
<td>14</td>
</tr>
<tr>
<td>PHYSICAL OCEANOGRAPHY</td>
<td>16</td>
</tr>
<tr>
<td>A. GENERAL</td>
<td>16</td>
</tr>
<tr>
<td>B. OCEAN CIRCULATION AND WIND STRESS</td>
<td>20</td>
</tr>
<tr>
<td>C. ESTUARIES</td>
<td>23</td>
</tr>
<tr>
<td>CHEMICAL OCEANOGRAPHY</td>
<td>26</td>
</tr>
<tr>
<td>AVAILABLE DATA</td>
<td>29</td>
</tr>
<tr>
<td>A. OBSERVATIONS IN THE NORTHEAST PACIFIC OCEAN</td>
<td>29</td>
</tr>
<tr>
<td>B. ATLASSES AND AVERAGE CONDITIONS</td>
<td>38</td>
</tr>
<tr>
<td>C. BIBLIOGRAPHIES, DATA INVENTORIES AND LITERATURE SURVEYS</td>
<td>41</td>
</tr>
</tbody>
</table>
HYDROLOGY AND METEOROLOGY

A. HYDROLOGY

Brooks, J. E.

Griffin, W. C.

Grover, Nathan C. and Glenn L. Pacher
1940. Summary of Records of Surface Waters in Washington. U. S. Geological Survey, Water-Supply Paper 870, 456 pp. (Stream-flow records in Washington up to 1919 representing an aggregate of 1,120 years at 209 gaging stations are summarized in Water-Supply Paper 492. Similar records for the period October 1, 1919 to September 30, 1935, representing an aggregate of 1,470 years at 203 gaging stations, are summarized in this volume.)

Landes, Henry

Mundorff, M. J., J. M. Weigle and G. D. Holmberg

Thompson, M. Ray

Tyler, Richard G.

U. S. Bureau of Reclamation

U. S. Geological Survey
(Annual volumes which give records of stage, discharge, and content of streams, lakes, and reservoirs. Each part is published as a separate volume.)

U. S. Geological Survey
(Summarize the discharge records from guaged streams of the Pacific slope basins in Washington, Oregon, and California and the Columbia River Basin.)

(Includes a summary of the monthly mean discharge from 1879 to 1953 of the Columbia River guaged at The Dalles.)

B. METEOROLOGY AND WIND EFFECT

Church, Phil E.

Cromwell, T.
(Tank experiments which demonstrate the behavior of pycnoclines under different conditions of mixing.)

Groen, P. and Dorrestein, R.
(Virtually all the data on wind waves published prior to 1957 have been used to obtain average wave characteristics as a function of wind duration and wind speed.)

Haight, F. J.
(Partially summarizes thirty years of drift pole current measurements made by lightships along the east coast.)

Jacobs, W. C.
(Includes the only available information on precipitation and evaporation for the region of investigation.)
Jeffreys, H.  
(The theory is advanced that the wind presses more strongly on the slopes of the waves facing it than on the sheltered slopes, and it is when the resulting tendency of the waves to grow is just able to overcome viscosity that waves are first formed.)

Keulegan, G. H.  

Miles, J. W.  

Munk, W. H.  
(Over water, the function of the two-dimensional spectrum of an irregular surface is not independent of the wind velocity, and hence the form drag is proportional to the wind speed cubed rather than the speed squared as obtains for a solid surface.)

Reed, T. R.  
(Discussion of high percentage of easterly gales at Tatoosh Island and the reasons for their occurrence.)

Reid, R. O. and W. H. Clayton  
(Preliminary report on the evaluation of wind stress upon the sea surface for varying conditions of wind speed. The evaluation was based on the Prandtl-von Kármán theory.)

Rossby, C. G. and R. B. Montgomery  

Rouse, H. and J. Dodu  
1955. Diffusion Turbulente a travers une Discontinuite de Densite. La Houille Blanche, August - September, no. 4, pp. 522-532.  
(In English).  
(Model experiments which show that: Agitation of a fluid layer has no effect upon a neighboring layer of slightly different density except in the immediate vicinity of the interface between them, that interface remaining continuously defined.)
Stewart, R. W.  
(It is shown to be probable that a large proportion of the drag exerted by a water surface on the wind is in the form of wave drag. As a result the usual relation between the wind profile and the surface stress and roughness length are modified. In particular, close to the surface the relation between the transport of momentum and that of heat and water vapour are different from that obtaining over a rough solid surface.)

Sverdrup, H. U.  
(It is shown that the transfer of water vapor and momentum obey similar laws and that the sea surface at wind velocity below 5 m/sec behaves as a hydrodynamically smooth surface and at velocities above 7 m/sec as a hydrodynamically rough surface with roughness length 0.6 cm.)

Van Dorn, W. G.  

PHYSICAL OCEANOGRAPHY

A. GENERAL

Aron, William  
(Contains a discussion of the relationship of the distribution of mid-water trawl catches to oceanographic conditions. Areas near British Columbia and Washington coasts are included.)

Bennett, E. B.  

Budinger, Thomas F.  

Budinger, Thomas F. and Betty J. Enbysk  
(Discussion of the topography, geology, biology and hydrography of the area. The section on hydrography deals with currents, water structure, and details of temperature structure in the upper layer.)
Dodimead, A. J.
1961. Some Features of the Upper Zone of the Sub-Arctic Pacific Ocean. International North Pacific Fisheries Commission, Bulletin No. 3, pp. 11-24. (Temperature and salinity structures and depth of the upper zone. West Coast of Vancouver Island and Washington are included in discussion. References.)

Doe, L. A. E.


Fleming, R. H.


Fleming, R. H. and E. Elliott

Fofonoff, N. P.

Geyer, R. A.

Herlinveaux, R. H.
1953. How to Predict Tidal Currents in Juan de Fuca Strait. Fisheries Research Board of Canada, Progress Report, Pacific No. 95, pp. 48-51. (Presentation of a set of rules for determining the direction and velocity of tidal currents in the subject area; also a short discussion on the nature of those currents.)
Hollister, H. J.
1953. Daily Seawater Observations on the Pacific Coast of Canada. Pacific Oceanographic Group, Manuscript Report File N 7-1-3-1, October 15, 1953, Nanaimo. (Results of daily observations. Discussion of climatic changes along Canadian coast as reflected by seawater observations.)

1954. What was the Temperature of the Sea Water on the British Columbia Coast in 1952? Fisheries Research Board of Canada, Progress Report, Pacific No. 98, pp. 6-9. (Discussion of coastal temperatures as observed at light stations. The 1952 temperatures were colder than a ten-year average. The locations of the sampling stations are classified into four types.)

Holway, Ruliff S.
1905. Cold Water Belt along the West Coast of the United States. University of California Publications, Bulletin of the Department of Geology, vol. 4, no. 13, pp. 263-286. (Temperature observations of TUSCARORA and ALBATROSS. General temperature conditions of the North Pacific Ocean, including a belt of cold water along the coast. Explanation of cold water: sinking of cold water south of Aleutians, movement southward at depths and then upwelling along coast due to shape of bottom.)

National Marine Consultants

Pacific Oceanographic Group of the Fisheries Research Board of Canada

Pickard, G. L. and D. C. McLeod

Powell, Donald E., Dayton L. Alverson, and Robert Livingstone, Jr.
1952. North Pacific Albacore Tuna Exploration-1950. U. S. Fish and Wildlife Service Fishery Leaflet No. 402. (The "magic number" according to Powell et al. is 57°F. This is the lowest surface temperature at which albacore are likely to be caught.)
Reid, J. L., Jr.

Robinson, M. K.

Sverdrup, H. U.
(Shows that the processes of upwelling are far more complicated than previously described. Thorough analysis of and discussion of upwelling phenomena based on the data in the following reference.)

Sverdrup, H. U. and R. H. Fleming

Sette, Oscar E. and John D. Isaacs (editors)
(Discussion of meteorological, physical oceanographic, and biological evidences of changes in the Pacific during 1957-58. Washington, Oregon coastal areas are included in the area under discussion.)

Tibby, Richard B.
(A discussion of the distribution of various water masses in the area named based on analysis of temperature-salinity relationships.)

Tully, John P.
(Discussion of warmer surface temperatures during the summer of 1936 as compared to 1935, as observed at five light stations along the British Columbia coast.)
Tully, John P.

1937. Report on Dynamic Studies off the Canadian Pacific Coast, 1936. Transactions of the American Geophysical Union, 18th Annual Meeting, Part I, pp. 228-231. (Description of seasonal cycles of surface temperature and salinity, the effect of meteorological conditions on coastal currents, discussion of gradient and tidal currents off the west coast of Vancouver Island and near the entrance to the Strait of Juan de Fuca.)

1937. Seasons in the Sea. Biological Board of Canada, Progress Reports of Pacific Biological Station, Nanaimo, No. 33, pp. 11-12. (Discussion of how seasons in the sea are governed by the temperature cycle of the water. Illustrated by a graph of temperature cycle at Quatsino station. This information is incorporated into Tully, 1937, Trans. A. G. U.)

1937. Why is the Water Along the West Coast of Vancouver Island so Cold? Biological Board of Canada, Progress Reports of the Pacific Biological Station, Nanaimo, No. 34, pp. 13-15. (A simplified explanation of the upwelling induced by northwest winds along the Vancouver Island coast.)

Tully, John P. and E. Bertram Bennett

1952. Project "Offshore", Coastal Temperatures, and Tuna. Fisheries Research Board of Canada, Progress Report of Pacific Coast Stations, No. 92, October 1952, pp. 6-9. (Preliminary results from offshore oceanographic and tuna catch data. The temperature picture off Vancouver Island in August 1950 was anomalous as this was a good tuna year. The 1951 temperature picture was regular and there were poor tuna catches.)

Tully, J. P. and L. A. E. Doe


Tully, J. P. and A. J. Dodimead

1957. Canadian Oceanographic Research in the North Pacific Ocean. Fisheries Research Board of Canada, Manuscript Report, Pacific Oceanographic Group, Nanaimo, February 28, 1957 File N 7-20-6. (Distribution and structure of temperature and salinity, water masses, and mechanisms causing these distributions.)

B. OCEAN CIRCULATION AND WIND STRESS

Barnes, C. A. and Robert G. Paquette

Barnes, Clifford A. and Robert G. Paquette  
(Results of oceanographic measurements and current studies; comparison of GEK and other current measurements.)

Dodimead, A. J.  
(Discussion of temperature and salinity distribution and structure, water masses and calculated currents. Maps.)

Dodimead, A. J., and H. J. Hollister  
(Report on drift bottle releases from Station Papa and at other ocean locations. The results substantiate the seasonal changes shown by the geopotential topography. Charts show the probable drifts, including some along the British Columbia and Washington coasts.)

Fofonoff, N. P.  
(A mathematical model of a zonally uniform ocean is constructed in order to investigate the steady circulation and the non-homogeneous distribution of density maintained by elementary thermodynamic processes. It is concluded that thermodynamic processes affecting the density of sea water cannot be neglected in the study of zonally uniform currents in the ocean.)

(The steady-state model of mass transport has been applied to extensive calculation of transports in the North Pacific Ocean. Charts representing the monthly means of Ekman and total mass transport are shown together with charts of the integrated total and geostrophic transport for 1955.)

Fofonoff, N. P. and C. Froese  
(Gives the details of the computations and a description of the computer program for determining the components of Ekman and total transport from atmospheric pressure observations.)
Marmer, H. A.
1926. Coastal Currents Along the Pacific Coast of the United States. U. S. Coast and Geodetic Survey, Special Pub. No. 121, Washington. (Based on observations at five lightships. Description of tidal, non-tidal and wind currents at each station. Included are Columbia River, Umatilla Reef and Swiftsure Lightships.)

McEwen, George F.
1928. Ocean Surface Drift in the Pacific Coastal Belt off North America. Proceedings of the Third Pacific Science Congress, vol. 1, pp. 191-198. (Calculation of surface currents from temperature data collected by naval vessels. This work was done to obtain an independent check on the work of Marmer (1926) relating surface currents to winds. Conclusion is that along the Pacific Coast the observed winds constitute the chief cause of the main surface currents.)

Munk, W. H.
1950. On the Wind-Driven Ocean Circulation. Journal of Meteorology, vol. 7, no. 2, pp. 79-93. (Attempt to account theoretically for the main features in the general ocean circulation. Concludes that the circulation in the upper layer of the oceans is the result chiefly of the stresses exerted by the winds.)

Reid, R. O.
1948. The Equatorial Currents of the Eastern Pacific as Maintained by the Stress of the Wind. Journal of Marine Research, vol. 7, no. 2, pp. 74-99. (Verifies that, in the eastern equatorial Pacific, the predominant features of the distribution of mass and of mass transports of water can be accounted for semiquantitatively in terms of the wind stress alone. Thermodynamic processes and lateral friction are ignored.)

Reid, Joseph L., Jr., Gunnar I. Roden and John G. Wyllie
1958. Studies of the California Current System, In California Cooperative Oceanic Fisheries Investigations, Progress Report 1 July 1956 to 1 January 1958. Marine Research Committee, California Department of Fish and Game, pp. 27-56. (Discussion of winds, currents, water masses, distribution and variation of properties, relation of the environment to plants and animals, non-seasonal variations in the system. Discussion includes Oregon and Washington coasts.)

Sverdrup, H. U.

1947. Wind-Driven Currents in a Baroclinic Ocean; With Application to the Equatorial Currents of the Eastern Pacific. Proceedings of the National Academy of Sciences, vol. 33, no. 11, pp. 318-326. (Derivation of equations which relate the distribution of mass, and corresponding mass transport to wind stress. Excellent agreement was found between the mean wind stress and the distribution of mass and accompanying currents of the equatorial Pacific Ocean.)
Thompson, W. F. and R. VanCleave

Tully, John P.
(Summary of meteorological and oceanographic conditions off the west coast of Vancouver Island during various seasons of the year and their effect on the ocean currents.)

1942. Surface Non-Tidal Currents in the Approaches to Juan de Fuca Strait. Journal of the Fisheries Research Board of Canada, vol. 5, no. 4.

C. ESTUARIES

Burt, Wayne V.

Burt, Wayne V. and Lowell D. Marriage
(Computation using equations of Stommel (1957—same journal) and measured salinity and river flow data give the expected distribution of pollutants in the estuary.)

Burt, Wayne V. and John Queen
(A discussion of the process of eddy diffusion caused by tidal currents in Coos Bay.)

Burt, Wayne V. and W. Bruce McAlister
(Discussion of classification of estuaries according to the system of Pritchard, and how the Oregon estuaries fit into this classification. Applications of oceanographic data to biological and engineering problems in Oregon estuaries.)

Callaway, Richard J.
Committee on Tidal Hydraulics, U. S. Army Corps of Engineers
(Comments and recommendations by the committee after examining results of 1959 prototype study, include jetty rehabilitations, problems of shoaling, selection of spoil areas, and extent of salt water intrusion. A model study is suggested.)

Cromwell, T.
(Tank experiments which demonstrate the behavior of pycnoclines under different conditions of mixing.)

Eriksen, Arne and Lawrence D. Townsend
(Includes data from stations near the mouth of Grays Harbor. Data from chemical analyses: Chlorinity, dissolved oxygen, and pH are given.)

Herlinveaux, R. H.
(Description of tidal currents, methods of prediction.)

Hickson, R. E.
(On file at Portland District Office.)
(A discussion of the salinity distribution from the mouth of the river to Harrington Point.)

National Marine Consultants

(This reference was not examined. Contents include wave refraction diagrams.)

Pritchard, D. W.
Rattray, Maurice, Jr.
(The tides and tidal currents in offshore regions where the frictional effect is negligible are obtained from the tides at the adjacent shore stations by an approximate solution of the tidal equations. Data from Umatilla Reef Lightship are used as an example.)

Rouse, H. and J. Dodu
1955. Diffusion turbulente a travers une discontinuite de dendite.
La Houille Blanche, August - September No. 4, pp. 522-532.
In English.
(Model experiments which show that: "Agitation of a fluid layer has no effect upon a neighboring layer of slightly different density except in the immediate vicinity of the interface between them, that interface remaining continuously defined.")

Schultz, E. A. and H. B. Simons
(Describes various types of saline wedges as related to mixing in the Columbia River estuary. Describes various types of shoals formed including deposition at the mouth of the river.)

Thompson, Thomas G. and Kenneth T. Barkey
(Distribution of temperature, salinity, density, oxygen, nitrites, silicates and phosphates in Seymour Inlet (west coast of British Columbia) and adjacent waters. Discussion of water movements and structure.)

Trites, R. W.
(Discussion of salt balance and diffusion coefficient. Describes technique for determining total water inflow using precipitation observations and river flow measurements, also a method for determining seaward movement of brackish layer.)

Tully, John P.
(Describes characteristic tidal circulation in a canal, a fiard and and a fiord. The oxygen content gives evidence of upwelling offshore. A zone of photosynthetic activity is present.)
Tully, J. P.
(Theoretical discussion illustrated with examples from Alberni Inlet, Chatham Sound, and the west coast of Vancouver Island.)

Tully, J. P. and F. G. Barber
(Discusses entrainment process, a unidirectional upward transfer of sea water coupled with a random mixing process in the halocline, as applied to the open sea.)

U. S. Army Corps of Engineers
Vol. 1, 15 pp (Describes program and methods.)
Vol. 2 - 4 (Describe velocity, direct, and volume of flow, tide gaging, and salinity data from 7 ranges across lower 57 miles of the Columbia River.)

CHEMICAL OCEANOGRAPHY

Clarke, Frank W.
(Columbia River covered.)

Columbia Basin Inter-Agency Committee, Subcommittee on Water Pollution
(Chehalis River and tributaries included.)

Haendler, Helmut M. and Thomas G. Thompson
(Method of analysis. Results of samples taken at Friday Harbor and at stations off Cape Flattery.)

Richards, F. A.
(Discusses the phenomena of oxygen minimum in the oceans.)
Robeck, Gordon G., Croswell Henderson and Ralph C. Palange
Public Health Service, Robert A. Taft Sanitary Engineering
Center, Cincinnati.
(This publication deals mostly with the river itself. However,
the results of a few radio-activity measurements made at
Astoria are given.)

Robinson, Rex J. and Henry E. Wirth
1934. Free Ammonia, Albuminoid Nitrogen and Organic Nitrogen in the
Waters of the Pacific Ocean off the Coasts of Washington and
(Methods of analysis, description and analysis of results based
on stations off Vancouver Island, offshore from Cape Flattery,
and in the Strait of Juan de Fuca.)

Thompson, Thomas G. and Raymond W. Bremner
1935. The Occurrence of Iron in the Waters of the North-East Pacific
(Includes results of analyses from stations off Washington
and Vancouver Island and Gulf of Alaska.)

Thompson, Thomas G., Joseph W. Lang and Lucile Anderson
1927. The Sulfate-Chloride Ratio of the Waters of the North Pacific.
Publications of the Puget Sound Biological Station, vol. 5,
pp. 277-292.
(Methods of analysis, discussion of results, and data. Areas
studied include Grays Harbor.)

Thompson, T. G., B. D. Thomas, and C. A. Barnes
1934. Distribution of Dissolved Oxygen in the North Pacific Ocean.
James Johnston Memorial Volume, University of Liverpool Press,
pp. 203-234.

Utterback, C. L. and Wilhelm Jorgensen
1934. Absorption of Daylight in the North Pacific Ocean. Journal
(Results of measurements of total vertical absorption coefficients
with a submarine photometer at stations off Washington and
Vancouver Island coasts. Comparison with inshore and lake
measurements by others.)

Wirth, Henry E., Thomas G. Thompson and Clinton L. Utterback
1935. Distribution of Isotopic Water in the Sea. Journal of
the American Chemical Society, vol. 57, pp. 400-404.
(The discussion includes results from one station 90 miles
west of Cape Flattery. Comparison of density between water
distilled from tap water.)

U. S. Geological Survey
1959. Study and Interpretation of the Chemical Characteristics of
Natural Water. Department of Commerce, Geological Survey
U. S. Geological Survey
AVAILABLE DATA

A. OBSERVATIONS IN THE NORTHEAST PACIFIC OCEAN

Association d' Oceanographie Physique, Union Geodesique et Geophysique Internationale

1940. Monthly and Annual Mean Heights of Sea Level, up to and Including the Year 1936. Publication Scientifique No. 5.


(All three volumes contain data from Victoria, Seattle, and Clayoquot, B. C.)

Barnes, Clifford A. and Thomas G. Thompson


(Some observations of surface temperature, salinity and pH apply to the area under consideration.)

Burt, Wayne V.


(Contains a tabulation of oceanographic data from Oregon estuaries, including temperature, salinity, and current velocity.)

Callaway, Richard J.


(Both parts contain physical, chemical and current measurement data from stations inside the river entrance.)

Canadian Joint Committee on Oceanography


(Contains tabulated data. Sta. 1-3, 82-85 are applicable to the area under consideration.)

Collias, Eugene E., Cuthbert M. Love and Robert G. Paquette


(This and other University of Washington reports cited in this section contain tabulated physical and chemical data from oceanographic stations.)
Dodimead, A. J., K. B. Abbott-Smith and H. J. Hollister
(This and other Canadian data reports cited in this section contain tabulated physical and chemical data from oceanographic stations and, in some cases, reproductions of BT traces.)

Note: In citing future reports in this series the phrase "Manuscript Report Series (Oceanographic and Limnological) No. . ." will be abbreviated as "MSS . . .".

Dodimead, A. J., L. F. Giovando, R. H. Herlinveaux, R. K. Lane, and H. J. Hollister
1960. Oceanographic Data Record, North Pacific Surveys, July 10 to September 6, 1960. MSS No. 82, Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo.

Favorite, Felix, and Cuthbert M. Love

Favorite, Felix and Glenn Pedersen
(Contains tabulated data. One station, Paragon 25 at 50°N, 130°W near the north end of Vancouver Island applies to area under consideration.)

(Contains tabulated station data and surface temperature and weather observations from BT lowerings. Three Pioneer stations, Nos. 103, 104, 105 are applicable to the area under consideration, also some of the BT data.)

Fleming, Richard H. and Staff


Goodman, Joe and Thomas G. Thompson
(Contains tabulated data. Stations 10-12 Oglala (1935) first section and 1-4 of second section apply to the area under consideration. Some of the Northland (1938) surface data also applies.)

Herlinveaux, R. H., O. D. Kennedy, H. J. Hollister
1960. Oceanographic Data Record, Coastal-Seaways Project, November 16 to December 11, 1959. MSS No. 58, Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo.

Hollister, H. J.
(Contains reproductions of BT traces and a tabulation of meteorological data, both obtained twice daily.)

Iglesrud, Iver, Rex J. Robinson and Thomas G. Thompson
(Contains data from Catalyst (1932) stations.)

Lane, R. K., J. Butters, W. Atkinson, H. J. Hollister

Lane, R. K., J. Butters, W. R. Harling, H. J. Hollister
1961. Oceanographic Data Record, Coastal Project, November 27 to December 9, 1960. MSS 84, Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo.

Lane, R. K., R. H. Herlinveaux, W. R. Harling, H. J. Hollister

Lane, R. K., J. H. Meikle, H. J. Hollister

1960b. Oceanographic Data Record, Coastal Project, June 6 to 16, 1960. MSS 76, Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo.

Love, Cuthbert M.
Love, Cuthbert M.


Manzer, J. I. and H. J. Hollister
1960. Data Record of Bathythermograms Observed by Fisheries Research Board Chartered Fishing Vessels, March - September 1959. MSS 66, Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo. (Contains reproductions of BT traces.)

Matudaira, Y.

NORPAC Committee
1960. Oceanic Observations of the Pacific: 1955. The NORPAC Data Prepared by the NORPAC Committee, University of California Press and University of Tokyo Press, Berkeley and Tokyo. (Contains tabulated data from all agencies participating in the NORPAC operation.)

Pacific Oceanographic Group of the Fisheries Research Board of Canada


1956. Physical and Chemical Data Record, Approaches to Juan de Fuca Strait, 1936-1938. MSS Report. File N-7-1-3(1), November 15, 1956, Nanaimo.


(Contains reproductions of BT traces and a tabulation of meteorological data.)


1958. Physical, Chemical and Plankton Data Record, Coastal Surveys April 25 to December 17, 1957. MSS 17, Nanaimo.

(Contains reproductions of BT traces and a tabulation of meteorological data.)

1958. Physical and Chemical Data Record, North Pacific Surveys, Western Aleutians and Bering Sea, June 27 to August 14, 1958. MSS 28, Nanaimo.


1959. Physical and Chemical Data Record, Coastal Seaways Project, November 12 to December 5, 1958. MSS 36, Nanaimo.

(Contains reproductions of BT traces and a tabulation of meteorological data.)


1959. Physical and Chemical Data Record, Coastal Seaways Project, March 31 to April 22, 1959. MSS 47, Nanaimo.


1959. Oceanographic Data Record, Coastal-Seaways Project, June 8 to July 1, 1959. MSS 52, Nanaimo.
Pacific Oceanographic Group of the Fisheries Research Board of Canada


Vol. I, 1914 to 1934 Vol. XI, 1951
Vol. II, 1935 to 1937 Vol. XII, 1952
Vol. III, 1938 to 1939 Vol. XIII, 1953
Vol. IV, 1940 to 1941 Vol. XIV, 1954
Vol. VI, 1944 to 1945 Vol. XVI, 1956
Vol. VIII, 1948 Vol. XVIII, 1958
Vol. X, 1950
(These volumes contain tabulations of daily temperature, salinity and density (up to 1951) observations.

Paquette, Robert G., Eugene E. Collias, and Cuthbert M. Love


Queen, John and Wayne V. Burt
(This reference was not examined.)

Sands, Walter Casper
(Contains data from a few Catalyst (1935-36) stations off the Washington coast and Queen Charlotte Islands.)

Strickland, J. D. H.
(Contents are indicated by the title.)

Sverdrup, H. U., et al.
(The data from E. W. Scripps Cruise VIII includes stations off the Oregon coast.)
Tabata, S., C. D. McAllister, D. G. Robertson, and H. J. Hollister 1960. Data Record Ocean Weather Station "P" (latitude 50°00' N, longitude 145°00' W), January 21 - November 24, 1959. M.S. No. 59. Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo. (Also contains station data taken en route to and from Station "Papa" which are applicable to the area under consideration.)

Thompson, Thomas G., Bertram D. Thomas and Clifford A. Barnes 1934. Distribution of Dissolved Oxygen in the North Pacific Ocean. James Johnstone Memorial Volume, University of Liverpool. Also University of Washington Publications in Oceanography, Supplementary Series No. 21. (Contains temperature, chlorinity, oxygen, phosphate, density, carbon dioxide and silicate data from Catalyst (1932-33) stations off Washington and Vancouver Island coasts.)


U. S. Bureau of Fisheries 1921. Dredging and Hydrographic Records of the U. S. Fisheries Steamer Albatross 1911 - 1920. Bureau of Fisheries Document No. 897 (Appendix III to the Report of the U. S. Commissioner of Fisheries for 1920.) (Data collected off the Oregon-Washington coasts in 1914-15 are tabulated on pp. 82-113. These data are mostly bottom notations, surface and air temperatures.)


U. S. Coast and Geodetic Survey


U. S. Navy Hydrographic Office

(Some of the tabulated surface temperature and salinity data observed by naval vessels are applicable to the area under consideration.)

University of California, Scripps Institution of Oceanography

1935-1960- Daily Surface Water Temperature and Salinity at Shore Stations of Washington, Oregon, California and Baja California Coasts. Data Archives Scripps Institution of Oceanography.
(Tabulation of daily sea water temperature and at some stations daily salinity. Information available for Swiftsure, Umatilla, Neah Bay, Depoe Bay, Columbia River, Port Orford, Crescent City, and Blunts reef.)

(Includes tabulated oceanographic station data from the area off the Oregon-Washington coasts.)

(Contains tabulations of daily temperature, also means, maxima, minima, range and standard deviation. Stations in Oregon-Washington are included.)

(In this second volume the contents were changed and monthly means, 10-day means, maxima, minima, range and standard deviation are published.)


1957. Volume containing 1949 observations.
(Contains all available oceanographic data from the Pacific collected by several agencies, also maps slowing the number of BT observations available in the Pacific area. Both volumes contain data from the area under consideration.)
University of California, Scripps Institution of Oceanography, 
Marine Life Research

The following reports contain data from the Oregon Coast, i.e., north of 42°N latitude:

1949. Physical and Chemical Data, Cruise 2, March 28 to April 12, 1949.
1950. Physical and Chemical Data, Cruise 7, September 5 to September 18, 1949.
1950. Physical and Chemical Data, Cruise 8, October 3 to October 20, 1949.
1951. Physical and Chemical Data, Cruise 17, 5-19 August 1950.
1951. Physical and Chemical Data, Cruise 18, 6-22 September 1950.

University of California, Scripps Institution of Oceanography Manuscript Data.

Unpublished data from three Pioneer (1928) stations and from two Serrano (1949) stations off Oregon coast are available at Scripps Institution of Oceanography. Copies also on file at University of Washington, Department of Oceanography.

University of Washington, Department of Oceanography, Manuscript Data

Unpublished data from the following Brown Bear cruises are on file:
Cruise 202: September - October 1958, Coasts of Washington and Vancouver Island
Cruise 234: June - July 1959, Coast of Washington
Cruise 235: July 1959, Gulf of Alaska
Cruise 254: March 1960, Western Pacific
Cruise 265: June 1960, Washington Coast
Cruise 275: January 1961, Coasts of Oregon and Washington
Cruise 280: March 1961, Coasts of Oregon and Washington
Cruise 282: April 1961, Coast of Washington
Cruise 287: May 1961, Coasts of Oregon and Washington

Westley, Ronald E.
(Includes observations from Grays Harbor and Willapa Bay.)

Wyatt, Bruce and Richard Callaway
(Contains data from a line of oceanographic stations running from the entrance to Yaquina Bay to 25 miles offshore.)
B. ATLASES AND AVERAGE CONDITIONS

Deitch, Samuel
(There is no mention of from what data the means were taken.)

McGary, James W. and Thomas M. Naito
(A summary of average wind speeds in the Pacific north of 30°N. Conditions are portrayed by a series of five charts for each month.)

Dodimead, A. J.
(Contains charts and cross-sections of various properties measured during the subject cruises.)

Dodimead, A. J. and F. Favorite
(Contains charts and cross-sections compiled from data from twelve oceanographic cruises which took place during the subject period.)

Fofonoff, N. P.
1960. MSS 77 - contains 1955 data.
1960. MSS 78 - contains 1956 data.
1960. MSS 79 - contains 1957 data.
(These volumes contain a series of charts for various months of the year showing the following: atmospheric pressure, meridional component of Ekman transport, zonal component of Ekman transport, meridional component of total mass transport, integrated total transport, and integrated geostrophic transport.)

Leipper, Dale F. and Project Staff
(Contains graphical summaries of temperature conditions.)
Muromtsev, A. M.
(There is a supplement (atlas) in a separate volume. Main volume contains averages by ten-degree squares of temperature, salinity, density, and oxygen at various levels for most of the Pacific. The supplement contains charts and cross-sections of the above data.)

NORPAC Committee

Pacific Oceanographic Group, Fisheries Research Board of Canada
1959. Atlas of Physical and Chemical Data, North Pacific Surveys, January 20 to February 15, 1959. MSS Report Series, No. 50, Nanaimo. (Contains charts and cross-sections of various properties measured during the subject cruises.)

Patterson, J.
1933. Water Temperatures on the Pacific and Their Effect on the Weather of Canada. Proceedings of the 5th Pacific Science Congress, vol. 3, p. 1775. (Contains a table of normal sea-surface temperatures by five-degree squares for each week of the year along certain ship routes in the Pacific, based on observations from 1923-1932. There is also a table of departure from normal for each season of each year listed and graphs of mean temperatures and departures from normal.)

Robinson, Margaret K.
1957. Sea Temperature in the Gulf of Alaska and in the Northeast Pacific Ocean, 1941-1952. Bulletin of Scripps Institution of Oceanography, vol. 7, no. 1, pp. 1-98, University of California Press, Berkeley and Los Angeles. (The main feature of this work is a series of charts showing the average temperature at the surface and the 100, 200, 300- and 400-foot levels for each month. These charts are based on 16,000 BT observations taken over an eleven-year period. There is also a discussion of the methods used in processing the data and of the errors involved.

Sea Surface Temperature, Anomaly of Sea Surface Temperature and
Distribution of Observations (10-day period) Northeast Pacific.
(A series of charts showing the above-mentioned properties for
the 10-day period in the middle of each month. These were
issued by P.O.F.I. from October 1957 to December 1959.)

U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, San Diego
Biological Laboratory
Sea Surface Temperature Charts, Eastern Pacific Ocean.
(Starting with January 1960 issuance of similar charts was taken
over by the San Diego Biological Lab. Monthly charts are issued for
each month of the year covering the area 20° - 52° N, coast to 180°.
In addition, 15-day charts of surface temperature only are issued
April through October. These cover the area 25° - 52° N, coast
to 135° W.)

U. S. Navy, Chief of Naval Operations
(Contains monthly or seasonal charts of many surface and upper
air properties. Seasonal charts of air-sea temperature difference
are included.)

U. S. Navy Hydrographic Office
(One map for each month. Current roses for 5° squares. Also
shows surface temperature isotherms (every 5°F).

(Monthly contoured charts for each ocean.)

U. S. Weather Bureau
1938. Atlas of Climatic Charts of the Oceans. Weather Bureau No. 1247,
(Meteorological data are presented by means of monthly or seasonal
charts. Included are monthly charts of sea-surface temperature by
five-degree squares.)

Manuscript Data Purchased from National Weather Records Center,
U. S. Weather Bureau, by University of Washington, Department of
Oceanography and Oregon Fish Commission. Copies on file at
University of Washington Department of Oceanography.
Job No. 8110: Monthly mean air and sea surface temperature for
Marsden square 157 (45°-50°N, 125°-130°W) for the years 1937-1952
(months March through August only).
Job No. 9325: Similar data for 5 Marsden squares for 1937-1954
(all months) Square 158 (40°-45°N, 130°-135°W) is applicable to
area under consideration.
(No job number): Monthly mean sea surface temperature for a number
of Marsden squares in the Pacific for various years up to 1936
(all months). Squares applicable to this project include
40°-45°N, 120°-125°W; 40°-45°N, 125°-130°W; 40°-45°N, 130°-135°W
(No. 158); 45°-50°N, 120°-125°W; 45°-50°N, 125°-130°W (No. 157);
45°-50°N, 130°-135°W. Some data start in 1911.
University of California, Scripps Institution of Oceanography, Marine Life Research Program


C. BIBLIOGRAPHIES, DATA INVENTORIES, AND LITERATURE SURVEYS

Grier, Mary C.

Love, Cuthbert M.

Saur, J. F. T.

U. S. Navy Hydrographic Office
1958. Index to Oceanographic Station Data. Special Publication 12. Washington. (An index of all station data on file at the Hydrographic Office arranged by area. "North Pacific Ocean" includes the area under consideration.)

1960. Inventory of BT Data (National Oceanographic Data Center), World Wide, all Oceans and Seasons. Special Publication 12, (Part II). Washington. (Maps show number of BT observations available for each Marsden square for 3-month periods.)
1954. Puget Sound and Approaches, A Literature Survey
Vol. I, Geography, Climatology, Hydrology
Vol. II, Geology, Volcanology, Seismology, Geomagnetism,
Geodesy, Hydrography
Vol. III, Physical Oceanography, Marine Biology, General
Summary.
(Summarized, tabular and graphical information on the subjects
listed. There is a large bibliography on each subject.)

(This work is in the form of an abstract of the current
knowledge of each subject covered. The subjects include:
geography, climatology, hydrology, regional geology, geophysics,
recent sedimentation, hydrography, physical oceanography, and
marine biology. There are tables and a bibliography for each
section.)

(This work is in the form of an abstract of the current
knowledge of each subject covered. The subjects include:
geography, climatology, hydrology, regional geology, geophysics,
recent sedimentation, hydrography, physical oceanography, and
marine biology.)
SECTION II: BIOLOGICAL OCEANOGRAPHY
INTRODUCTION

For the Northeast Pacific Ocean there exists little information on the quantitative and qualitative distribution of the smaller pelagic organisms and the relation of that distribution to the environmental conditions. The effect of a large fresh water discharge into an otherwise wholly marine environment is virtually unknown. The influence of the Columbia River is of major importance in the seasonal, vertical and geographical distribution of plankton. Major research must be conducted first to determine the distribution of organisms and then to relate the effect of the Columbia effluent on the biological regime. Only then will it be possible to evaluate the local effects as the Columbia Plume changes in size and location throughout the annual cycle of runoff.

Because a study of the effects of the Columbia River on the distribution and productivity of plankton is a pioneering investigation, many references included in the present survey have been drawn from outside areas, with particular emphasis on the North Pacific Ocean. Included in the bibliography are references pertinent to methods of collection, analysis and identification of plankton. Some references are also given for research in other areas or on general plankton problems. References pertaining to studies made in the freshwater environment of the Columbia River and those on the contiguous littoral area have been largely excluded.

BIOLOGICAL REGIMES

Phytoplankton

Several studies have been made of phytoplankton composition and standing stock in the North Pacific Ocean, but unfortunately, most were based on net samples and therefore do not include the nanoplanlkton. Allen (1936) and Cupp (1937) have made extensive observations using surface net samples and have described some seasonal and geographic variations in the Northeast Pacific including Alaskan waters. At low latitudes of the North Pacific, there have been extensive studies of phytoplankton standing stock and productivity measurements (Holmes, 1958; Doty, 1960; McGary, 1960). Holmes has included some measurements seaward from the area of immediate Columbia River influence. From the 1958 cruise of the Vitiaz, Koblerntz-Mishke (1960) report measurements from one or two stations in or near the area of Columbia River effect plus many measurements from elsewhere in the North Pacific. However, these studies were not of a seasonal nature. To the north, the Pacific Oceanographic Group in Canada have made intensive measurements at Ocean Station PAPA (50°N, 145°W). Weekly studies during a six week period were made of plant nutrients, standing stock and rate of phytoplankton photosynthesis. Doty and Oguri (1957) and Shimada (1958) have reported daily fluctuations in productivity and chlorophyll content from 24 hour studies in the tropical Pacific. More general works on phytoplankton production and environmental factors in the oceans have been discussed by Steemann Nielsen (1960) and Sorokin (1959).
Zooplankton Studies

Relatively little has been done on the pelagic zooplankton of the Northeast Pacific Ocean with the exception of zooplankton volume measurements (Norpac Atlas, 1955) and a seasonal study of zooplankton volumes with qualitative enumeration of species off the coast of Washington (Frolander, unpub. Ms). Much of the work in the North Pacific has been in the direction of the relationship of plankton distribution to water masses (Aron, 1960; Beklemishev, 1960). Biere (1959) has described the distribution of 27 species of planktonic chaetognatha in the Pacific and their relationship to water masses. Johnson (1938) has made a study of the copepod Eucalanus elongatus Dana in which two subspecies were shown to overlap somewhat in distribution, but the division line was located near the latitude of the Strait of Juan de Fuca. McAllister (1961) conducted a study of the vertical distribution of zooplankton along with a seasonal study of the organisms in surface water at Ocean Station PAPA. He concluded that the zooplankton found there was representative of that in a wide area of the Gulf of Alaska.

Bays and Estuaries

The major bays and estuaries bordering the study area are the Strait of Juan de Fuca, Grays Harbor, Willapa Harbor and the entrance to the Columbia River. Smaller bays are found along the Oregon coast. The discharge from all of these bays can be expected to influence biological conditions seaward, the extent of the influence depending upon the amount and composition of the discharge. The University of Washington, Department of Oceanography (1954, 1955a, 1956b) has contributed literature surveys which include references to biological work done in Puget Sound and the Strait of Juan de Fuca, Grays Harbor, and Coos Bay, Oregon. Several references cited in these surveys and more recent unpublished work of this department establish some of the biological conditions to be expected in the Strait of Juan de Fuca. References to a surface phytoplankton survey, in connection with a pollution problem, and a beach survey are listed in the work on Grays Harbor. In Coos Bay, Oregon the major emphasis of biological work has been on benthos and littoral algae. At the present time, there is underway a seasonal study of primary production in relation to oyster production in Willapa Harbor (Westley, unpub.). Klement and Wallen (1960) have compiled a list of references on aquatic radiobiology which contains titles to many studies conducted on the fauna and flora of the Columbia River in relation to the Hanford Atomic Operations.

METHODS OF STUDY

General

A study of the Columbia River effluent and contiguous ocean areas from the biological standpoint involves coordinated investigations of both phytoplankton and zooplankton relative to environmental conditions. These investigations should include comparisons between coastal and offshore regimes, the seasonal influence, and vertical distribution. A primary difficulty encountered in marine plankton research is the selection of
suitable methods which will make possible comparison with other investigations. Recently, major attempts have been made to overcome these problems with international symposia directed at their solutions.

Especially significant among these was the "Symposium on Primary Production" held at Bergen in 1957. In October, 1961 a "Symposium on Zooplankton Production" will be held in Copenhagen. The most useful references listed in this section are Steemann Nielsen (1958) and Strickland (1960) on measurements of primary production and Braarud (1958) on microscopic examination and enumeration of phytoplankton organisms. At present, there is no up-to-date standard reference work that may be cited for zooplankton technique, and none will be available until the results of the Copenhagen symposium are published.

Identification of Organisms

Proper taxonomic identification is often very difficult in those areas where the biological composition is little known. The Pacific is still largely unknown but some significant guides are available. Cupp (1943) should prove to be especially useful for the identification of diatoms, Brodskii (1950) - copepods, Banner (1947, 1948 and 1950) and Boden, et al. (1955) - mysids and euphausiids; and Tesch - heteropods and pteropods. The literature survey by Grier (1941) contains many useful references pertaining to the identification of other groups of invertebrates which might be encountered. It should be stated that although there are great gaps in our knowledge of the taxonomy of plankton organisms, there is sufficient knowledge of the major taxonomic groups to justify comprehensive studies of plankton distribution.

Light Measurements

As light intensity is generally known to be one of the major limiting factors for phytoplankton production in temperate latitudes of the North Pacific Ocean, it is essential that it be measured in the various parts of the study area on a continuing basis. One of the simpler, but highly useful, measurements of light penetration into the sea can be made with a Secchi disc. This device is useful not only for obtaining the relative amount of light available to the organisms but also can be used to calculate the depth of the euphotic zone and might be indicative of the size of the standing crop, especially in offshore waters. More refined techniques, using underwater photometers, can be used to determine extinction coefficients more accurately and with the use of color filters to determine the spectral composition of light at different depths in the euphotic zone. These methods have been adequately reviewed and the significance of light to photosynthesis discussed by Holmes (1957) and Strickland (1958). Kimball (1928) has published tables for the computation of mean solar radiation at different latitudes but shipboard measurements of incident radiation by continuous recording are preferable.
## BIBLIOGRAPHY

**BIOLOGICAL REGIMES**

- A. PHYTOPLANKTON ........................................... 48
- B. ZOOPLANKTON ........................................... 51
- C. BAYS AND ESTUARIES ..................................... 54

**METHODS OF STUDY**

- A. GENERAL .................................................. 55
- B. IDENTIFICATION OF PLANKTON ORGANISMS .............. 57
- C. LIGHT MEASUREMENTS .................................... 60
BIOLOGICAL REGIMES

A. PHYTOPLANKTON

Allen, W. E.


Cupp, E. E.

Doty, M. S.

Doty, M. S. and M. Oguri
1957. Evidence for a Photosynthetic Daily Periodicity. Limnology and Oceanography, vol. 2, no. 1, pp. 37-40. (Description of a 5.7-fold variation in the ability of oceanic phytoplankton to photosynthetically fix carbon depending upon the time of day the productivity is determined.)

Fleming, R. H.

Holmes, R. W.
Kiselev, I. A.


Koblentz-Mishke, O. I.


Kon, H.

Lohmann, H.

McAllister, C. D., T. R. Parsons and J. D. H. Strickland
1960. Primary Productivity at Station "P" in the Northeast Pacific Ocean. J. Cons. Intern. Explor. Mer, vol. 25, no. 3, pp. 240-259. (Location 50°N, 145°W. Work done between 10 July and 21 August 1959 - to monitor summer productivity at a fixed point in the open ocean. Weekly measurements were made of all major nutrients, the standing crop of particulate organic matter and in situ rate of phytoplankton photosynthesis.)
McGary, J. W.

Parsons, T. R.

Ryther, J. H.
1960. The Plankton Ecology, Related Chemistry and Hydrography of the Sargasso Sea. Geographic Variations in Productivity. Bermuda Biological Station, Final Report to the Atomic Energy Commission. (A discussion of the manner and degree to which light and nutrients control and limit the rate of primary production in the sea. The range and magnitude of the process in representative parts of the ocean are considered.)

Scripps Institution of Oceanography, University of California.
Operation Wigwam, Report to the Scientific Director, Project 2.5, 1956. Effects of nuclear explosions on marine biology. Weapons Test Report WT-1013, La Jolla, California. (Contains chapters by different authors on phytoplankton and zooplankton investigations, midwater trawl surveys and uptake of radioisotopes by marine organisms.)

Semina, H. J.

Shimada, B. M.
1958. Diurnal Fluctuations in Photosynthetic Rate and Chlorophyll "a" Content of Phytoplankton from Eastern Pacific Waters. Limnology and Oceanography, vol. 3, no. 3, pp. 336-339. (Measurements were made of photosynthetic activity and chlorophyll "a" content of phytoplankton samples taken at regular intervals over a 46-hour period in May 1957.)

Sorokin, U. I.
Sorokin, U. I. and M. V. Kozlyaninob  
1957. The Determination of the Dependence of Phytoplankton Photosynthesis  
on Water Mass Illumination in the Sea of Japan and the Pacific  
Ocean. Reports of the Academy of Sciences, USSR, vol. 116,  
no. 5, pp. 863-865.  
(In Russian.)

Steemann Nielsen, E.  
(A general discussion of phytoplankton standing stock,  
productivity and factors governing production in the oceans.)

Steemann Nielsen, E. and E. Aabye Jensen  
1957. Primary Oceanic Production. The Autotrophic Production of  
(Measurements of primary production and interpretation of the  
data collected from the Galathea in the Atlantic, Indian and  
Pacific Oceans.)

Sverdrup, H. U.  
pp. 287-295.

Westley, R.  
Willapa Bay Hydrographic and Productivity Project. Washington  
Department of Fisheries, Shellfish Investigation.  
(Study in progress.)

B. ZOOPLANKTON

Aron, W.  
and Oceanography, vol. 4, no. 4, pp. 409-418.  
(Summary of midwater trawl studies in the North Pacific during  
the summer of 1957. Includes description of diurnal and  
geographic variations as related to oceanographic conditions.)

1960. The Distribution of Animals in the Eastern North Pacific and  
Its Relationship to Physical and Chemical Conditions.  
University of Washington, Department of Oceanography Technical  
(Results of three cruises during 1957 and 1958. Concerns the  
relationship which exists between physical and chemical  
conditions and the resident biological population obtained  
with a modified version of the Isaacs-Kidd midwater trawl.)
Bieri, R.
(Geographic extents of 27 species in the Pacific. A sharp boundary exists in the Eastern Pacific at 18° - 20°N latitude and is associated with temperature, O₂, and probably salinity gradients.)

Beklemishev, C. W.
(Description of some of the features important in the distribution of plankton in the North Pacific. Particular emphasis is placed upon the distribution of water masses.)

Beklemishev, C. W. and V. A. Burkov
(In Russian.)

Beklemishev, C. W. and E. A. Lubny-Gertsik
(In Russian.)

Beklemishev, C. W. and N. V. Parin
(In Russian. Discussion of the division of the North Pacific into the boreal region and tropical regions between which is a zone of mixed zoogeographical origin in the North Pacific Drift.)

Beklemishev, C. W. and H. J. Semina

Bogorov, V. G. and M. E. Vinogradov
(In Russian.)

Frolander, H. F.
Quantitative Estimation of the Seasonal Variations of Zooplankton off the Coast of the State of Washington. University of Washington, Department of Oceanography, unpublished manuscript.
(Seasonal studies of zooplankton volumes and qualitative net samples, July 1956 to February 1958.)
Graham, H. W.
(North of 40° or 45°N there is abundant plankton which extends in the east, southward along the west coast of North America. In the South Pacific bordering Antarctica abundant plankton population extends in the east, northward along the west coast of South America. The rest of the South Pacific and tropical Pacific have medium quantities while the central part of the north Pacific supports a poor population. Differential distribution of plankton appears to be caused by variations in the vertical stability of the water.)

Hida, T. S.
(Chaetognaths occurred in greatest abundance in the subtropical zone; Pteropods were an important constituent in both subtropical and transition zones.)

Johnson, M. W.
(E. bungii bungii occurs in more northern waters, but overlaps with E. bungii californicus, a more southern variety. E. bungii bungii is capable of reproducing in Bering Strait within the Arctic Circle. Only larvae of the southern variety have been identified in the waters south of the Straits of Juan de Fuca. E. bungii bungii seems to be dominant off the Straits of Juan de Fuca - southern limit not established.)

Lea, H. E.
(Purpose was to determine species and distribution. Collections were made in the summers of 1953 and 1954 in 11 regions along the British Columbia coast.)

Marumo, R.
(Gives four examples where plankton populations in the western North Pacific are used as well as temperature and chlorinity in the identification of water masses.)

McAllister, C. D.
(Location: 50°W - 145°W. Compares this station with other areas; vertical distributions; seasonal cycle at the surface; pronounced diurnal variation in the concentration of surface zooplankton. Zooplankton abundance at Station "P" appears representative of that in a wide area of the central Gulf of Alaska.)
Nakai, Z.
(In Japanese.)

(Area: 6° - 54°N from May to July, 1952. Found much greater quantities of macroplankton in the northern area than in the southern. None of the species which occurred during this study were common to both areas.)

Nakai, Z. and K. Honjo
(Area: Waters adjacent to the Aleutian Islands. The quantitative distribution of plankton from net hauls and from plankton found in salmon stomachs. Mostly copepods occurred in the net hauls while Thysanoessa was abundant in the salmon stomach contents.)

Oceanic Observations of the Pacific,

South Pacific Fishery Investigations
1952 - # 73, 37 pp.
1953 - #100, 41 pp.
1954 - #125, 54 pp.
(Plankton volume data.)

Thrailkill, James R.
(An atlas-type publication containing maps showing plankton volumes for various months from March 1949 - December 1955 off the west coast of U. S. and Baja, California. Some of the earlier maps cover the Oregon coast.)

C. BAYS AND ESTUARIES

Klement, A. W. and I. E. Wallen
(Contains many references to radiobiological work done in the Columbia River with reference to Hanford operations.)
University of Washington, Department of Oceanography
(Contains a summary, with references, of biological studies made within Puget Sound and approaches to it.)


METHODS OF STUDY

A. GENERAL

Bogorov, B. G.
(Recommendations concerning the collection and treatment of both phytoplankton and zooplankton in order to make different studies comparative.)

Braarud, T.
(Discusses suitable methods for satisfactory numerical estimation of oceanic plant communities.)

Creitz, G. I. and F. A. Richards
(Concerns the use of membrane filters in the Richards with Thompson (1952) method of estimating plankton pigments.)

Fleming, R. H.
(Discusses: 1. Ratios between essential constituents of marine organisms; 2. Rational units for reporting quantities of plankton and numerical relationships between these units. Literature review; table of plankton equivalents: C: N: P ratios and quantitative methods.)

Gillbricht, M.
(Discussion of particulate matter (seston); Detrital chlorophyll.)
Goldberg, E. D., M. Baker and D. L. Fox
(Method for the determination of total suspended particulate matter.)

Lund, J. W. G. and J. F. Talling
(Among 800 references, many of which deal with studies on marine problems.)

Palmer, C. M. and T. E. Maloney
(Description and use of a new slide for counting very small organisms.)

Richards, F. A. with T. G. Thompson
(A semimicro spectrophotometric method is described for the estimation of chlorophyll a, b and c and of astacin and nonastacin type carotenoids.)

Steemann Nielsen, E.
(A discussion of the oxygen and carbon-14 techniques for investigation of the production of organic matter by phytoplankton.)

Strickland, J. D. H.
(A comprehensive discussion of the techniques used in phytoplankton research.)

Strickland, J. D. H. and T. R. Parsons
(The format of this manual is designed specifically for the instruction and use of analysts undertaking established or new oceanographic chemical analyses under operational conditions. Basic working instructions are given in detail.)
B. IDENTIFICATION OF PLANKTON ORGANISMS

Banner, A. H.


Boden, B. P., M. W. Johnson and E. Brinton
1955. The Euphausiacea (Crustacea) of the Northern Pacific. Bulletin of Scripps Institution of Oceanography, vol. 6, pp. 287-400. (Taxonomy on a "wide geographic basis". Area: Columbia River, south to below the tip of Baja California plus material from elsewhere in the Pacific. Includes descriptions, distributions and taxonomy.)

Brodskii, K. A.

Clemens, W. A. and G. V. Wilby
1946. Fishes of the Pacific Coast of Canada. Fisheries Research Board of Canada, Bulletin 68, 368 pp. (The systematics, distribution, life histories and illustrations of the fishes of the Pacific Coast of Canada, complete with a key to family and species. New edition is imminent.)
Cupp, E. E.
(Description of centric diatoms likely to be found in the northeast Pacific Ocean.)

Davis, C. C.
(Area: San Francisco Bay to the Aleutians including inland waterways of Washington and British Columbia. Taxonomic with keys and figures.)

Gran, H. H. and E. C. Angst
(Description of a small number of plankton diatoms found in the Puget Sound region.)

Grier, M. C.
(Bibliography of publications pertaining to oceanography and biology.)

Hustedt, F.
(Description of the centric diatoms of European regions many of which apply to the Pacific Ocean region.)

(Description of the pennate diatoms of European regions many of which apply to the Pacific Ocean region.)

Kokubo, S.
(Author draws material from many sources and therefore the book represents a good starting place for the identification of various diatoms from the Pacific Ocean area.)

McGowan, J. A.
(Identification of Pteropods.)
Scheffer, V. B. and J. W. Slipp
(Contains a checklist of whales and dolphins of Washington waters, description of shore whaling industry, notes on anatomy and behavior and a key to the Cetaceans of the West Coast of North America.)

Schiller, J.
(Description of the dinoflagellates of the European area. Many of the organisms described occur in the Pacific region.)

(Description of the flagellates of the European area. Many of the organisms described occur in the Pacific region.)

Tattersall, W. M.

Tesch, J. J.
(Identification of Pteropods.)

(Identification of Pteropods.)

1949. Heteropoda. Dana Report No. 34, Fig. 1-44, Pl. I-V.
(Identification of Heteropoda.)

1950. The Gymnosomata; II. Dana Report No. 36.
(Identification of Pteropods.)

Wailes, G. H.
1929. The Marine Zooplankton of British Columbia. Museum (Vancouver) and Art Notes, vol. 4, no. 4, pp. 159-165.

(Taxonomic description of the Sarcodina of the Northeast Pacific Ocean.)

(Taxonomic description of the Mastigophora of the Northeast Pacific Ocean.)

(Taxonomic description of the Ciliata and Suctoria of the Northeast Pacific Ocean.)
Wilson, C. B.

C. LIGHT MEASUREMENTS

Holmes, R. W.

Kimball, H. H.
1928. Amount of Solar Radiation that Reaches the Surface of the Earth on the Land and on the Sea and the Methods by which it is Measured. Monthly Weather Review, vol. 56, pp. 393-398. (Author wants to determine if knowledge of meteorological conditions over the oceans, and of the relation between meteorological conditions and solar radiation intensities at the surface of the earth, is not sufficient to enable us to compute mean solar radiation intensities for different latitudes. He concludes that with reliable climatological data the radiation intensity over the ocean can be computed with reasonable accuracy.)

Lane, R. K., J. Butters, W. Atkinson and H. J. Hollister
1961. Oceanographic Data Record. Coastal and Seaways Projects, February 6 to March 2, 1961. Fisheries Research Board of Canada, MSS Report Series, No. 91, 128 pp. (Physical and chemical observations from 48° to 55°N and the coast to 141°W. Secchi disc observations at each station.)

Strickland, J. D. H.
SECTION III: GEOLOGICAL OCEANOGRAPHY
Physiography

From east to west across the Pacific Northwest are the broad north-south bands of the Cascade Mountains, the Puget-Willamette Lowland, the Coast Ranges, and a very narrow coastal plain. The Columbia River which drains over 200,000 square miles east of the Cascades flows across these four physiographic sections along the Washington-Oregon state line. Only the coastal plain and western slope of the Coast Ranges have direct significance on the present study from the aspect of marine geology. The Puget-Willamette Lowland, the Cascade Mountains, and the plateau country to the east, however, are drained by, and thus affect, the flow and composition of the Columbia River.

The drainage basin hydrology is discussed in Section I.

Regional Geology

The Coast ranges are composed of Lower to Middle Tertiary sediments, mainly fine to coarse clastic rocks with volcanic detritus in part, but including debris of plutonic rocks derived from the east. The sequence is marine with thick units showing graded bedding. To the east the units grade into littoral, brackish, and continental sediments. Interbedded pillow volcanics are present in the Eocene and Oligocene parts of the sequence. The seaward-dipping Tertiary to Recent strata forming the coastal plain are also composed of slightly folded and faulted clastic sediments and volcanics.

Economic Geology and Geography

Farming, mining, and lumbering are the three basic industries in the economy of the Columbia River Basin. These activities affect the local composition of dissolved solids and sediments. Of particular importance are beach-placer deposits of chromium, platinum, and associated heavy metals along the coast of southwestern Oregon (Day and Richards, 1906; Griggs, 1945). The processing of silica sand (Wilson, Skinner, and Couch, 1942) might also have some affect on the sediment type distribution. Perhaps of greatest importance, however, are various phases of the lumber industry (Freeman and Martin, 1951) which the sawdust, wood chips, or pulp processing by-products might locally affect the composition of suspended and dissolved solids in the river water. The effect of numerous dams on the Columbia River was noted in Section I.

Coastal Estuaries

The largest estuaries along the coast, omitting the Columbia River, are Grays Harbor and Willapa Bay in southwestern Washington. Very little information is available on sediments and physical conditions in Willapa Bay; however the literature available on neighboring Grays Harbor has been
collected and summarized by the Department of Oceanography, University of Washington (1955b). The inner harbor is poorly sampled. A similar summary by the same organization (1955a) of previous investigations is available for Coos Bay, Oregon.

The coastal plain is less than ten miles wide along much of the area and reaches a maximum of about 20 miles in width near the Columbia. For some distance north and south of the mouth of the Columbia there are long stretches of sandy beach with associated belts of dunes. Bays or estuaries are partly cut off from the sea by spits and bars of sand. Although a few prominent headlands interrupt the shoreline near the Columbia and along parts of the Oregon coast, steep sea cliffs, 50 to 300 feet high, face the sea along most of the northern two-thirds of the Washington coast. At the base of the cliffs is a rocky platform, up to two miles in width, which is usually exposed at low tide.

Inland from the coastal plain in the north are the Olympic Mountains, about 4,000 square miles of ridges rising to 8,000 feet near the center. South of the Olympics are low hills and irregular lowlands to the Columbia River, beyond which are the Coast Ranges of Oregon rising from a level of 1,700 feet in the north to 3,500 feet in the south (Pennesman, 1931).

SEDIMENTS

Columbia River

The relation of the rocks forming the valley of the Columbia to the sediment carried by the river is at present uncertain. The sedimentary and volcanic formations in the valley comprise one of the most nearly complete records of the Late Cenozoic terrestrial history of the Western United States (Lowry, 1952). General discussions of the geology are also included in the works of Bretz (1919) and Hodge (1938).

The bulk of the knowledge of sediment transport by the Columbia River is in reports on file with the Portland District, U. S. Army Corps of Engineers. Sediment concentrations in the Willamette River and its tributaries have been measured, and low rates of transport have been realized (U. S. Army Corps of Engineers, 1954). Measurements of sediment concentration and relation to discharge have been made at some localities on the Columbia, as at Vancouver, Washington (U. S. Army Corps of Engineers, 1961), but the most intensive study has been along the lower 60 miles of the river. These studies included current speed and direction, temperature, and salinity measurements along seven ranges across the river (U. S. Army Corps of Engineers, 1960a, 1960b; Committee on Tidal Hydraulics, 1960) and together with bottom samples will form the basis for a movable-bed model of the lower part of the Columbia River to be constructed at the Waterways Experiment Station, Vicksburg, Mississippi. Preliminary interpretations of these measurements have helped define the environmental conditions associated with shoaling at the mouth of the Columbia (Lockett and Kidby, 1961). The importance of the salt water intrusion in regards to river flow and sediment dispersal, especially shoal formation, is now generally realized. A discussion of this particular aspect of sedimentation is given in several works (Lockett and Kidby, 1961; Schultz and Simmons, 1957). The history of the jetties at the mouth of the Columbia
reveals the degree of changes in shoaling and the shifting of the isobaths with time as erosion and deposition alter the bottom near the Columbia (Hickson and Rodolf, U. S. Army Corps of Engineers, 1938).

Textural and mineralogical studies of bottom samples from the lower part of the Columbia and its tributaries are presently in progress by the Geology Section of the Portland District, Corps of Engineers.

**Beach Sediments**

Most of the previous investigations of the beach sediments along the Washington-Oregon coast have been associated, directly or indirectly, with the so-called "black sands". These sands are local concentrations of certain dark, heavy minerals, mainly magnetite, ilmenite, and chromite. Typically, the reports describe the type of deposit, mineralogy, origin, and distribution (Griggs, 1945; Honar, 1918; Pardee, 1934). The most comprehensive reports are a series on the Oregon coast by Twenhofel (1943, 1946a, 1946b, 1946c). According to Twenhofel, the black sand deposits are found on present beaches and in deposits beneath elevated coastal plains. Prevailing southwesterly winds concentrate the sand south of the promontories or at the north side of embayments. Fluctuations in sea level caused changes in the position of embayments and promontories with resultant changes in deposition of black sands. These studies have included examination of coastal physiography, roundness, sorting, and size distribution of beach sands, heavy mineral determination, and investigations of streams discharging along the coast. All of the previous studies of the beach sediments, most of which deal only with the Oregon coast, are of a general reconnaissance nature and none have included considerations of wave, current, and surf conditions except in broadest generalities. Exceptions to this, however, are provided by the beach and surf studies of Bascom and McAdam (1947) and Isaacs (1947) which include numerous photographs of conditions in early autumn and late summer, respectively. Sedimentologic investigations of some Oregon beaches are presently being pursued by the Department of Geology, University of Wisconsin.

Along most of the Oregon and southwestern Washington coasts are large dune masses which on the coast of northern Oregon are related to the mouths of bays and rivers. Each dune mass originally consisted of a massive parabolic complex built by the southwest winds of winter. The rising sea has since eroded large parts of these masses. A transverse-ridge pattern has developed on the coastal dune sheets of Oregon wherever the shore is bordered by a level strip free from obstacles. The ridges lie essentially at right angles to the northerly sea breeze of summer. Winter winds partially destroy these ridges but, because of the wetness of the sand, cannot establish a corresponding system of their own (Byrd, 1950; Cooper, 1934, 1953, 1954, 1958).

**Offshore Sediments**

Knowledge of sediments off the coast of Washington and Oregon is extremely limited. Bottom type designations on U. S. Coast and Geodetic Survey charts furnish most of the information available for the narrow continental shelf, although studies are underway for regions off the Oregon
coast by the Department of Oceanography, Oregon State University. Preliminary analysis made at the Department of Oceanography, University of Washington, of a few bottom samples from the area indicate a sandy texture for much of the shelf sediment. Locally, as near the Strait of Juan de Fuca, large areas of gravel are found, but mud is the most commonly reported sediment. Additional sources of information are samples taken on the seventh cruise of the Carnegie (Revelle, 1944), on Scripps' Operation Northern Holiday (Wooster, 1951), and Scripps' Cascadia Expedition (Menard, 1955).

Approximately 300 miles offshore is a northward-trending seamount chain (Nayudu, 1961), on which Cobb Seamount is a prominent feature. This appears to be a pre-Late Eocene volcano which has been terraced by wave abrasion and subsequently subsided about 500 fathoms (Budinger, 1957). This seamount chain forms a barrier for terrigenous material. It is believed that the large area of sedimentation between the seamount chain and the mainland is a result of the retaining effect of the chain. The sedimentation area becomes deeper toward the south where exits occur around the southern end of the seamount chain (Menard, 1955). Not only are terrigenous sediments present in the area (Menard, 1953; Tyler, 1951), but also there are some sediments with abundant pelagic components, as Globigerina-rich silts and clays (Nayudu, 1959).

Foraminifera

A reconnaissance survey of papers relating to foraminifera present in the Washington-Oregon coastal waters is included. More than 60 of the 80 reports deal with Recent benthonic and pelagic foraminifers, although only a few deal specifically with the area under study (Cushman and Todd, 1947; Detling, 1958; Jarman, in progress). Most of the remaining papers describe Cenozoic foraminifers from the coastal formations. Research on the foraminifers of the Northeast Pacific Ocean is in progress at the Department of Oceanography, University of Washington (Embysk, 1961; Smith, 1961).

MAPS AND CHARTS

A list of maps and charts is included. Most of these are geologic maps published in various series by the U. S. Geological Survey, but also included are river and harbor charts published by the U. S. Army Corps of Engineers and charts of the U. S. Coast and Geodetic Survey.
BIBLIOGRAPHY

HINTERLAND .......................................................... 67

A. PHYSIOGRAPHY ...................................................... 67

B. REGIONAL GEOLOGY ............................................... 68
   (1) General ....................................................... 68
   (2) Petrology .................................................... 71
   (3) Stratigraphy ................................................ 73

C. ESTUARIES .......................................................... 76
   (1) Coos Bay ..................................................... 76
   (2) Grays Harbor ................................................ 78

SEDIMENTS ............................................................. 80

A. COLUMBIA RIVER .................................................. 80

B. BEACH SEDIMENTS ............................................... 84

C. OFFSHORE SEDIMENTS .......................................... 88

D. FORAMINIFERA ................................................... 94

MAPS AND CHARTS .......................................................... 97
HINTERLAND

A. PHYSIOGRAPHY

Atwood, Wallace W.

Buwalda, J. P.

Dicken, S. N.

Fagerlund, G. O. and F. I. Fagerlund

Fenneman, N. M.
(General description and discussion of area.)

Grover, Nathan C. and Glenn L. Pacher
(Stream-flow records in Washington up to 1919 representing an aggregate of 1,120 years at 209 gaging stations are summarized in Water-Supply Paper 492. Similar records for the period October 1, 1919 to September 30, 1935, representing an aggregate of 1,470 years at 203 gaging stations, are summarized in this volume.)

Smith, Warren D.
(Describes shoreline processes and evaluation of the coast as well as individual inlets and bays.)

(Describes shoreline processes and evolution of the coast as well as individual inlets and bays. Includes Coos Bay area in discussions.)


(Describes the coastal area.)
U. S. Geological Survey


B. REGIONAL GEOLOGY

(1) General

Allen, John Eliot and Ewart M. Baldwin
1944. Geology and Coal Resources of the Coos Bay Quadrangle, Oregon. State of Oregon Department of Geology and Mineral Industries, 157 pp. (Describes in detail the stratigraphy, paleontology and structure in the Coos Bay Area. Latter part of bulletin is concerned primarily with the coal deposits of Eocene Age to present.)

Arnold, Ralph

Baldwin, E. M.

Bostwick, D. A.

Butler, G. M. and G. J. Mitchell

Danner, W. R.

Diller, J. S.

(Describes topography, marine benches, alluvium, Empire (miocene), Arago (Eocene) divided into Coaledo (younger) coal member and Pulaski (older). Coaledo contains brackish water fossils, Pulaski very few. Coal in basins. Two geologic maps, many cross and stratigraphic sections.)

(Topography of the Pacific Coast and Coos Bay quadrangle. Sedimentary rocks - myrtle (Cretaceous) Pulaski (Eocene), Coaledo formation (development and structure of coal seams) Empire (Neocene). Coos Conglomerate and marine sands of Pleistocene age. Igneous rocks - serpentine and basalts. Gold has been found in Pleistocene sand deposits.)


Dodds, R. Kenneth

Geology and Stratigraphy of the Astoria, Svenson, Cannon Beach and Saddle Mountain Quadrangles, Oregon. U. S. Army Corps of Engineers field work nearly completed.

Dott, Robert H., Jr.
(Describes sedimentary features in clastic formation exposed in sea cliffs. Suggested origin of features is slumping and turbidity currents.)

Duncan, D. C.

Foster, R. J.

Freeman, O. W. and H. H. Martin
Howard, John K.

Koch, John G.

Oles, K. F.

Shenon, P. J.
1933. Geology and Ore Deposits of the Takilma-Waldo District, Oregon. U. S. Geological Survey Bulletin 846-B. (Describes the mineral (and relations to the geology) of the area.)

Snavely, Park D., Jr. et al.

Treasher, R. C.


Washburne, C. W.

Weaver, Charles E.

Wells, F. G., P. E. Hotz and F. W. Carter

Widnmer, John M.

Wilkinson, W. D. and W. D. Lowry and E. M. Baldwin
(2) Petrology

Allen, John Eliot

Allen, Victor T. and Robert L. Nichols


Brown, R. E.
1942. Some Manganese Deposits in the Southern Oregon Coastal Region. State of Oregon Department of Geology and Mineral Industries Short Paper No. 9

Campbell, C. D. and S. K. Runcorn
(The remanent magnetization of late-tertiary lavas in seven sections of Columbia River basalts has been examined. At least three field reversals during their eruption are indicated.)

Cook, Earl Ferguson

Day, David T. and R. H. Richards

Diller, J. S.

Felts, Wayne M.

Granquist, Donald Paul

Griggs, H. B.

Hill, Myron Donald
Kaiser, William

Kauffman, Albert J., Jr.
(Includes discussion of industrial minerals - quantity and location in Oregon and Washington.)

Kelly, Hal J., Henry M. Harris and Herbert G. Schlinker

Laval, William Norris
(Brief description of structures and lithology of basalt in south-central Washington.)

McHenry, J. R.
(Six samples of agriculturally valuable land in the Puyallup were found to have high phosphate-fixing ability. A series of laboratory determinations were subsequently run.)

Popoff, C. C.
(The most valuable clays are confined to a 50-foot bed overlying volcanic breccia; both formations presumably are of early Tertiary age.)

Ramp, Len

Schlinker, Herbert G.

Smith, Thaddeus Oliver

(Includes descriptions of the Coos Bay area, topography, geology and climate.)
Wells, F. G., L. R. Page, and H. L. James

Wilson, Hewitt, K. G. Skinner, and A. H. Couch

Youngberg, E. A.

Zvanut, Frank Joseph

(3) Stratigraphy

Anderson, F. M.
1958. Upper Cretaceous of the Pacific Coast. Geological Society of America Bulletin, Memoir 71, 378 pp. (Upper Cretaceous sequences occur from Mexico to British Columbia. The Oregon-Washington sequences are similar to those in Baja California but in neither area are the thicknesses comparable to the California region. In the whole region, Upper Cretaceous seem to rest unconformably on various Lower Cretaceous or old rocks. Five hundred and four species of invertebrates were recorded.)

Arnold, Ralph and Harold Hannibal
1913. The Marine Tertiary Stratigraphy of the North Pacific Coast of America. Proceedings of the American Philosophical Society, vol. 52, no. 212, pp. 559-605. (Describes formations in the Grays Harbor area with maps and lithology. Also describes Coos Bay area with maps and lithology.)

Brown, R. D., Jr., P. D. Snavely, Jr., and H. D. Gower
1956. Lyre Formation (redefinition), Northern Olympic Peninsula, Washington. American Association of Petroleum Geologists Bulletin, vol. 40, no. 1, pp. 94-107. (Detailed geologic mapping in the Northern Olympic Peninsula has shown the Lyre formation can now be divided into two mappable units. Strata are conglomerate, sandstone and siltstone. Once thought to be Oligocene, they are now defined as early Eocene.)

Dall, William H. and Gilbert D. Harris
Dott, R. H., Jr.

Durham, J. W.
(Early Tertiary poles and continents were in approximately the same position as at present. In Paleocene, the 20°C marine isotherm was north of 49°N lat. Beginning its shifting south in Middle Oligocene, it reached its present position by Middle Pliocene. Since then it has oscillated back and forth.)

Etherington, Thomas John

Grosvenor, Edward Rickman

Hendriksen, D. A.
(Physiography and topography briefly discussed.)

Hertlein, Leo G. and Colin H. Crickmay
(Includes Coos Bay and Grays Harbor formation.)

Howe, Henry V. W.
(Distribution, description and fossil content of the Empire formation and overlying Coos conglomerate. Gives faunal proof of Pliocene age of both.)

Imlay, Ralph W., et al.
(Concerns formations - Myrtle, Riddle and Days Creek. Some of the Myrtle mapped by Diller is excluded and reassigned to the Dothan formation. The Riddle is 1000' siltstone of the latest Jurassic above which lies 2000' of the Days Creek - massive sandstone and siltstone.)

Natland, M. L.
Park, C. F., Jr.
(It is concluded that the structure of the Peninsula is not a simple anticline (as previously concluded) and that rock formation which has been called the Solduc formation includes material of Oligocene and possibly younger age.)

Rau, W. W.

Schenck, Hubert G.
(General discussion of Oligocene in Oregon, relation of Oligocene to Eocene, includes stratigraphy of Coos Bay district.)

(General discussion of oligocene stratigraphy in Western Oregon including Eugene district, Coos Bay, Yaquina, Alsea Bay districts.)

Snavely, P. D., Jr.
(The name McIntosh formation is proposed for more than 4000-5000 feet of dark gray marine siltstone and claystone, and interbedded achoric and basaltic sandstone which crops out in the Centralia-Chehalis coal district, Lewis and Thurston Counties, Washington.)

(Short, general discussion of the stratigraphy and economic possibilities of the area.)

Turner, F. E.
(Contains a description of the Cape Arago section exposed along the ocean front south of Coos Bay. Invertebrate faunal list plus fossil localities also included.)

Weaver, Charles E.
(Detailed report on area including maps, diagrams, and sections.)

(Correlation chart with annotations describing local areas along Washington-Oregon coast.)
Weaver, Charles E.
(Detailed discussions of Tertiary strata exposed along ocean front in Coos Bay area.)

C. ESTUARIES

(1) Coos Bay

Brown, Stuart G. and R. C. Newcomb
(Contains extent of dunes, rainfall, runoff and storage, evaporation and storage, ground water, and physical description of sands.)

University of Washington, Department of Oceanography

U. S. Army Corps of Engineers
(Ten curves for survey obtained between 1952 and 1954.)

(1949 through 1954 summarized for this survey.)

U. S. Army Corps of Engineers

1926. Entrance Surveys of March and October with Cross Sections showing Amount of Material Excavated and a profile along Charnel Range. Portland, Oregon District, File No. CB-1-138.


1928. Progress Profile, South Jetty and North Getty. Portland, Oregon District, Map No. CB-1-163.


Williams, Howel

(2) Grays Harbor

Department of Oceanography, University of Washington

Henderson, J. R.

Port of Grays Harbor
(Concerned with the condition of the harbor, dredging, bar formation, and cargo. Diagrams, maps, and photos.)

(Concerned with dredging, surveys, and initial current surveys, no data presented. Diagrams, maps, and photos.)

(An annual report containing data on dredging, damage by storms, etc., vessel statistics.)

U. S. Army Corps of Engineers


(Samples described in text.)

(Geomorphology, composition of beach and offshore zones, tides, local and offshore winds, waves and swells, storms, and their effect, shore-line changes, offshore depth changes shown in tables, figures, and plates.)

Model Study of Grays Harbor and Point Chehalis, Washington. Waterways Experiment Station, Vicksburg, Mississippi, (type-written).

1951. 2nd Interim Report in 1 vol.
1951. 3rd Interim Report in 1 vol.
1952. 5th Interim Report in 3 vols.

(Discusses results and shows data in the form of photos of patterns made by time exposures of surface current directions. Tables and plates also included.)

1954. Grays Harbor and Chehalis River, Washington, Design Memo No. 3--West Shore Revetment at Point Chehalis. On file Seattle, Washington District, 14 pp. (Recent erosion studies and sounding lines shown presenting history of change in bottom topography about Point Chehalis.)

n.d. A Set of Four Photographs Showing the Changing Shape of the Spit North of the South Jetty at Grays Harbor, 1900-1942. Original data Seattle, Washington District. (Photos obtained by cutting cards to the outline of the spit found on various maps of the spit and racking them in proper order, from 1900 to 1941. These racked cards were then photographed.)


n.d. Point Chehalis, Computation of Erosion. Original data on file Seattle, Washington District. (Result of study shows net accretion 1936-1940 was 515,057 cu. yds.; net erosion 1940-1945 was 6,527,193 cu. yds.)
SEDMENTS

A. COLUMBIA RIVER

Allen, John Eliot

Allen, John E.

Barton, Manes

Bretz, J. Harlen
1919. The Late Pleistocene Submergence in the Columbia River of Oregon and Washington. Journal of Geology, vol. 27, no. 7, pp. 489-506. (Reviews previous references to a Champlain submergence in the lower drainage of the Columbia River and tries to eliminate erroneous interpretations and correlate data character and extent of the submergence with the Pleistocene history of northwestern Washington.)

Clarke, Frank Wigglesworth

Columbia Basin Inter-Agency Committee on Water Pollution

Committee on Tidal Hydraulics, U. S. Army Corps of Engineers
1960. Present and Potential Channel Maintenance Problems in Lower Columbia Estuary. pp. 1-13 plus 30-page discussion. (Comments and recommendations by the committee after examining results of 1959 prototype study, include jetty rehabilitations, problems of shoaling, selection of spoil areas, and extent of salt-water intrusion. Suggests model study.)

Foster, R. F.
Gottschalk, L.

Hickson, R. E. and F. W. Rodolf

Hodge, Edwin T.
1938b. Geology of the Lower Columbia River. Geological Society of America Bulletin 49, no. 6, pp. 831-930. (Describes the general geology of the lower Columbia River and shows how the river came to have its present course through the Cascade Mountains.)

Holdridge, Claire P.

Kelly, J. V.

Landes, Henry (and others)

Lockett, J. B.
Lockett, J. B. and H. A. Kidby
(Modern methods of measuring flow characteristics of the Columbia River entrance system define the environmental conditions affecting the problem of shoaling in the entrance area and reveal phenomena which appear to have important significance relating to this problem.)

Lowry, W. D.
(The formations present in the valley of the Columbia River constitute one of the most nearly complete records of the late Cenozoic terrestrial history of Western America. The area discussed extends from the Cascade Mountains on the east to the Pacific Ocean. It includes the lower Columbia River Valley and the Willamette Valley as far south as Salem.)

Mundroff, Maurice John
(Although stressing mainly the water yield of the area, this paper gives an insight into the geology of Clark County - both igneous and sedimentary.)

Schultz, E. A. and H. B. Simmons
(Describes various types of saline wedges as related to mixing in the estuary. Describes various types of shoals formed, including deposition at mouth of Columbia River.)

U. S. Army, Corps of Engineers
(Charts showing location and amount of material in disposal areas from 1950-1960, below mi. 57.)

(Discussion of jetty construction at mouth of Columbia, with profiles of jetties and sounding charts of river entrance in 1851, 1885, 1913, 1937.)
U. S. Army, Corps of Engineers


1961. Sedimentation Investigation Lower Columbia and Lower Willamette Rivers, July 1959-August 1960. On file District Library, Portland, Oregon, pp. 1-17 plus charts and graphs. (Sediment concentration curves, total load, suspended material relations to discharge. Measures at Hood River, Vancouver (Columbia), and Newberg (Willamette).)

U. S. Bureau of Reclamation

U. S. Geological Survey
Walker, F. C. and W. H. Irwin

Williams, I. A.

B. BEACH SEDIMENTS

Baldwin, Ewart M.
(Describes marine terraces in Coos Bay area and Cape Blanco.)

Bascom, Willard N.
(A series of diagrams is presented which illustrates the variability of sand size and beach-face slope and the relationship between the two as observed on 20 Pacific Coast beaches.)

Bascom, Willard and Donald McAdam
(Includes profiles, surf conditions, tire impressions, sand samples, and water table profiles. Data for Humboldt Bay, Coos Bay, and Grays Harbor areas. Large number of photos obtained in survey which were not included in the report.)

Byrd, Nathan L.
(Study of dune vegetation in an area north of Coos Bay. Environmental factors studied.)

Cooper, William S.
(Describes sand dunes and types of dunes. Coos Bay dunes used as an Oregon example.)

(The transverse-ridge pattern is richly developed on the coastal dune sheets of Oregon wherever the shore is bordered by a level strip free from obstacles. The ridges lie essentially at right angles to the north-northwest sea breeze of summer.)
Winter winds partially destroy these ridges but, because of the wetness of the sand, cannot establish a corresponding system of their own. Slow motion photographs of smoke streams are included.

Cooper, William S.
(The important dune masses on the coast of northern Oregon are related to the mouths of bays and rivers. Each originally consisted of a massive parabola complex built by the southwest winds of winter. The rising sea has since eroded large parts of these masses.)

(The environment of the coastal dunes of Oregon and Washington, forms and processes, and a description of the dune localities of the Oregon-Washington coast and an account of their history.)

Day, David T. and R. H. Richards

Griggs, H. B.
(Describes type of deposits, mineralogy, origin and distribution, and reserves of chromite-bearing sands.)

Gulliver, F. P.
(Comprehensive dissertation. Grays Harbor shown as example of bay-delta. Coos Bay shown as an example of sea intention versus river intention.)

Honor, R. R.
(A comprehensive report covering from Coos Bay to Crescent City, includes location, analyses and values.)

Hundhausen, Robert J.

Isaacs, John D.
(Covers beaches off Grays Harbor and Coos Bay. Photos
of beach and surf conditions and tire impressions. Beach profiles, sieve analysis of sand samples shown in tables and diagrams.)

Johnson, Douglas W.
(Not specifically applicable to survey area but useful in analyzing shore processes involved in shoreline development.)

Johnson, J. W. and R. L. Wiegel

Marmer, H. A.
(In recent years, there has been observed a rise in sea level along the Pacific coast---averaging out to a few hundredths of a foot per year.)

McLaughlin, Willard T. and Robert L. Brown
(Causes, extent, and methods of control discussed. Includes Grays Harbor and Coos Bay.)

Pardee, J. T.
(General history of mining and geology of the Washington coastal areas.)

(Description of the beaches, terraces, and history of the Oregon coast in the vicinity of Coos Bay and south to the Rogue River. Describes the gold and platinum deposits of the black sands. N.S. and E.W. sections of South Slough at Coos Bay shown among shore profiles.)

Sahu, Basanta K.
Theoretical and Laboratory Investigation of Beach and Dune Sands between Port Orford and Coos Bay. Doctoral Thesis, University of Wisconsin, in progress.

Smith, Warren D.
(Describes, among the other areas along the coast, the general geology of the Coos Bay area.)
Smith, Warren D.  1940. Oregon Shoreline. Geological Society of America Bulletin (Abstract), vol. 51, no. 12, pt. 2, p. 2033.  (This paper deals with some of the more essential features of the Oregon coast and particularly some of the recent changes that have taken place.)


Todd, D. K. and R. L. Wiegel  1951. Local Storms of the Pacific Coast and their Effects on Wave and Beach Conditions. University of California Institute of Engineering Research Wave Investigation Technical Report HE-116-324, 15 pp.  (The meteorological situations causing local storms in near coastal areas are investigated because of the erosive action on beaches of high, short-period waves generated. Two local storms at Oceanside, California, are examined in detail.)

Twenhofel, W. H.  1943. Origin of the Black Sands of the Coast of Southwest Oregon. State of Oregon Department of Geology and Mineral Industries Bulletin 24, 25 pp.  (Black sand deposits are found on present beaches and in deposits beneath elevated coastal plains. Prevailing southwesterly winds concentrate the sand south of promontories or at the north side of embayments. Fluctuations in sea-level caused change in position of embayments and promontories with resultant changes in deposition of black sands.)

1946a. Mineralogical and Physical Composition of the Sands of the Oregon Coast from Coos Bay to the Mouth of the Columbia River. State of Oregon Department of Geology and Mineral Industries Bulletin 30, 64 pp.  (Shore physiography, character and composition of the beaches, and mineral analysis including mechanical analysis and identification of heavy minerals.)

1946b. Beach and River Sands of the Coastal Region of Southwest Oregon with Particular Reference to Black Sands, Part 1. American Journal of Science, vol. 244, no. 2, pp. 114-139.  (Description with mechanical and mineral analyses of sands between Coos Bay and Pistol River. Rounding, sorting, and sizing are considered. Sands of streams flowing over coastal areas are considered.)
Twenhofel, William H.
(This part of the report describes the minerals in the sand.)

University of California Department of Engineering
(Captions accompanying the photos constitute the report. Photos show surf conditions, beaches, and sand dunes in the various areas studied.)

C. OFFSHORE SEDIMENTS

Arrhenius, G.

Arrhenius, G., G. Kjellberg, and W. F. Libby
(Measurements have been carried out on the average radiocarbon activity of a sediment core of eupelagic chalk ooze and the age of the lower boundary was calculated by integration of the radiocarbon decay function.)

Barnes, C. A. and R. G. Paquette
(The Washington coast, being mountainous, has considerable runoff to the sea from heavy precipitation in winter and the melting of the snow in early summer. Two concentrated sources of fresh water are the Strait of Juan de Fuca and the Columbia River which drain large inland areas. In this general area, 7 R. V. Brown Bear cruises (1952-1953) measured circulation patterns.)

Betz, F. and H. H. Hess
(A general survey of the North Pacific Ocean's bathymetry with the main interest in the islands of Hawaii and eastern island arcs.)

Budinger, T. F.
(The Cobb Seamount is a deep-sea feature 270 nautical miles west of Grays Harbor, Washington. It rises from a base at 1,500 fathoms below the sea surface to within 18.5 fathoms of the surface and
covers an area of 240 square nautical miles. It is concluded to be a pre-late Eocene volcano which has been terraced by wave abrasion and which has subsided about 500 fathoms subsequent to its formation.

Budinger, T. F. and Betty J. Enbysk
(A general study of the Cobb Seamount including bathymetric topography of the area, fathograms, photographs of bottom samples, bottom samples, and temperature, salinity and chemical data.)

Carritt, D. E. and J. H. Harley
(An attempt to define the processes by which radioactive waste material may be carried to the ocean floor and thus be kept out of human environment; notes the conditions under which these several processes can be expected to operate and assesses the extent to which these processes have been responsible for the removal of activity from the bottom in cases where bottom accumulation has been measured.)

Carsola, Alfred J., R. S. Dietz and R. D. Russell
(Survey, bottom photograph and bottom samples have been taken from Erben and Noname banks--two flat-topped seamounts lying 800 and 600 miles west of San Diego. Both are thought to be basaltic cones truncated by wave action. The truncated summits lie 400 fathoms (Erben) and 280 fathoms (Noname) lower than present sea level.)

Curray, Joseph R.
(A strong tendency for elongate grains to align themselves with their long dimensions parallel with the direction of the depositing current of water or air. Averages are approximately perpendicular to the beach trend.)

Department of Oceanography, University of Washington
(Contains oceanographic data collected during eight offshore cruises of the R.V. Brown Bear made during the period April 1956 to April 1958. Includes offshore and Cobb Seamount cruises.)
Dietz, R. S.
(Dredging by H.M.S. Challenger, the U.S.S. Albatross, U.S.S. EEC(R) and vessels of the Scripps Institution of Oceanography shows extensive deposits of manganese nodules on the sea floor and crusts of manganese dioxide cover many seamounts. Also, relatively high concentrations of iron and the trace elements nickel, copper, and cobalt are present.)

Hamilton, E. L.
(A study of five flat-topped seamounts 600-1100 miles west of Hawaii. The flat-topped guyots are submerged between 700 and 900 fathoms.)

Hough, J. L.
(A core taken in the Southeastern Pacific had several alternating layers of red clay and globigerina ooze. The red clay is indicative of cold water, while the core is correlated to warmer water conditions.)

Inman, Douglas L.
(Ripples were found to always be present on sandy bottoms when the significant orbital velocity had a value between 1/3 and 3 feet per second. The type of ripple was related to the size of the sand and the nature and rigor of wave motion. In areas of abundant sand, the largest and least dense material occurred on the ripple crests and the finest and heaviest in the trough. On more rocky bottoms, this relationship was often reversed.)

Inman, D. L. and T. K. Chamberlain
(A study in patterns of the areal variation in the distribution of sediments along the California and Gulf of Mexico coasts.)

Menard, H. W., Jr.
(Sediment from seven dredge hauls includes glacial marine drift - deposited over several hundred thousand square miles in the northeast Pacific. In more recent times blue mud has spread out from shore.)
Menard, Henry W., Jr.

(Dominant features of the northeastern Pacific sea floor are four great fracture zones—subparallel bands of grossly irregular topography which transect the whole area in a westerly direction. Characteristic features of the topography are volcanoes, linear ridges and scarpas. Distinctive topographic provinces lie between fracture zones.)

(Turbidity accounts for many minor topographic features of the present day Northeast Pacific Ocean. Relationships between basins, channels, topography and sedimentation are discussed.)

(Four great bands of unusually irregular topography named "fracture zones" have been discovered in the northeastern Pacific basin, and three have been traced into western North America. The fractured area covers 3,000,000 square miles and the parallel trend indicates a single origin. It is tentatively concluded that an annular convection current rising near the Hawaiian Islands and sinking near North America stressed the crust and produced the fracture zones by plastic deformation.)

(Concerns the general geologic and bathymetric features of the Pacific Ocean floor.)

Menard, H. W. and R. S. Dietz

(Describes escarpment and gives bathymetric charts. Considers three hypothesis of origin.)

Moore, D. G.

( Assuming a constant rate of production of Foraminifera, depositional rate of total sediment was calculated from seven deep borings in San Antonio Bay, Texas.)
Nayudu, Y. R.
1959. Recent Sediments of the Northeast Pacific. Ph.D. Thesis, University of Washington, 217 pp. (This study is based on 150 slope and deep-sea sediment cores from the Northeast Pacific. The area can be delineated into seven well defined sedimentary types—terrigenous deposits (pebble to clay), terrigenous deposits (fine sand to clay) with diatoms (less than 20%), diatom rich sediments with fine sand to clay, clay with Radiolaria, Globigerina-rich silts and clays, glacial marine remnants with diatoms, and Katami volcanic ash. Source areas and the depositional history of the area are discussed.)


Nichols, H.
1950. New Seamounts in the North Pacific. Geographical Review, vol. 40, pp. 457-461. (A new seamount, at a deptn of 665 fathoms, was recorded at 50°10' N, 141°59' W, some 400 nautical miles southwest of the Queen Charlotte Islands (Canada), on September 26, 1949, by the United States Coast and Geodetic Survey Ship Explorer.)

O'Brien, M. P.
n.d. Oceanography of Coastal Harbors. U. S. Army Beach Erosion Board, Washington, D. C. (on file). (Sections on Grays Harbor, Coos Bay, and Humboldt Bay include description, tides, tidal current, waves, wind, sand samples and beach profiles, sand movement, and structures.)


Revelle, R. R.
1944. Marine Bottom Samples Collected in the Pacific Ocean by Carnegie on its Seventh Cruise. Carnegie Institute, Washington Publication 556, 182 pp. (An account of the general character of 75 samples of deep-sea deposits in the southeastern and north Pacific. Also includes distribution of the various deposit types, chemical, mechanical, X-ray and other types of analyses (including biological.).)

Rex, Robert W. and Edward D. Goldberg
1957. Quartz Content of Pelagic Sediments of the North Pacific Ocean. Geological Society of America Bulletin (Abstract), vol. 68, no. 12, pt. 2, p. 1843. (The quartz contents of pelagic clays from the Eastern Pacific Ocean show a marked latitudinal dependence with a maximum around 30°N. Quartz appears to be transported mainly by air.)

Tocher, Don 1955. Earthquakes off the North Pacific Coast of the United States. Geological Society of America Bulletin (Abstract), vol. 66, no. 12, pt. 2, p. 1666. (Epicenters of most of the larger earthquakes occurring off the coast of Northern California and Oregon lie in two zones. One zone includes the Gorda Escarpment which extends nearly due west from Punta Gorda. The other zone extends northwestward from the region of Cape Mendocino, indicating a linear extension of the San Andreas Rift Zone as far as Latitude 44° or 45° N.)

Tyler, S. A. 1931. The Petrography of some Bottom Samples from the North Pacific Ocean. Journal of Sedimentary Petrology, vol. 1, pp. 12-22. (Sixteen samples of mud and one of sand, dredged from the bottom of the North Pacific Ocean, at depths ranging from 276 feet to 13,134 feet, are described, and their mineral constituents determined. Complete chemical analyses of eight samples are given.)


Wooster, W. S. 1951. Operation Northern Holiday. University of California, Scripps Institution of Oceanography Ref. 51-46. (Presents general results of cruise in Northeastern Pacific Ocean. Summarizes observations and sample analyses and gives plans for future work.)
D. FORAMINIFERA

Bagg, R. M., Jr.

Bandy, Orville L.
(The lithology and significant fossils of the Cenozoic formations exposed at Cape Blanco, Oregon are discussed briefly. Twenty-four species of Foraminifera are described, figured and analyzed; four new species and two new varieties are reported. Information is introduced which raises a question as to the correlation of the terrace beds at the Cape with the Elk River beds just north of Elk River.)


Brady, H. B.

Cole, W. S.

Cushman, J. A.


Cushman, J. A. and Irene McCulloch


1948. The Species of Bulimina and Related Genera in the Collections of the Allan Hancock Foundation. Allan Hancock Pacific Expedition, vol. 6, no. 5, pp. 231-294, pl. 29-36.
Cushman, J. A. and Irene McCulloch  

Cushman, J. A. and F. L. Parker  

Cushman, Joseph A., Roscoe E. Stewart and Katherine C. Stewart  

Cushman, J. A. and Ruth Todd  


Dall, William H.  
(Study began with Tertiary fauna of Coos Bay. Described as same species as those of upper Cretaceous. Discusses family Volutidae and compares with forms elsewhere in the world.)

(Tertiary description of Astoria and Coos Bay, including invertebrate fauna. Thirteen appendices covering early reports by T. A. Conrad, J. D. Dana, B. F. Shepard, P. P. Carpenter, not usually available.)

Detling, Mildred Riechers  


Emiliani, C.  
(Different species of pelagic Foraminifera occupy different habitats depending on temperature and water density.)
Enbysk, B. J.

Flint, J. M.

Hamilton, E. L.

Jarman, Gary C.

Jones, Robert W.

Lalicker, C. G. and Irene McCulloch
1940. Some Textulariidae of the Pacific Ocean. Allan Hancock Pacific Expedition, vol. 6, no. 2, pp. 115-143, pls. 13-16.

Myers, E. H. and W. S. Cole

Rau, Weldon W.


Rau, W. W.


Smith, A. B.

Distribution of Living Planktonic Foraminifera in the Northeast Pacific Ocean, in progress.

Sohn, Israel G.

MAPS AND CHARTS

Baldwin, E. M.


Boardman, Leona

Gard, L. M., Jr.


Henderson, John R., Jr., Natalie S. Tyson et al.


Koch, John G.

Snavely, P. D., Jr.

Snavely, Park D., Jr. and Holly C. Wagner

Trimble, D. E.

U. S. Army Corps of Engineers

(Survey of bar and entrance from 1862 through 1953, a total of 54 surveys, including all U. S. Coast and Geodetic Survey work.)

1954. Project and Maps (active and inactive River and Harbor and Flood Controls Projects are shown). Portland District.

U. S. Geological Survey


Vokes, H. E., Hans Norbisrath and P. D. Snavely

Vokes, H. E., P. D. Snavely and D. A. Myers

Vokes, H. E., D. A. Myers and Linn Hoover

Waldron, H. H.


Warren, W. C. et al.

Wells, F. G.

Wells, F. G. and G. W. Walker