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High-Altitude Photographs of the Oregon Coast

They provide an exceptional "big picture" showing oceanographic features related to productivity, pollution, coastal zone management and ocean circulation.

Abstract: *Photographs were taken from 60,000 feet with black-and-white, color and color-infrared films in a study of the mouth of the Columbia River and the coasts to the southward in cooperation with the National Aeronautics and Space Administration, the U.S. Bureau of Commercial Fisheries and the U.S. Naval Oceanographic Office. In addition to standard mapping cameras, four 70-mm Hasselblad cameras were used equipped with panchromatic film and different filters. Studied were ocean color and color fronts, sea-surface banding, slicks, windrows over shallow banks, etc. The high-altitude photographs provide a "big picture" perspective of the ocean with good resolution characteristics. Along with space imagery, they show oceanographic features related to productivity, pollution, coastal-zone management and ocean circulation enhancing one's understanding of the marine environment.*

Introduction

During 1969 the National Aeronautics and Space Administration (NASA) obtained extensive aerial photographs of the ocean off Oregon with their RB-57F aircraft at an altitude of 60,000 feet. These unique photographs covered most of the 300 nautical mile Oregon coast out to 50 miles offshore providing a small-scale, almost simultaneous perspective with excellent resolution. Thus it is similar to space craft photography because most of the effects of atmospheric color attenuation are confined to the lower 30,000 feet of the atmosphere (Ross, 1969).

The photographs provided new and useful information on upwelling and the Columbia River plume, the two major oceanographic features off Oregon during the summer. Coastal upwelling is induced by northerly winds and the earth's rotation which causes a net offshore transport of surface waters. Surface waters are replaced by deep upwelled water which is colder and more saline. The high nutrient content of upwelled water results in high productivity. Therefore large commercial fisheries are often located in upwelling regions.

The Columbia River discharges huge volumes of fresh water into the Pacific Ocean (average discharge during July is about 9,000 m^3 per second). During the summer the river water is transported off the Oregon coast to the southwest as a plume or tongue of low-salinity water. In the spring and early summer this thin stable lens of plume water is heated more rapidly than the surrounding ocean water and is often detectable by its warm temperature (Pearcy and Mueller, 1970; Owen, 1968.).

The upwelled water and Columbia River water thus have distinctive and opposing physical characteristics. Boundaries between these water types off Oregon can be obvious and abrupt. Marked changes of salinity, temperature, nutrients and plant and animal life are found across the *fronts* produced by these dynamic processes. As these boundaries are often associated with sharp color and temperature changes, the ocean off Oregon is a good *test area* for remote ocean sensing for aircraft or spacecraft. Moreover, frontal areas are known to be regions where commercially important species of fishes often aggregate. Off Oregon, high catches of albacore tuna and salmon are frequently made near color and thermal boundaries.

Photography and Comparison of Film/Filter Combinations

A preliminary flight of the RB-57 was made on May 21, 1969, over the Columbia River estuary and the oceanic region immediately adjacent to the river mouth. Thirteen frames of Panatomic-X film with a Wratten 58 filter gave contrasting color separation of the blue oceanic water and green Columbia River water.

An extensive second photographic mission was flown on July 16, 1969. The flight plan consisted of six lines parallel to the coast, each about ten miles progressively farther to sea, providing complete coverage of the coast and coastal waters from Cape Blanco to the Columbia River estuary and seaward to about 40 nautical miles. About four hours (12:00 to 16:00 PST) were required to complete the entire mission.

Four 70-mm Hasselblad cameras (scale of 1:240,000) using Kodak 3400 film, each equipped with a different filter, provided 362 frames of black-and-white coverage of the coastline and the Columbia River estuary. Another 187 frames of near-infrared coverage was taken with a Zeiss camera using Kodak SO-117 film. The scale of the Zeiss camera (1:60,000) gave continouous coverage along each flight line but not between consecutive flight lines. Complete overlapping coverage of the area was intended with the 213 color photographs using a Wild RC-8 camera (scale of 1:120,000) with Ektachrome 2448 film.

A frame-by-frame comparison of the Ektachrome, the color-infrared and each of the four black-and-white films was made to determine the usefulness of each film/filter for detecting or enhancing particular features. In general the Ektachrome provided the most useful coverage for all features except coastal boundaries, estuaries and terrestrial vegetation which were more obvious in the color-infrared (see Plate 1.).

The Hasselblad cameras with various blue and green transmitting filters to emphasize changes in water color unfortunately were not operating over the extreme northern or southern areas where major color changes were located. Where we had coverage the magnitude of the differences among the four filters was apparently insufficient to discriminate between subtle color changes seen along the coast. Atmospheric attenuation of color, especially in the blue region, produced hazy indistinct pictures with the blue and green filters. The clearest and sharpest contrast was obtained with the red 25-A Wratten filter which excluded both the blue and green regions of the spectrum where most ocean color changes are located.

Ocean Color and Color Fronts

To illustrate the general color features of the region, blue (.41–.47μm) and green (.54–.58μm) optical densities of the positive Ektachrome transparencies were measured using a densitometer (Densichron model). One measurement was taken on each frame at the same position relative to the sunspot. Plate 2 shows the ratios of the green to the blue optical densities for the region photographed. Areas of green water occurred in large patches along the coast and south of the Columbia River mouth. Anderson (1964) found dense and variable concentrations of chlorophyll *a* off Oregon during the summer in coastal upwelling areas and near the mouth of the Columbia River. Based on optical measurements, Pak (1970) also found offshore extensions of coastal water with large amounts of scattering particles in regions of the Columbia River and south of Newport, regions where green water is indicated (Plate 2). Thus the green water photographed was probably the result of high chlorophyll and phytoplankton concentrations in upwelled waters or plume waters of high productivity. Deep-blue water was associated with clear offshore water which contained less chlorophyll and scatterers than nearshore waters. Blue water was seldom found within 40 miles of the coast and occurred more continuously off southern than northern Oregon. The absence of blue water between 45°–46°N was probably related to the influence of the Columbia River plume in this area.

The Columbia River plume is obvious on the sea-surface temperature map (Figure 1) obtained by infrared radiometry on a low-level aircraft flight three days before the high-altitude photography. The plume waters extend as a tongue of warm water to the southwest from the mouth of the river. Off northern Oregon the tongue of 17.5°C-water extends 60 miles offshore, beyond the area of our photographic coverage. The sea-surface temperature map also shows effects of upwelling—cold inshore temperatures off

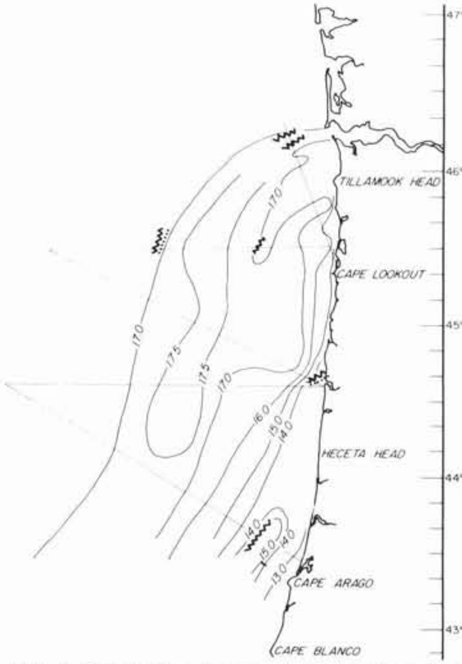

FIG. 1. Sea surface temperature map based on an infrared radiometer survey by a C-47 flown at 500 feet altitude, July 13, 1969 (from Pearcy and Mueller, 1970). Color, fronts are shown by short rows of dots, and thermal fronts by short wavy lines.

Newport and Coos Bay, Oregon, two of the regions where green water was localized on the day of the high altitude flight on July 16 (Figure 2). Definite color fronts that reflected changing water types were especially obvious in the imagery near the Columbia River plume and along the southern Oregon coastline.

The front associated with the Columbia plume marks the boundary between turbid-green plume waters and bluer offshore waters. The northern and western edges of the plume are sharp (Plate 3) whereas the southern and southwestern borders do not appear as distinct fronts, but rather merge into progressively bluer water. This photograph was taken several hours after the ebb current of a spring tide which produced a distinct tidal outflow into the nearshore region. The photographs from the RB-57 flight of May 21 also show the sharp color fronts associated with both the northern and southern edges of the plume (Figure 2).

A complex pattern of color changes occurred off the southern Oregon coast. A color front was noted that paralleled the southern Oregon coast from the outflow of the Umpqua and the Coos Rivers to the southern side of Cape Blanco. This front was probably

FIG. 2. High altitude photograph of May 16, 1969 showing mouth of the Columbia River and color fronts associated with the plume. Panatomix-X film with a Wratten 58 filter provides the strong contrast between the river and oceanic waters.

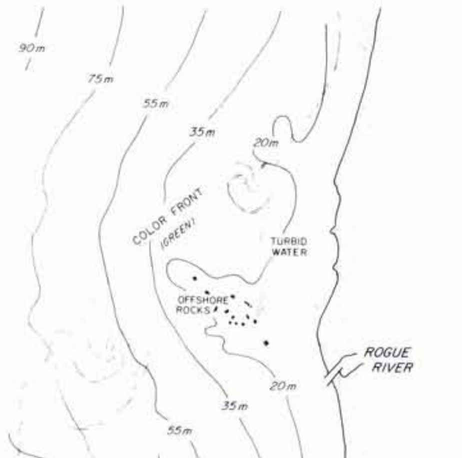

FIG. 3. Analysis of the color front and spirals off the Rogue River. Underwater topography apparently affects the location and alignment of the fronts.

caused by upwelling which is often pronounced just south of Cape Blanco (Smith, et al., 1966, Pearcy and Mueller, 1970). Figure 3 and Plate 4 show this front as it moves offshore encountering shoals and islands west of the Rogue River. First a clockwise spiral, several miles in diameter, formed along its northwestern border followed by a larger counterclockwise spiral several miles to the south. These spirals were probably related to rotational changes caused by bottom topography; the first spiral formed in a shallow basin whereas the second occurred as the depth of water increases rapidly to sixty meters or more.

Two obvious color fronts meeting at a right angle to form a *T* were seen south of the spirals and west of Cape Sebastian (Figure 3). The unusual east-west front was presumably caused by an offshore current associated with an eddy system. Laurs (1967) found geostrophic currents (computed from temperature and salinity measurements) flowing to the west off the Cape Sebastian region during a period of upwelling and northerly winds. A difference in sea state was also seen across this front. White caps were numerous along the northern edge of the front while calmer conditions occurred south of the front.

Sea-Surface Banding Off the Columbia River

A most unusual feature revealed by the photography was a distinctive wave-like pattern off the mouth of the Columbia River (Plate 5). The complex pattern of overlapping crescent shaped *bands* is most prominent near the southern edge of the Columbia River plume over water depths of 50 to 100 meters. The distance between individual bands varies from about 70 to more than 300 meters.

Although these *waves* seem to have height or relief because of the changes of reflectance across them, they are not surface waves. Shoaling effects related to bottom topography are absent. Moreover, stereo viewing of overlapping frames indicated that the *waves* are essentially motionless for periods of at least ten minutes.

Color separations of a portion of Plate 5 were made to determine the possible origin of water making up the bands and whether the bands were surface features. The red separation, which yields near-surface detail only, provided the most prominent display of the bands, indicating their surface nature. Plate 6 is a false-color enhancement of increasing film density levels of the red separation. Three types of water can be seen in the figure. Columbia River water appears red, upwelled water appears blue and coastal water, which is a mixture of water types, appears green.

The river water is well-defined in the upper left corner as is the upwelled water in the upper right. This latter region of upwelling has been noted by Duxbury and McGary (1967). The large bands have the same photographic density of the plume, but the bands appear to be separated from the plume by a mixture of upwelled water and coastal water. The smaller bands appear to be separated from each other by upwelled water and not associated with the plume.

Because of the peculiar nature of this pattern, we attempted additional studies of these banded patterns off the Columbia River using low-flying aircraft and surface ships. Although bands and slicks were observed, we are uncertain of their relationships to the pattern seen in the high-altitude photographs.

A low-altitude flight in August 1970 revealed distinct bands of brown and green water over this same region. We believe that the brown streaks were accumulations of phytoplankton (diatoms) in bands of convergence or downwelling and the green water was located in zones of divergence. The continuity of these bands are interrupted by the ebbing Columbia plume (seen at the right of Plates 6, 7), suggesting the bands were formed earlier, rather than from an instantaneous or continuous process. If viewed obliquely (Plate 8), the brown bands appeared as slicks or streaks possibly because of the smoothing of the sea surface from accumulated organic oils. These slicks usually, but not always, were accompanied by slight temperature increases as measured by our airborne infrared radiometer.

During June 1970, a combined ship and low-altitude aircraft operation studied another series of streaks off the mouth of the Columbia River. Each streak appeared to be a line of white caps separated by 100 to 250 meters of calmer water. No differences of color were noted between the two areas. The pattern appeared to progress into the direction of prevailing winds and swell. Dye traces (introduced by towing a bag of dye through the water) sank in the area of the streaks, indicating zones of convergence. Bathythermograph traces taken along a track perpendicular to the pattern showed large vertical fluctuations in the upper isotherms (Figure 4) which suggest the presence of internal waves (see also Perry and Schimke, 1965).

Slicks, streaks and bands on the sea surface have been observed by others. Aerial observations of the Mississippi River outflow showed well-defined banded patterns which originated near the jetties of South Pass (Walsh, 1969). Internal waves were suggested as the cause of the patterns. Scruton and Moore (1953) also observed banded patterns parallel to the boundary between the Mississippi River outflow and Gulf of Mexico waters. La Fond (1959) reported that slicks are surface manifestations of shallow progressive internal waves between layers of different density water. Scott, et al. (1969) reviewed six mechanisms proposed to explain surface slicks and concluded that all slicks cannot be attributed to the same mechanism. Most studies indicate convergence-divergence cells are associated with slicks and streaks (La Fond, 1959 and Scott, et al., 1969).

Thus strong density interfaces produced by the Columbia River plume overlying the dense ocean water may have created conditions particularly favorable to generation of these surface slicks by internal waves. The pattern seen in the high-altitude photographs may also be related to the tidal discharge plume of the Columbia River. The fact that the pattern is essentially motionless indicates that progressive internal waves are not necessarily associated with the bands and that their formation, as suggested by Walsh (1969), may be due to other than ocean influences. Harbor oscillations or complex interactions between river discharge and tidal motions may be responsible for the pattern. Further studies are needed obviously.

Slicks and Windrows Over Shallow Water Banks

Unlike the symmetrical pattern off the Columbia River, other irregular surface features were observed in much of the photography particularly over shallow water (less than 150 meters deep). Slicks, streaks and streamlines were often associated with bottom topography (Plate 9) and may be manifestations of the currents flowing around and over seafloor obstructions. They

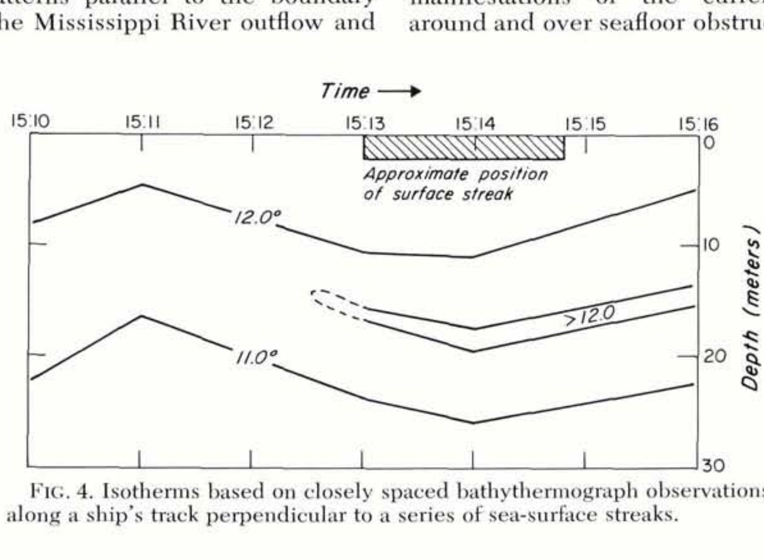

FIG. 4. Isotherms based on closely spaced bathythermograph observations along a ship's track perpendicular to a series of sea-surface streaks.

were especially visible around offshore banks which shoaled to 40 meters or less. These features were less structured than the patterns near the Columbia River mouth. La Violette and Seim (1969) found similar patterns in spacecraft photography, particularly in areas of the sun's reflection on the water. Hence, photographs from 60,000 feet or higher provides sufficient resolution to detect these areas of streamlines and surface discontinuities which may be useful in revealing offshore banks and shoals in unsurveyed regions.

Many additional features were seen in the high-altitude photography that are often not evident from surface ships, including, turbid water along the shore and extending for a mile or more in the leeward side of offshore islands, plumes of pollutants discharged into coastal waters by industries (Plate 10), and the appearance of deep-blue water behind the downwind side of promontories (Plates 1 and 9). White caps indicative of strong winds were numerous along the southern coast of Oregon (Plate 4) but were not seen north of Cape Blanco. Measured average wind velocities on the day of photography were: 13 knots from west-northwest at the Columbia River; 7 knots from north at Newport and 16 knots from north northeast at Cape Blanco.

Conclusions

High-altitude photographs provide an exceptional *big picture* perspective of the ocean at nearly shipboard resolution. Along with spacecraft imagery, they show that oceanographic features related to productivity, pollution, coastal zone management and ocean circulation may be manifested as surface phenomena and can be readily detected from high-altitude to enhance our understanding of the marine environment.

Acknowledgments

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PLATE 1. Color-infrared photograph (Kodak SO-117) of Netarts Bay, Oregon from 60,000 feet. Note the detailed drainage channels in the bay, slicks parallel to the coastline, the calm clearer water south of Cape Lookout, and the excellent differentiation of vegetation and clear-cut forests.

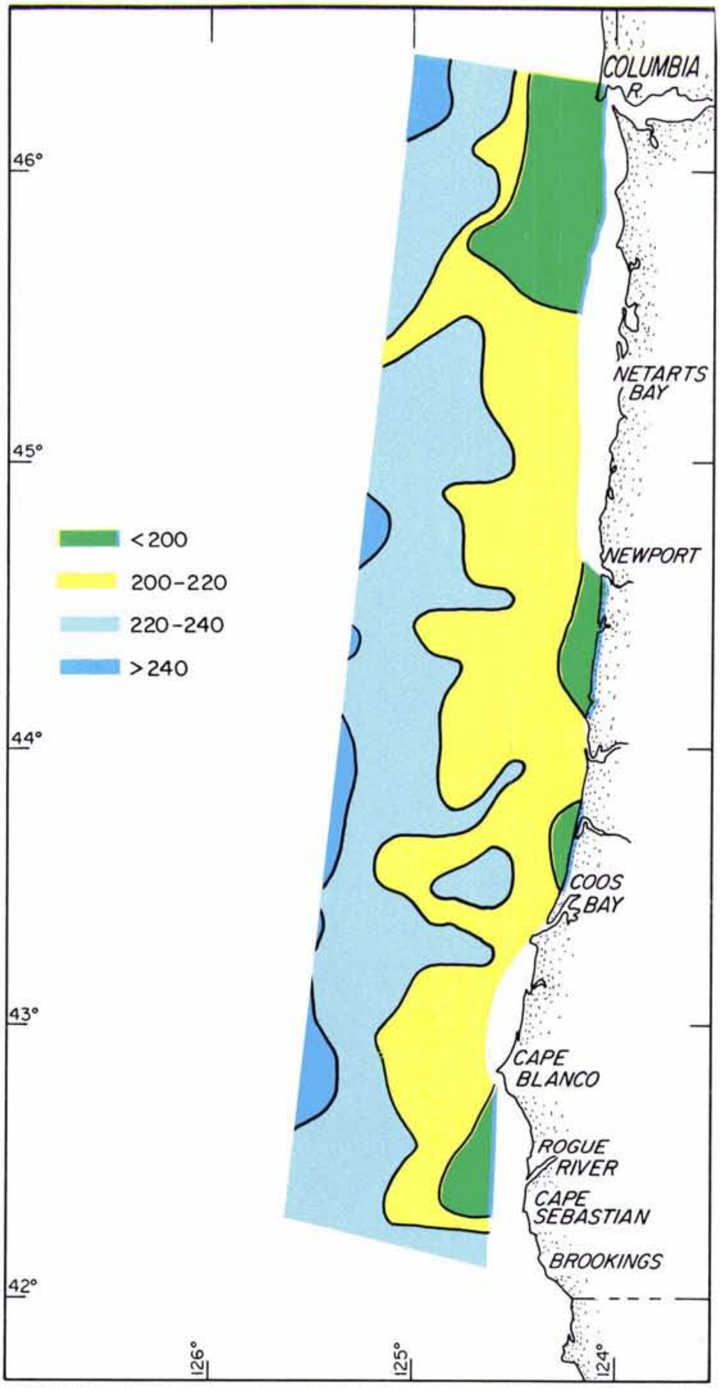

PLATE 2. A color composite showing blue:green ratios of water color based on optical densities of Ektachrome transparencies. Green water is from dense phytoplankton growth in regions of the Columbia River plume and upwelling.

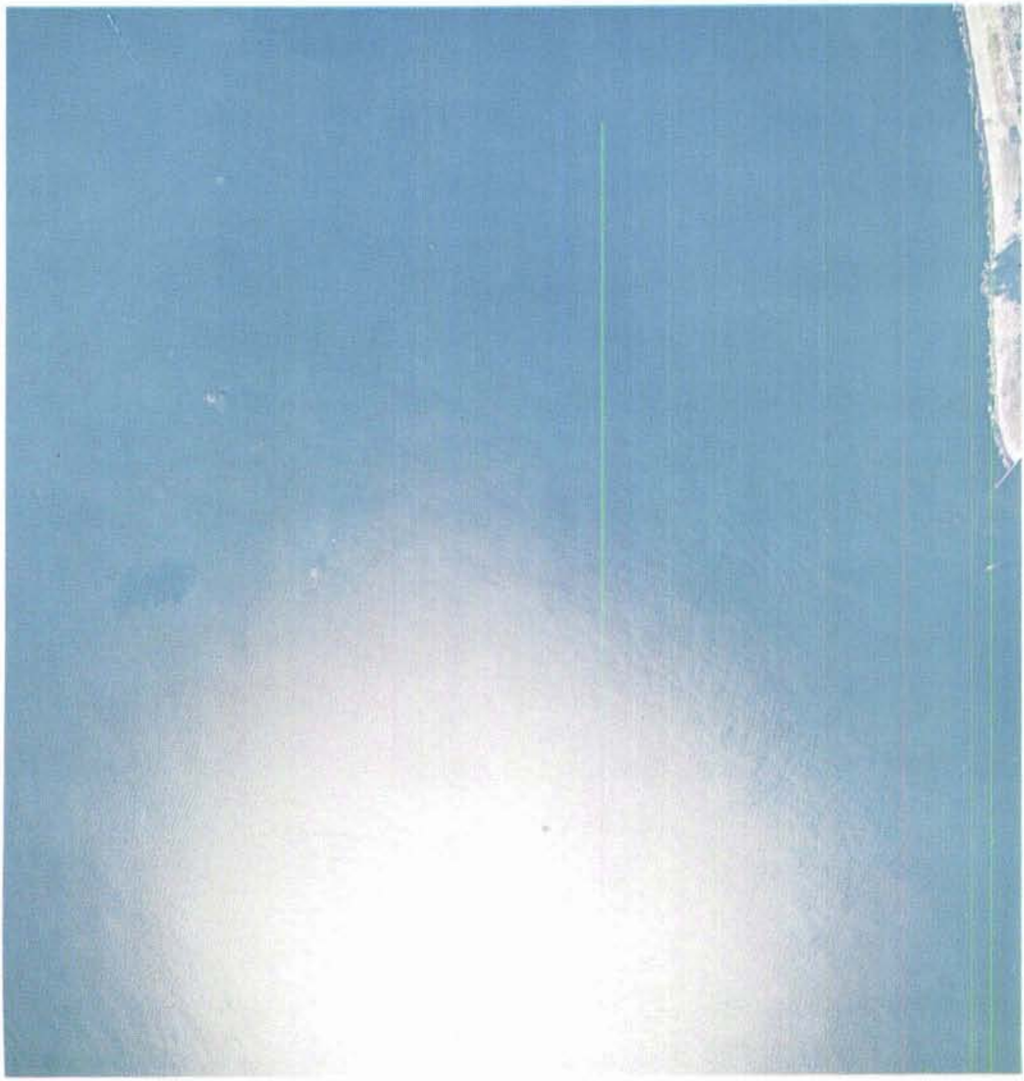

PLATE 3. High-altitude (60,000 feet) RC-8 Ektachrome of the Columbia River plume on July 16, 1969. Lighter, turbid water marks the northern and western edge of the river plume four hours after the ebb current.

PLATE 4. High-altitude RC-8 Ektachrome showing color front as it encounters offshore islands and shoals (see Figure 3 for topography) near Rogue River. A faint spiral can be seen above the islands. Smaller white spots above the islands are white caps.

PLATE 5. High-altitude RC-8 Ektachrome illustrating the wave-like banding of the sea surface off the mouth of the Columbia River. Note the differences between the structure of the bands at top-center of the photograph and in lower right-hand corner. The white spots in upper right are wakes from small salmon boats.

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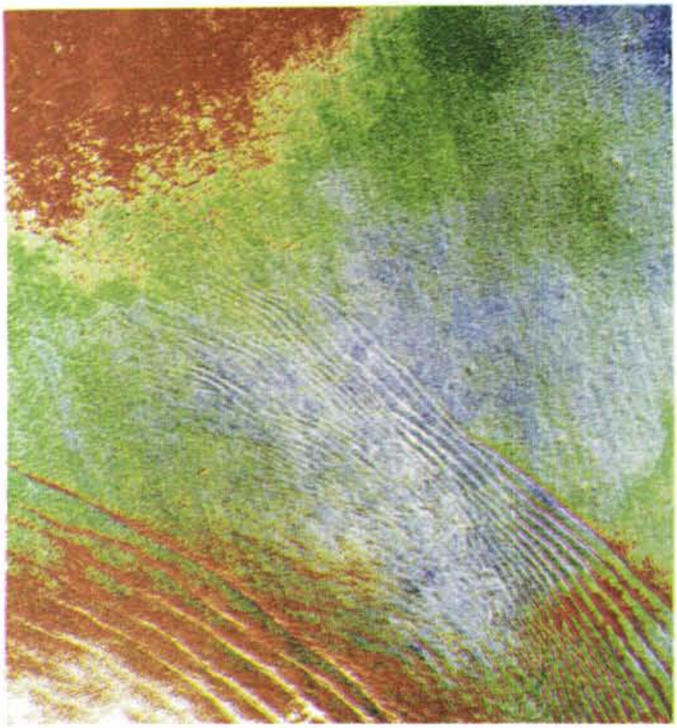

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PLATE 6. False-color enhancement of the upper right section of Plate 5. The Columbia River water appears as red in the upper left, upwelled water appears blue in the upper right, and coastal water is shown as green.

PLATE 7. Low altitude (500 ft.) 35 mm Kodachrome from U.S. Coast Guard HU-16, August, 1970 showing the bands or streaks on the sea surface off the mouth of the Columbia River. Bands visually appeared to extend to a depth of several meters. They terminated abruptly at the margin of the ebbing Columbia river outflow seen in the lower right corner.

PLATE 8. Kodachrome taken along the axis of the same bands shown in Plate 5. Bands of brown water (bottom of photograph) appeared as slicks if viewed obliquely (top of photograph).

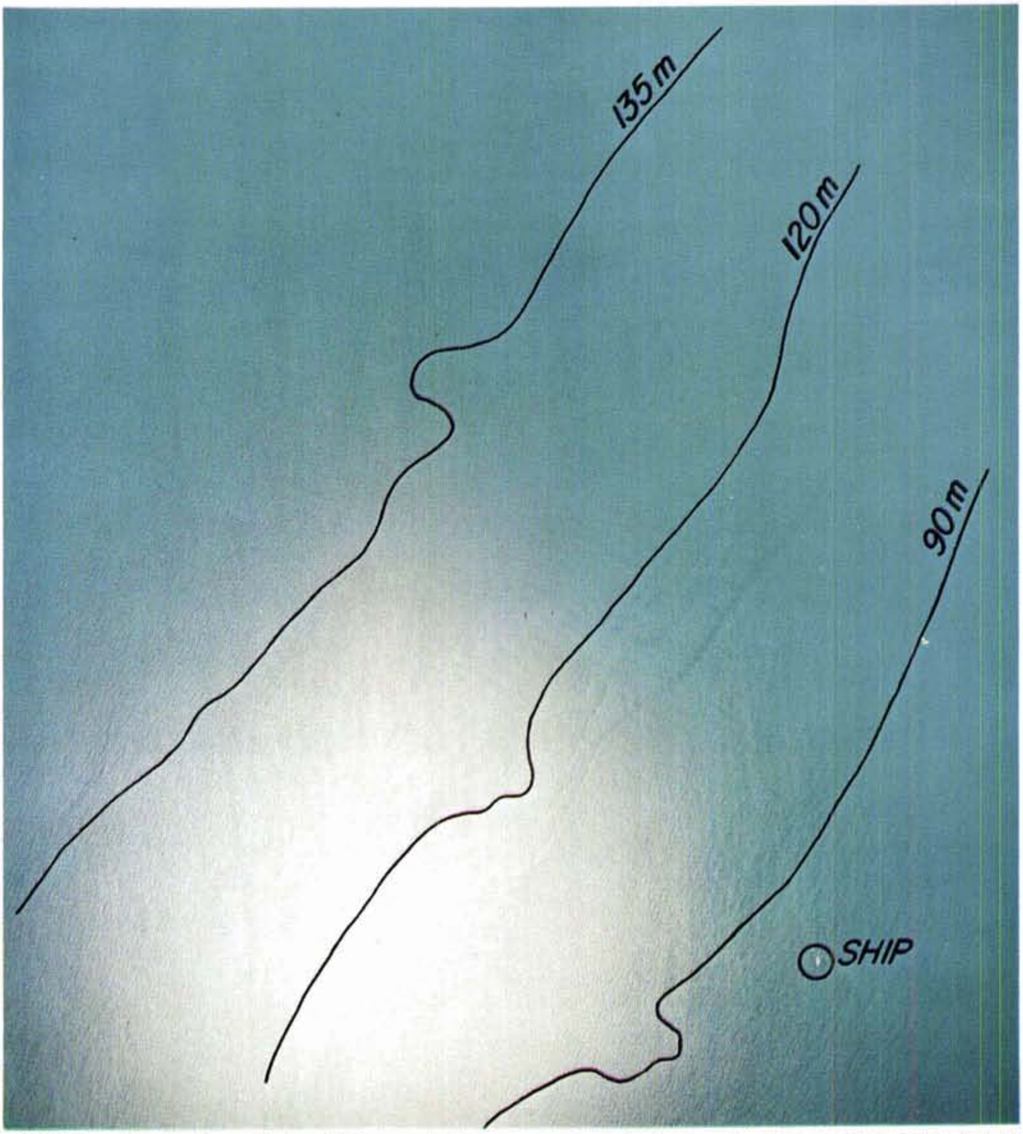

PLATE 9. Sea-surface slicks off Newport, Oregon, appear to follow the topography, indicated by the 120-m contour.

PLATE 10. High-altitude Ektachrome showing effluent trail from a pulpmill outfall located north of the Newport jetty. Discolored water appears to be entering Yaquina Bay on the flooding tide. Note also the turbid water seen along the coast in the top of the photograph.