Seibert Q. Duntley

Professor S. Q. Duntley was born in Bushnell, Illinois in 1911. He received his Bachelor's degree from the Massachusetts Institute of Technology in 1933, his Master's degree from California Institute of Technology in 1935, and Doctor of Science, in physics, from MIT in 1939. He taught and conducted research at MIT until joining Scripps Institution of Oceanography in 1952 as Director of the Visibility Laboratory. Presently he is teaching optics courses for graduate students in the Department of Applied Physics and Information Science and the Scripps Institution of Oceanography at the University of California, San Diego.

Dr. Duntley's major research interests include human visual capability and environmental optics, especially visibility through ocean water and through the atmosphere. During two Gemini flights (V and VII) optical patterns designed by Dr. Duntley and his colleagues to test the astronauts' vision through the atmosphere were laid out over land areas in the southwestern United States and northern Australia.

The program of the Scripps Visibility Laboratory which Dr. Duntley heads had its origin one year prior to World War II. During that war several of the present personnel of the Laboratory were associated with the work, then an activity of the National Research Committee. Much of the program has proceeded without interruption throughout the post-war period at MIT and at Scripps Institution.

Dr. Duntley was president of the Optical Society of America in 1965, and was designated by the Society's board of directors to fill the unexpired term in 1966 of the late Dr. VanZandt Williams, who died in May, 1966.

Dr. Duntley is chairman of the Optical Society of America's representatives to the International Commission on Illumination, also its Publications Committee.

A former director-at-large of the Optical Society of America, Dr. Duntley is a Fellow of that society, a member of Sigma Xi, of the American Association for the Advancement of Science, of the Armed Forces-National Research Council Committee on Vision, and of the Illuminating Society of America. He is the vice-chairman of the U.S. National Committee of the International Commission for Optics and a member of the U.S. National Committee of the International Commission on Illumination. He is a member of the National Academy of Sciences Committee on Observations from Space of Earth

Resources (COSPEAR) and chairman of the COSPEAR Panel on Oceanography and Marine Resources. He is also a member of the newly formed Optical Sciences Center Advisory Group of the University of Arizona.

In 1961, Dr. Duntley was awarded the Frederic E. Ives medal of the Optical Society of America for his distinguished work in optics. At various times he has served as a consultant to the Work Projects Administration, the U.S. Air Force, the U.S. Navy, the General Electric Company, and the Aerospace Corporation.

Robert E. Stevenson

Dr. Stevenson is a native Californian, is married, has two sons, and received his academic education at schools and universities in California (A.B. and A.M. from UCLA and Ph.D. from USC).

In 1942, Dr. Stevenson entered the military service and was a navigator for the U. S. Army Air Force. He was recalled to active duty in 1951 as Chief, Photo Interpretation Research, U.S. Air Force. From that duty, he received special commendation for his interpretation techniques with color and infrared films.

From 1953 to 1961, Dr. Stevenson was the Director of Inshore Research, Allan Hancock Foundation, University of Southern Calif. Here he directed all contract research of the ocean environment of southern California for the university. During a sabbatical in 1959, he conducted special research in England for the Office of Naval Research. He has held the position of Research Scientist and Professor of Oceanography and Meteorology, with Texas A & M University and Florida State University. From 1965 through half of 1970, Dr. Stevenson was Assistant Laboratory Director, Bureau of Commercial Fisheries, Galveston, Texas.

Since mid-June, 1970, he has been the Scientific Liaison Officer for the Office of Naval Research, La Jolla, California.

Dr. Stevenson has helped to pioneer the U. S. effort in space oceanography, during the course of which he has been an advisor to the National Council for Marine Resources and Engineering Development, the National Academy of Science, and continues to work with the National Aeronautics and Space Administration to develop space oceanography programs.

Almerian R. Boileau

Mr. Boileau was born February 6, 1904. He graduated from the U. S. Naval Academy in Annapolis, Maryland, in 1926 with a degree of B.S. He then served for the next twenty years in the U.S Navy retiring in 1946 with the rank of Commander. He received his M.A. in physics from San Diego State College in 1951. Since 1953 he has been with the Visibility Laboratory of Scripps Institution of Oceanography engaged in research in the field of atmospheric optics.

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EXPLORATION OF MARINE RESOURCES BY PHOTOGRAPHIC REMOTE SENSING

By

Seibert Q Duntley, Scripps Institution of Oceanography,
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and
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The subject of this paper is the interpretation of photographs in oceanographic remote sensing. The photographs to be presented here were made from spacecraft with two exceptions. Two photographs were made from aircraft.

There were three types of film used to make these photographs: black-and-white, color, and color IR. Black and white photography is well known; it presents pictures in various shades of gray from black to white. Color film presents pictures in color, very nearly as the human eye sees them.

Color IR film presents pictures in color also but not as seen by the human eye. Blue becomes much deeper blue, green is suppressed to some extent, and red is recorded beyond the visual range of the human eye, out in the near infrared. The most noticeable effect of the use of color IR film is that leaf materials which are highly reflective in the infrared part of the spectrum are presented as red.

This slide gives a comparison between color and color IR.

The first remote sensing photograph is in color. It was made in October 1968 by the crew of the Apollo 7 flight. This photograph shows (See Fig. 1) a portion of the Gulf of California, the body of water between Baja, California, and the mainland of Mexico. The spacecraft was north of the photographed area. The photograph was made with the camera looking in a southerly direction.

The bright reflection is from water roughened by wind. The blue color is from smooth, or less rough, water. We believe the streaks in the glitter pattern are oil on the surface of the water. The interesting thing about this photograph is that it confirms the theoretical work relating to the water circulation due to tides and winds.

In this slide (See Fig. 2) we identify the most common components of the ocean color. All of the light is from the sun. Some light appears to come from the sky, but this is, of course, only sunlight scattered by the atmosphere. Consider the direct sunlight falling on smooth water at point A. Of the light which is incident at that point about 2% is reflected at an angle of reflection equal to the angle of incidence and is not seen by the camera. Thus about 98% of the light incident at that point enters the water. Here it encounters scattering particles, water molecules and suspended materials (organic and inorganic), which scatter light. Some of this scattered light returns to the water surface and is seen by the camera. The camera also receives from point A some reflected skylight. Thus the color at point A, as seen by the camera, consists of reflected skylight, light scattered by atmospheric haze, and the color of the ocean water. Unfortunately, all three of these tend to be blue. Thus from space much of the ocean is seen as a pattern of subtle shades of blue.

At point B, for example, a dark blue portion of the sky is reflected toward the camera. In the water however is a concentration of light scatterers. These might be micro-organisms, schools of fish, or kelp. Often in costal waters the light scatterers are sediments being carried into the sea by rivers. Or they may be sediments being carried away from shore by the tidal action. Deductive reasoning is nearly always used in interpretation of this kind of ocean feature.

The graph on your right shows the absorption coefficient for pure water or the clearest of sea water. As you can see red light (wavelength around 0.6 μm and longer) is strongly absorbed by the water. Also the violet light at wavelengths from 0.4 μm and shorter is also strongly absorbed. The blue and blue-green light is transmitted by clear water to a greater degree than any other part of the spectrum.

Biological activity often gives a green color to the sea. This is because both dead plants and dead animals decompose and the soluble decomposed material is yellow. An accumulation of this yellow stain in the blue water causes the water to have a greenish color. This is common in tidal basins, in bays, and along shores. The dashed curve indicated by Y represents the absorption coefficient for typical bay water.

The dotted line portion of the lower curve, indicated by C, represents the change occurring in ocean water when chlorophyll-bearing green plants (phytoplankton) are present. These plants convert solar energy to food energy and initiate the food chain in the sea. Their concentration is usually too small to give a definite green color to the sea but a subtle change in the blue color can sometimes be distinguished. Of course the water itself absorbs red light to such a degree that the red absorption of the underwater chlorophyll is lost in remote sensing color photography. The subtle change of blue as shown by the dotted line at C may be discernible in the next photograph.

The area shown in the next color photograph (See Fig. 3) is along the coast of Aden. The Red Sea and the Gulf of Aden are well known for the tremendous plankton blooms that occur in their waters. These growths usually discolor the water, especially near the coasts where the concentrations of the microscopic plants are greatest. There is not always an even distribution of the concentrated blooms, the occurrence being patchy and frequently stretched out in long strings.

In March 1969, the Apollo 9 spacecraft crossed over the Strait of Bab el Mandeb and the astronauts had a perfect view of coastal Aden. In the waters were streamers of discoloration aligned with the light, easterly breezes. Even though no measurements or observations are known from these waters during these orbits, the appearance of the discolored water off Aden is so similar to plankton blooms observed from aircraft that any other interpretation seems unjustified.

Suspended sediments cause the red and infrared reflectance of water to increase so dramatically that the sediment clouds appear in high contrast. It is almost exactly analogous to adding cream to black coffee. Sediment clouds can always be distinguished from bottom features because bottom features do not show when photographed in the region of the spectrum whereas the sediment clouds are extremely prominent. Accordingly, clouds of sediment in clear sea water are easily seen in space photographs and yield valuable information of several kinds of marine resources. This is nicely illustrated in the next color photograph.

The photograph was made by the crew of Gemini 12 as the spacecraft passed over the Texas coast November 14, 1966. (See Fig. 4)

The skies were clear and the air was relatively dry. Winds were blowing from the northeast, following a cold front that had moved over the Gulf of Mexico two days before. The direction of the wind was marked clearly by smoke drifting from a marsh fire along the Louisiana coast.

The brisk northerly winds had driven water from the lagoons and estuaries into the Gulf of Mexico. Sediment-laden water (a light bluish color in the photograph) was flowing through all of the inlets and was caught in the southwesterly coastal current.

Off the coast, large eddies over the shallow Texas shelf (the water depth is 100 meters some 110 kilometers from shore) were outlined by the pattern of suspended sediments and could be seen to carry coastal waters 180 kilometers into the Gulf of Mexico. The seaward flowing currents mark the migration routes of the mature shrimp that live along the Texas coast as they travel to the offshore spawning grounds. By carefully fishing the waters marked by the suspended sediment streams, the shrimp fishermen have developed that fishery into the world's richest.

The next color photograph illustrates the appearance of the ocean bottom in clear ocean water free from sediment plumes.

In December 1965, the Gemini 7 spacecraft passed over the Bahama Islands (See Fig. 5) and a photograph was taken of the Berry Islands that lie to the north of Andros Island. The shallow sand bars and the accompanying surge channels, all composed of brilliant white, calcareous sands, were outlined clearly in this nearly vertical view.

The sands are soft and mobile so that currents, waves, and storm surges readily move and shape the sands. During tropical storms and hurricanes, the surge of water over the Bahama Banks is much greater than normal because of the tremendous masses of water moved in front of the storm by the strong winds. As the waters spill over the banks, large bars and channels are formed that show the direction of the surge. These storm-surge bars are easily noted in this photograph.

Photographs such as this one are of great value in correcting navigational charts. As a result of the study of such photographs a considerable number of chart corrections have been made.

The next color photograph is of the southern portion of Taiwan. (See Fig. 6) The major ocean current systems flow from south to north and around the island of Taiwan. The waters are warm and deeply mixed, having turned northward from the Equatorial Current east of the Philippine Islands. The main axis of the current is east of Taiwan, although its position, as well as its speed, varies seasonally in response to the monsoons of southeast Asia.

On July 19, 1965, the day before this photograph was taken, tropical storm "Nina" was about 180 kilometers east of Taiwan. "Nina" never developed fully and winds of 15 knots were the highest recorded at nearby land stations. By the next day, the storm had dissipated and easterly winds of 4 to 6 knots blew around Taiwan.

When the photograph was taken by the Gemini 4 astronauts, the northern edge of the sun glitter pattern covered the waters adjacent to the southern tip of Taiwan. A range of light-blue colors was produced by the diffuse reflection of the sun from an unevenly roughened sea surface. Winds from the northeast blew across the northerly flowing current to produce the varying roughness of the water. Where the water moved either with the wind, or not at all, the sea surface was smoother and the resulting reflectance color a darker blue than in the flowing current.

As the water flowed north it was parted by the island. As the waters spread away from the island, upwelling took place near shore. The upwelling waters had a smoother surface than those farther seaward. Consequently, they appear to be darker blue than wave-roughened waters. The upwelling water carries nutrients up from the ocean bottom and produces good fishing grounds. We understand that the area of upwelling west of the island has been a good fishing area for years and that the area east of the island is now being exploited.

The science of color measurement can be applied to ocean color. Color measurements can be made, of course, from color photographs by several well established techniques. Such measurements include however, the inaccuracies of color rendering which are inherent in all color photography processes. Direct measurement of ocean color from aerial vehicles or spacecraft is much more accurate. The next two slides show the result of spectroradiometric and colorimetric data obtained by one of the authors using a grating spectroradiometer in an airplane flown some 1300 meters above reefs, sandy shoals, and the Gulf Stream off Dania, Florida. Later the same instrument was mounted in a glass-bottomed boat and returned to the identical ocean locations, where it measured the color of the ocean floor, through the water, directly beneath the boat. (See Fig. 7) The figure on the left shows spectroradiometric curves obtained with the spectroradiometer in the boat, and the figure on the right shows the corresponding measurements when the spectroradiometer was flown at an altitude of 1300 meters. The presence of the reefs and shoals show clearly in the blue and green regions of the spectrum, and the screening effects of the atmosphere are clearly evident in the aerial measurements.

Colorimetric calculations from these data are plotted on a standard chromaticity diagram. (See Fig. 8) The lower, shorter curve represents the loci of the ocean colors as measured from the aircraft. The more saturated ocean colors measured from the glass-bottomed boat are shown by the upper, longer curve.

These are true measurements of ocean color. We are not aware that such measurements have yet been made from space.

Not all ocean color results from the water and its contents, or the ocean bottom, or reflection from the sky. Sometimes reflection of the sun by the surface of the wind roughened sea drastically affects ocean color and in so doing may reveal important clues to marine resources. Consider the geometry in this slide. (See Fig. 9) Parallel sunlight irradiates the surface and at some spot in the ocean a flat water surface would reflect an image of the sun. Although not always within the field of view of the camera, this solar reflection point can always be found, even when the water surface is roughened by wind. When this occurs the image of the sun enlarges into a glitter pattern, the size and shape of which depends upon the surface wind velocity. But even in the presence of wind-driven waves a greater fraction of the area of the sea surface is horizontal than at any other inclination. Thus the center of the glitter pattern stays at the solar reflection point. From the camera position the center of this glitter pattern is dazzling compared with any other point of the field of view and if included in a photograph it is usually overexposed. In our diagram, the water more nearly under the camera may also appear abnormally light because a few unresolved wave facets are tipped at precisely the right angle to reflect sunlight toward the camera. Each wave facet appears like a little piece of sun diminished in brightness by a factor of 2% since that is the reflectance of a clean water surface.

In the lower part of the figure the curve indicates the fractional area of the water-wave surface inclined to reflect sunlight toward the camera. This curve always has its maximum at the center of the sun glitter and the extent of the curve depends upon surface wind velocity. In the example shown, the water appears light wherever a sufficient fraction of the water-wave surface reflects the sun toward the camera. Farther from the glitter center no facets are sufficiently tipped to reflect sunlight to the camera. Here the water appears dark. The glitter pattern in most space photographs appears to have a rather sharp edge. This is partly due to the nonlinear properties of photographic film. Outside the glitter pattern sub-surface phenomena, such as clouds of sediment, can often be seen. Within the glitter pattern however these details are masked by the glitter.

It has already been noted that the extent of the glitter pattern depends upon sea surface roughness. Thus, in nearly calm water the curve is much more steeply peaked than was just shown. While the roughness of the sea depends primarily upon the wind, it is also dependent on the surface tension at the sea surface.

There is an old saying about pouring oil on troubled waters; and mariners have long known that spreading oil upon the surface of the wind-blown sea reduces the surface roughness and facilitates small boat operation for rescue purposes. Natural oils sometimes appear on the surface of the sea as a result of biological activity in the water. This effect is often seen in harbors where such natural vegetable and animal oils are sometimes supplemented by mineral oil from ships. Streaks and patches of oils of any kind can be seen when they occur within the sun glitter because decreased surface tension makes the water less rough. Lesser roughness means fewer slopes steep enough to cause facets to produce sun glitter. Thus, the oiled areas appear dark in the edge of the sun glitter pattern. In most instances the effect is limited to only a part of the field in view of the camera.

The photograph (See Fig. 10) which illustrates this phenomenon was made from an aircraft flying over San Diego, California.

This black-and-white photograph was made from an aircraft during an aerial survey of the San Diego area several years ago. Fortunately it just happened to show the San Diego harbor at the edge of the glitter pattern. Where the water surface appears light, the water is roughened by the wind. Where the water surface appears dark, a thin film of oil has increased the surface tension causing the water surface to be smoother and therefore less reflective. Incidentally, this black-and-white photograph was made on panchromatic film with a red filter. This, of course, tends to eliminate scattered light from below the water's surface from registering on the photographic film.

The next two photographs are examples of remote sensing from space when color IR film is used. (See Fig. 11.) The first one was made in March 1969 by the Apollo 9 crew. It shows the coast of the United States between Savannah, Georgia, and Jacksonville, Florida. The second was made by a mapping camera being flown at 13 000 meters (42000 feet); it shows several islands in the Florida Keys.

This first color IR photograph of the Georgia coast shows how the blue color of the ocean is accentuated by this type of film. The lighter shades of blue near the coastal islands are believed to be sediment. The vegitation, a dense growth of pine trees, appears red. The mud flats which are shallowly submerged at high tide, are blue gray in color. The channels and waterways through these mud flats are very plainly shown.

This color IR photograph of the Florida Keys shows very plainly the channels and water courses between the two islands of the Upper and Lower Matecumbe Keys. It is a very good example of how underwater topography can be determined by remote sensing.

There is a great difference in the scale of these last two photographs. The distance along the coastline of Georgia as shown in the preceding slide is about 130 kilometers (80 statute miles) while the section of the road shown in this slide is about 24 kilometers (about 15 miles) long.

SUMMARY

You have seen several examples of the capabilities of remote sensing.

First, it would appear that the knowledge of where the sediments are, the location of plankton, and determining the area of upwelling water would be of great benefit to the fishing industry.

Second, the use of space photography in remote sensing should be of the greatest value to the cartographers. Corrections to existing charts have already been done due to space photography.

Third, the overall view of the water surface and what can be learned from that view has already been used to confirm theoretical studies of water and wind circulations.

GLOSSARY

alcareous	- Consisting of or containing calcium carbonate.
artographer	- Maker of maps and charts.
not	- Unit of velocity equal to 1.85 kilometers per hour or 0.515 meters per second.
icrometer	- Unit of length equal to 1×10^{-6} meter (one millionth of a meter).
hytoplankton	- Microscopie green plants floating in water.
lankton bloom	- Mass or masses of phytoplankton.
catter	- Change in direction of light caused by the light being incident on suspended particles or organisms.
catterers	- Suspended particles or organisms causing scatter.
pawning grounds	- Fish breeding areas.

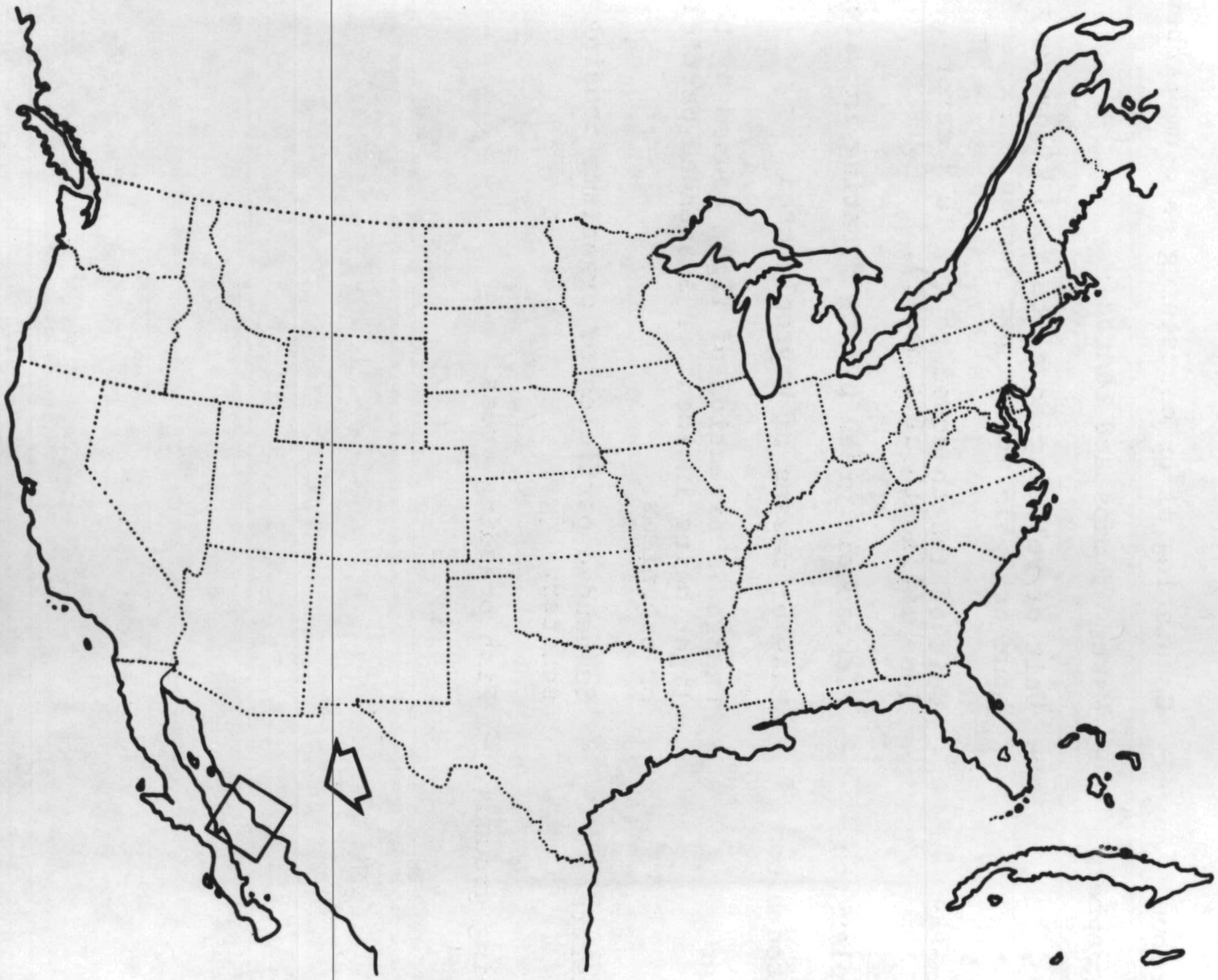

Fig. 1. Area of the Gulf of California shown in first color photograph.

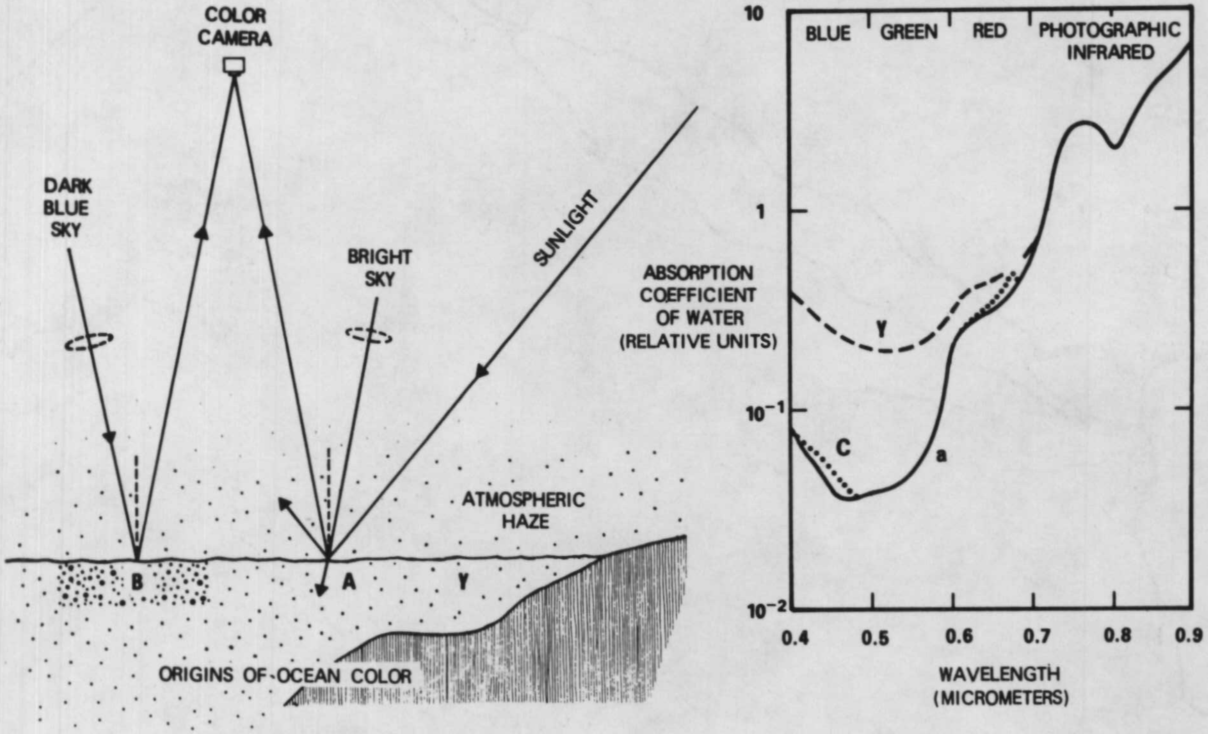

Fig. 2. Origins of Ocean Color.

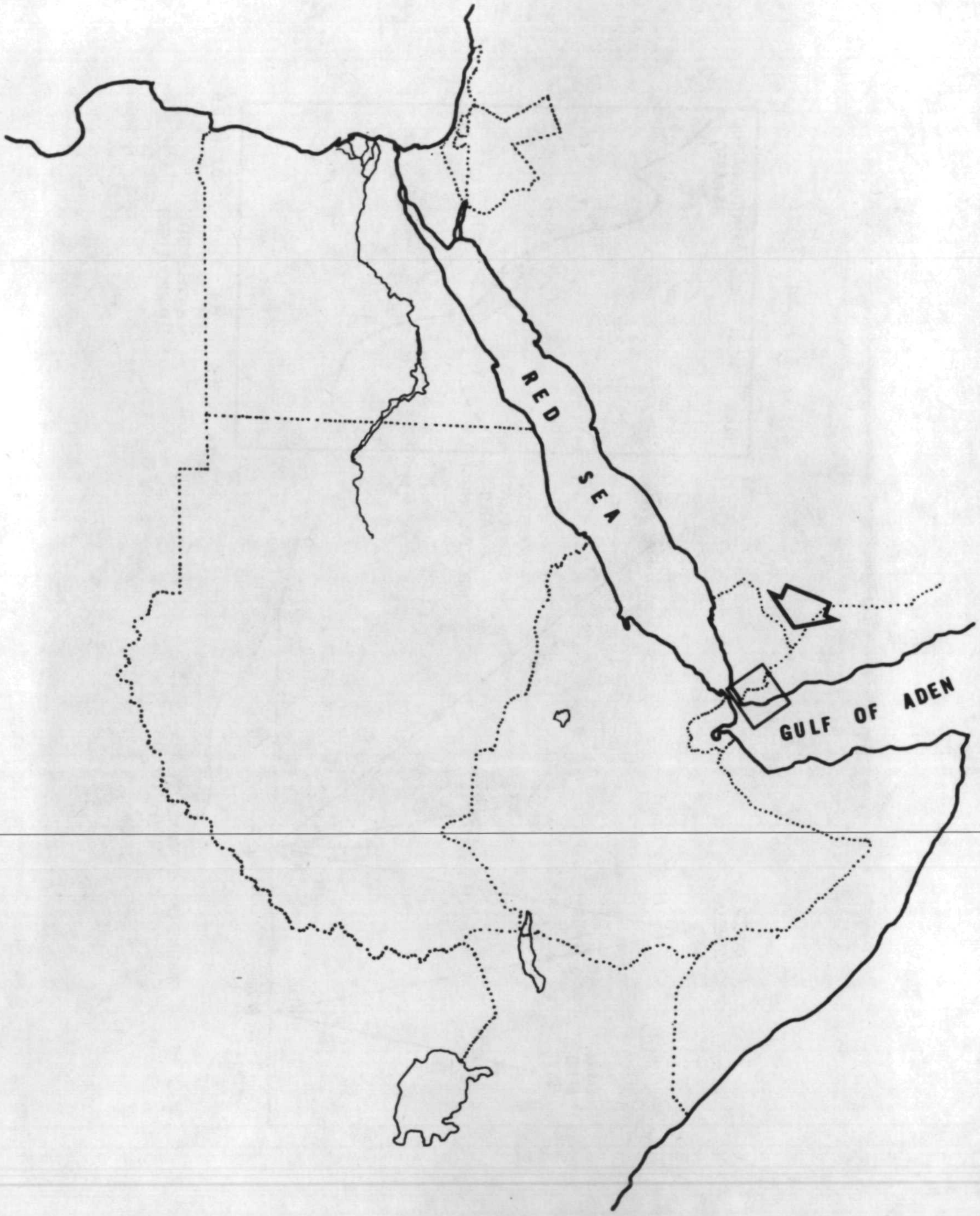

Fig. 3. Aden and the Gulf of Aden shown in second color photograph.

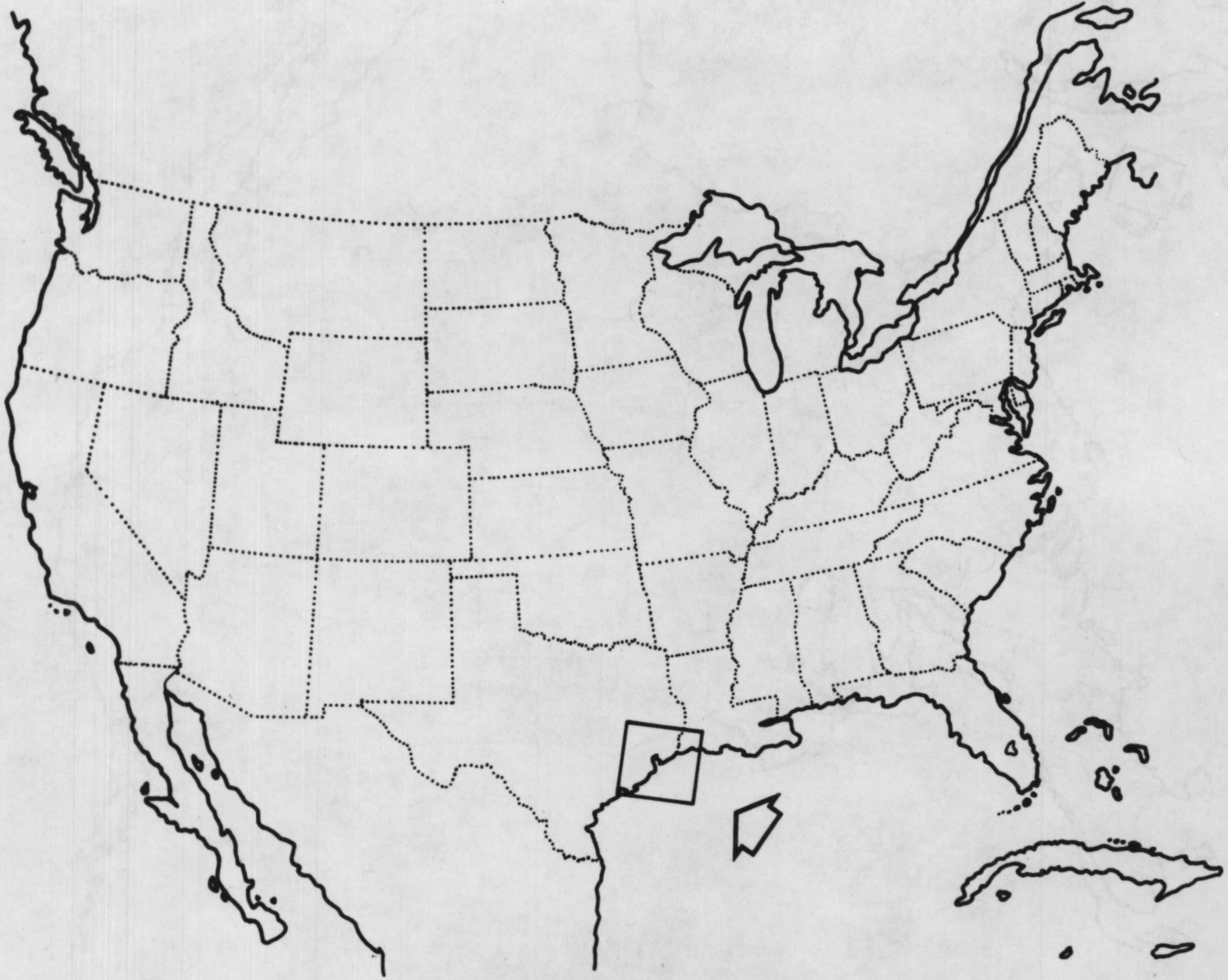

Fig. 4. Texas and Louisiana coastline shown in third color photograph.

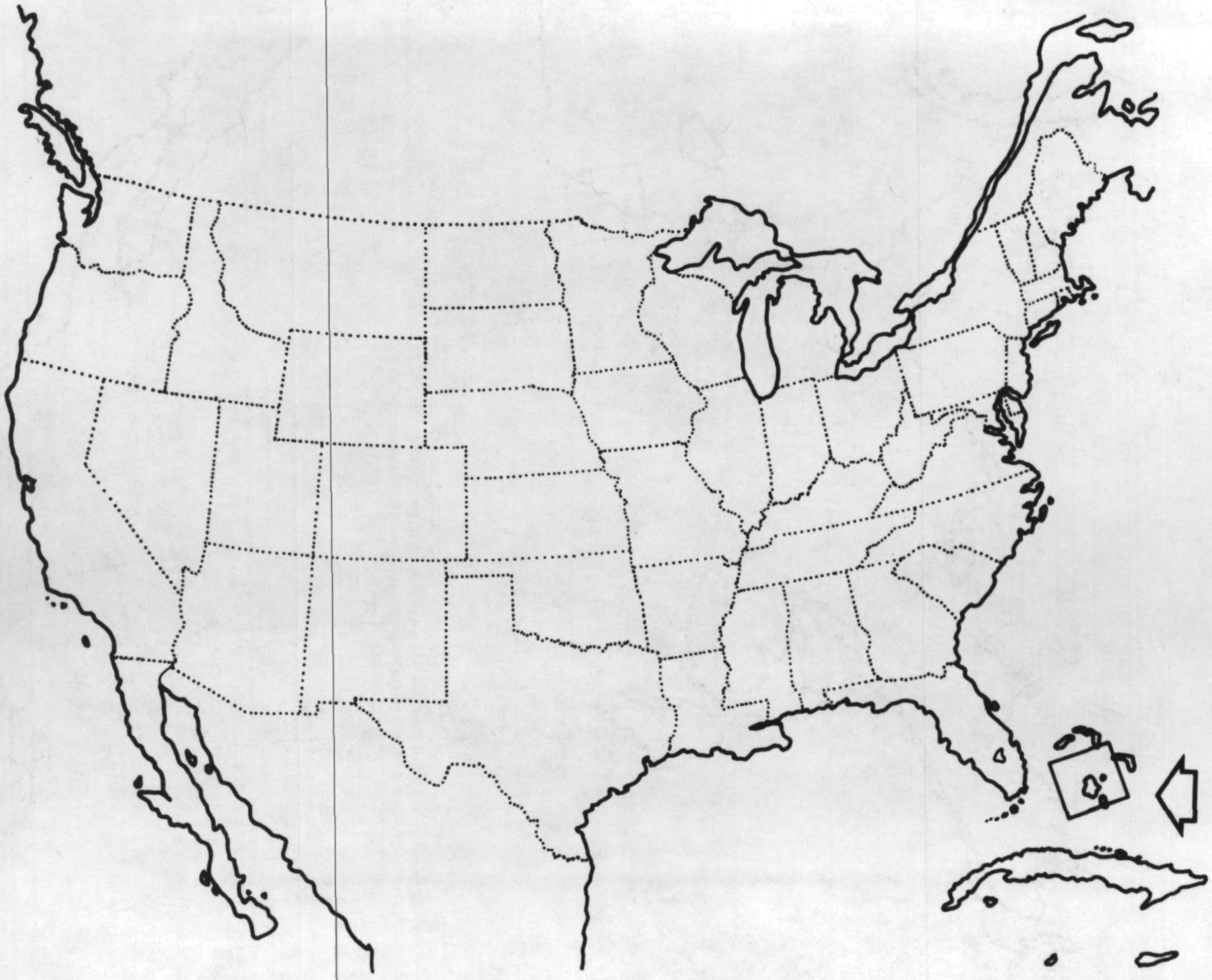

Fig. 5. Area of Berry Islands shown in fourth color photograph.

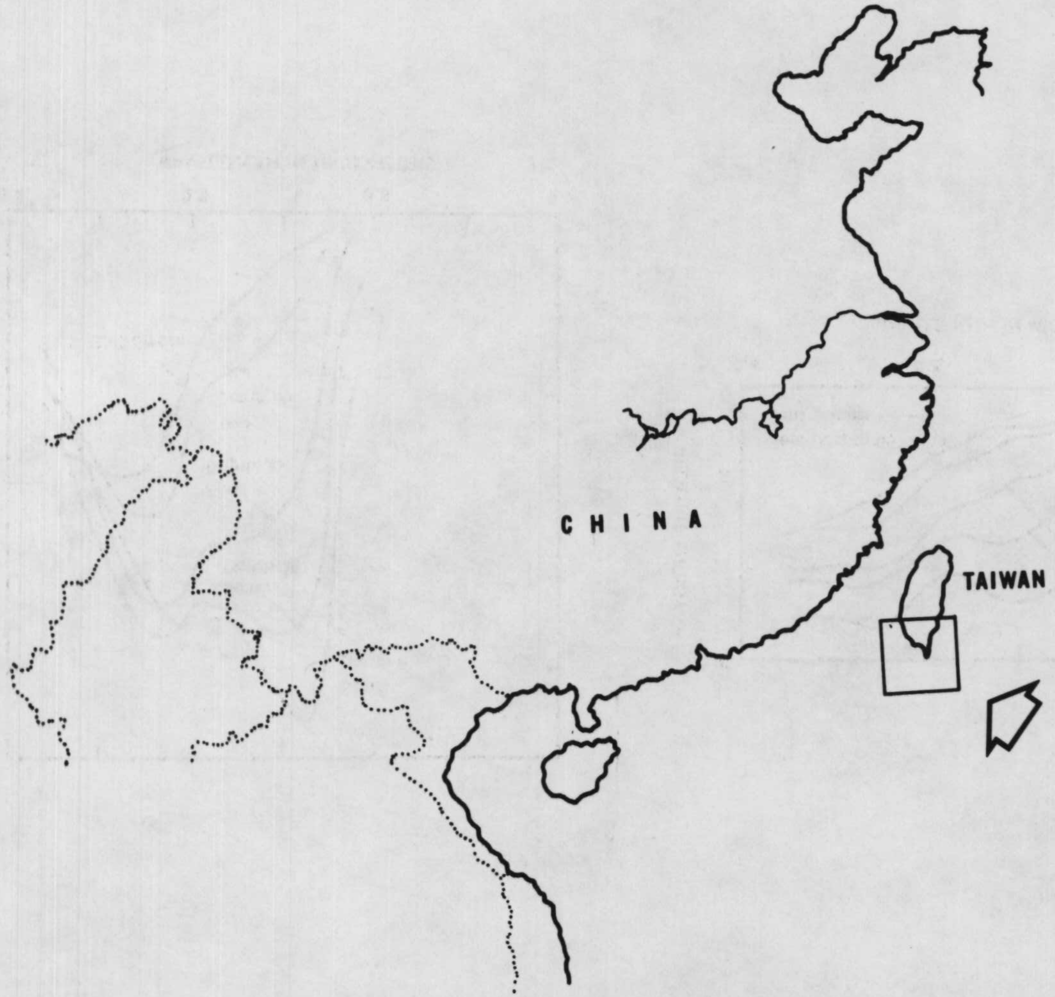

Fig. 6. The part of Taiwan and surrounding ocean shown in fifth color photograph.

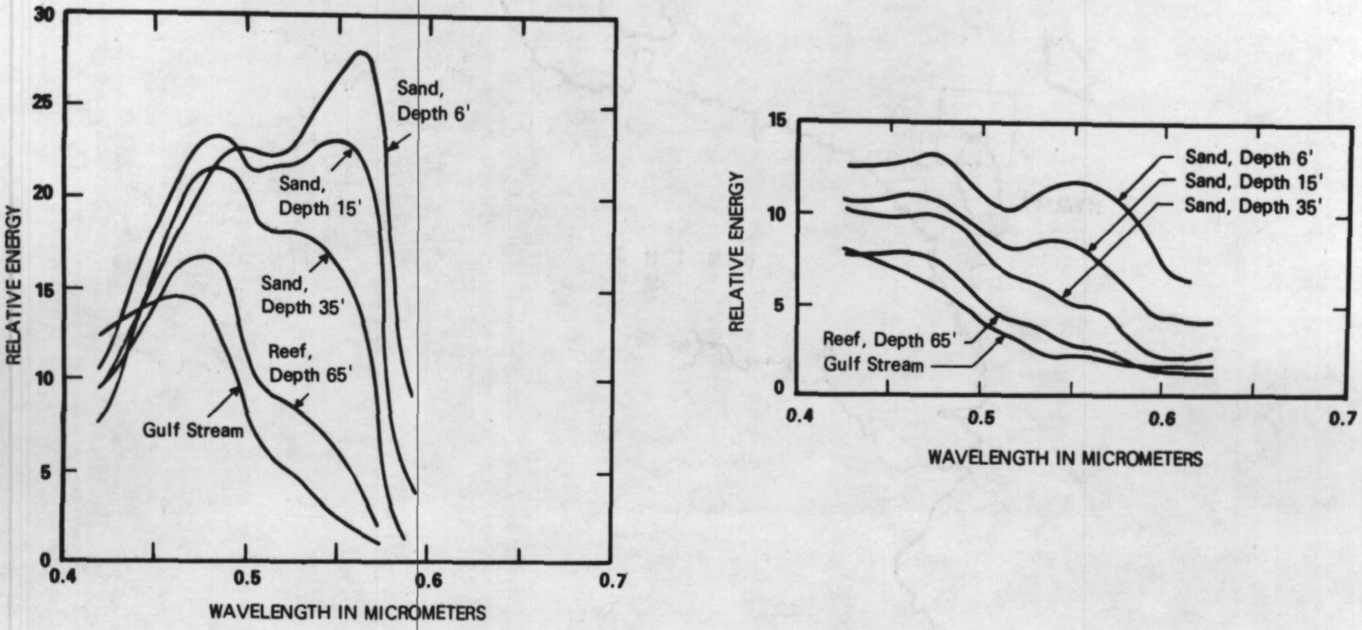

Fig. 7. Spectroradiometric data of Ocean Water.

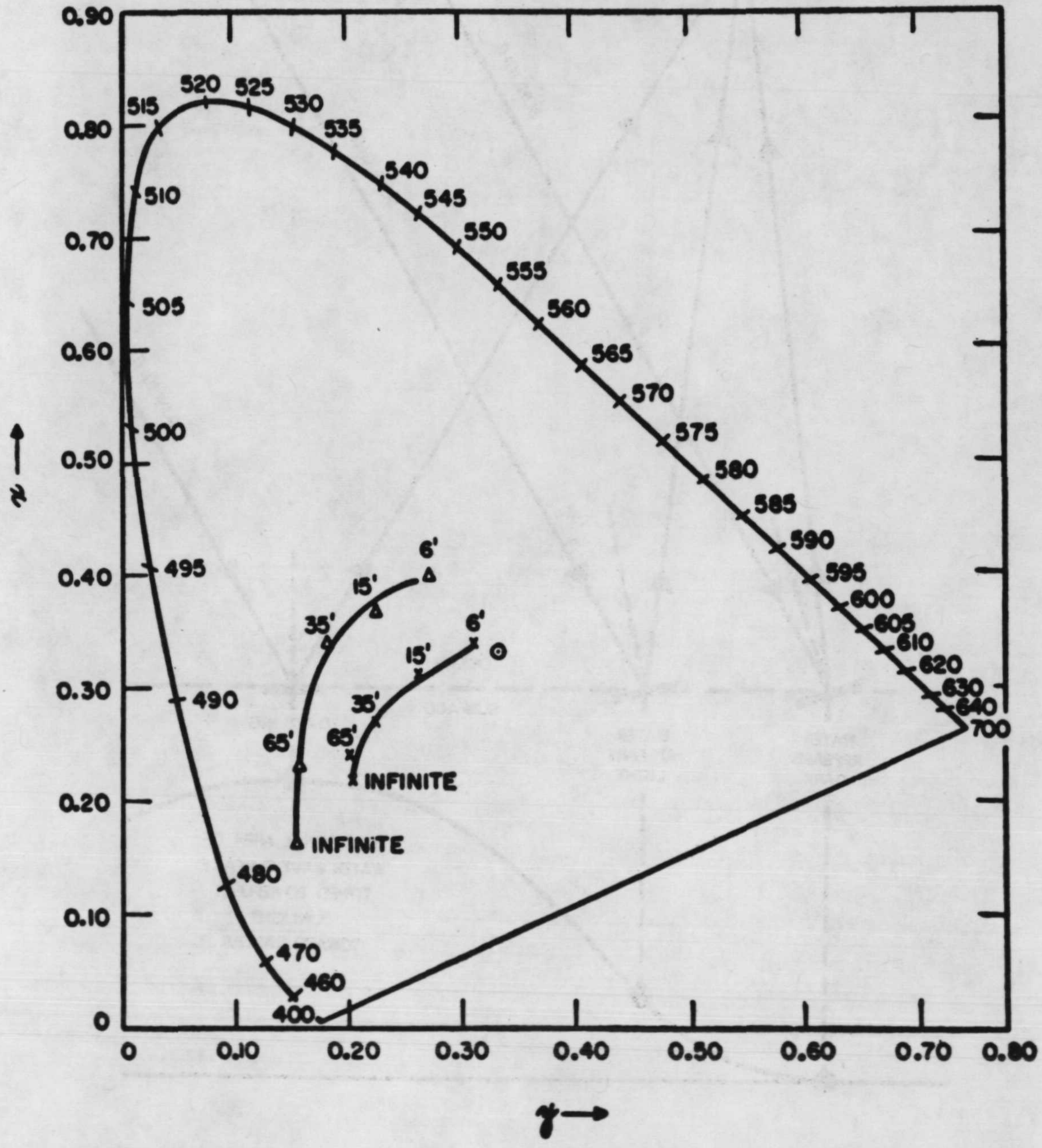

Fig. 8. Chromoticity diagram of data shown in Fig. 7.

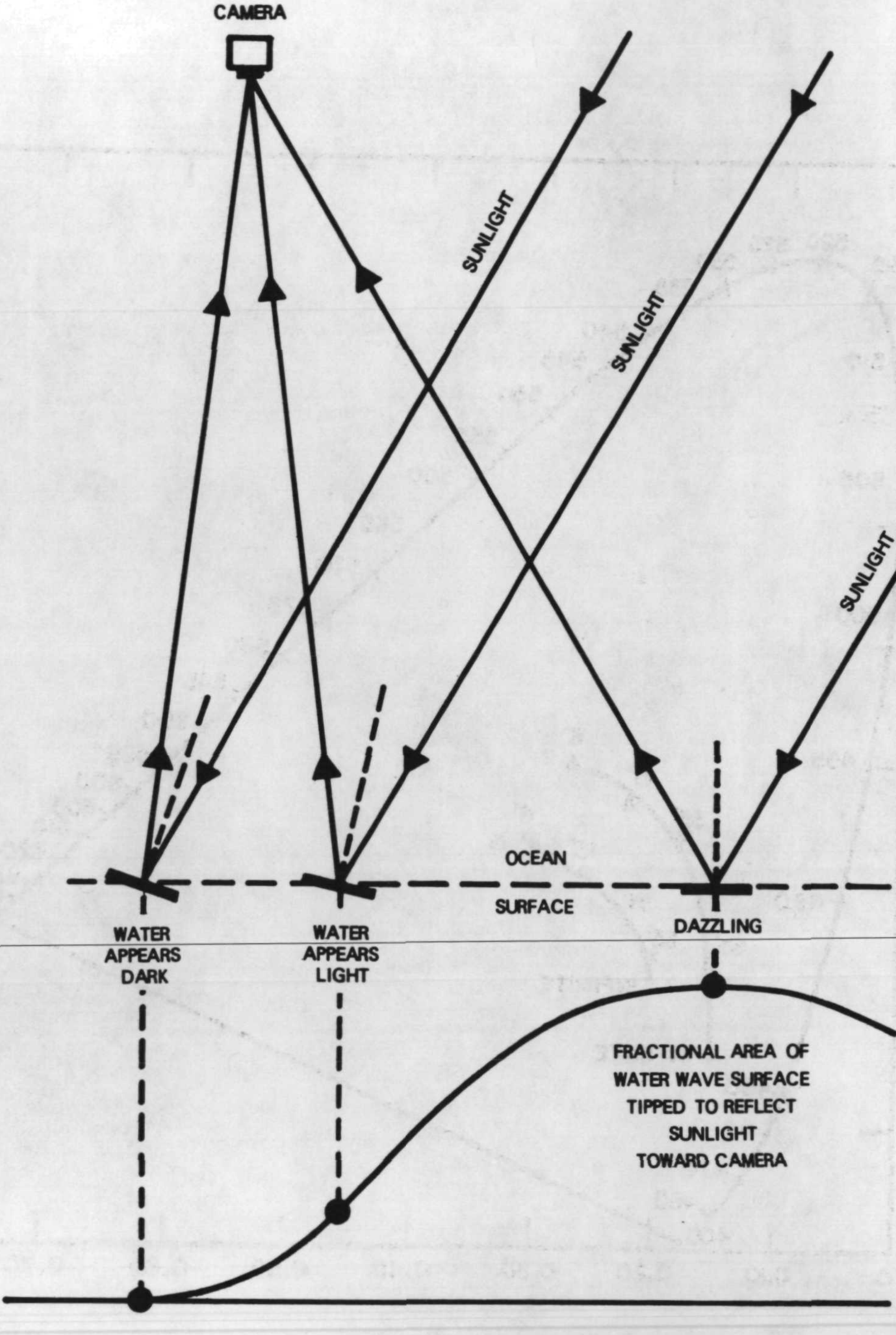

Fig. 9. The geometry of sun glitter patterns.

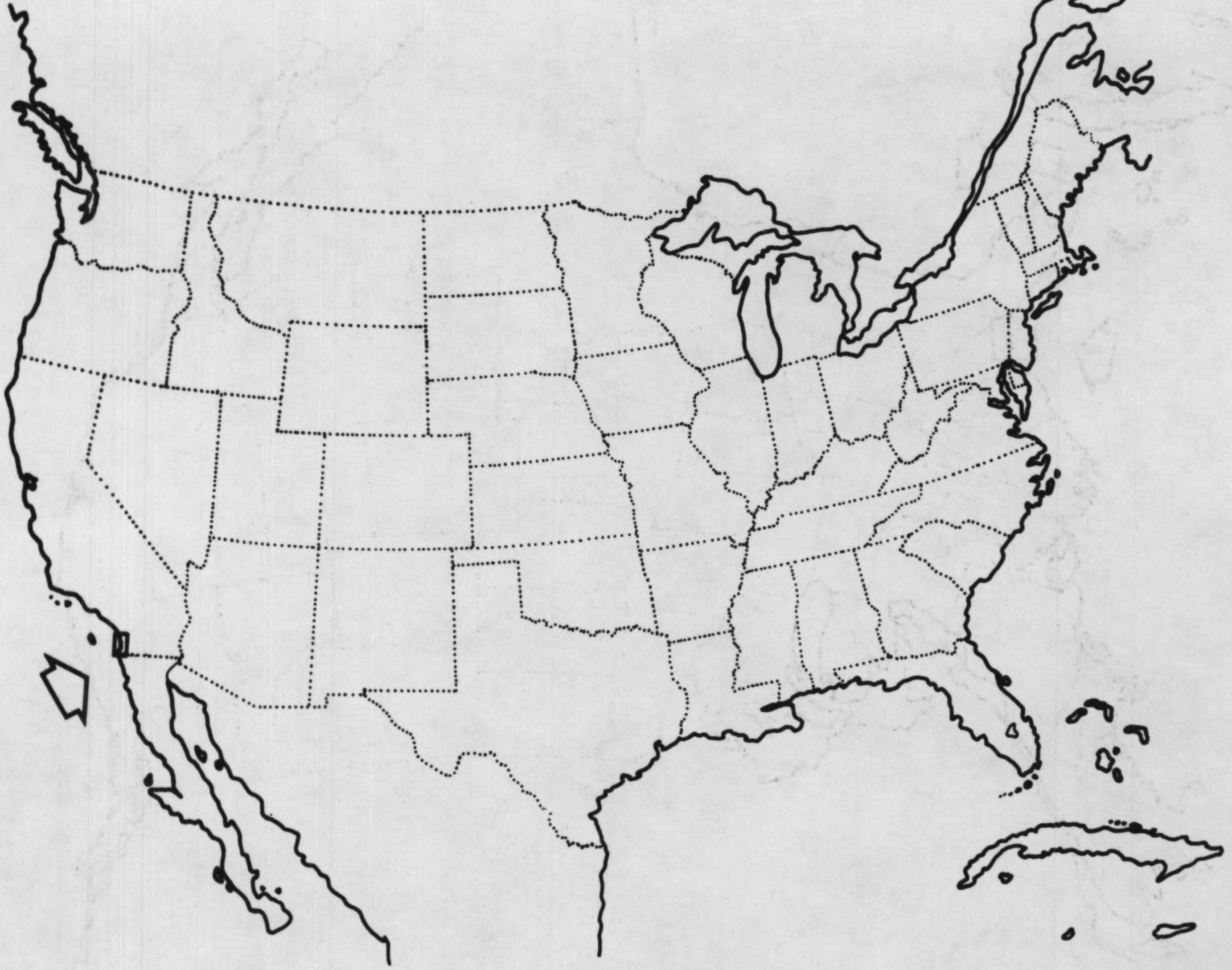

Fig. 10. Location of San Diego harbor shown in black-and-white photograph.

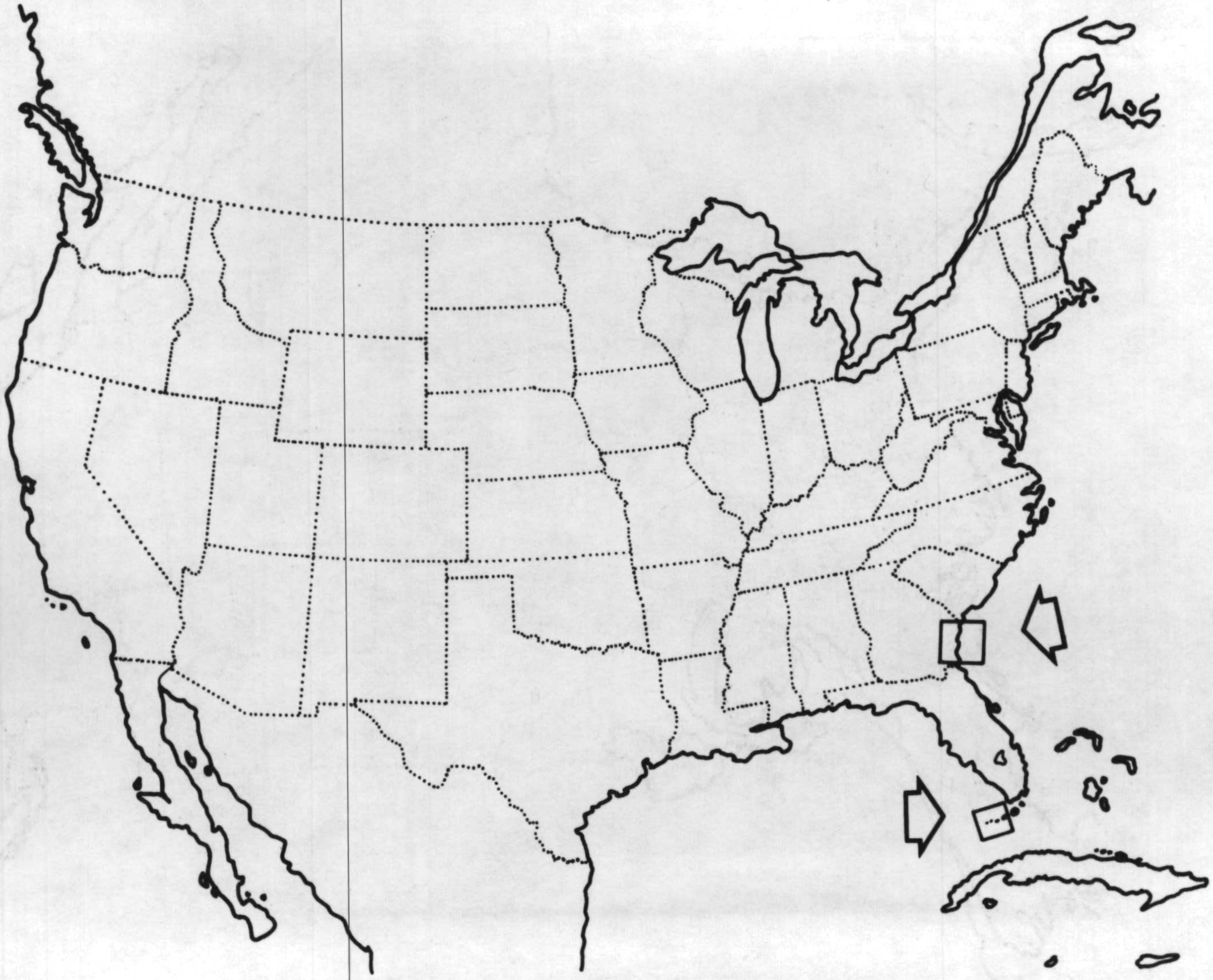

Fig. 11. Areas shown in two Color IR photographs, the coast of Georgia and a part of the Florida Keys.