Color–A New Dimension in Photogrammetry

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ABSTRACT: *Color aerial photography has great possibilities for improvement of photographic interpretation. This paper discusses the use of color aerial photography by the Coast and Geodetic Survey and presents illustrations of the application of color photography to a number of interpretative problems. It also describes Coast and Geodetic Survey techniques for color aerial photography and laboratory processing.*

COLOR film suitable for modern aerial photography is the most recent addition to a long list of improvements in the recording media and represents a very significant landmark in the development and application of aerial photography and photogrammetry to surveying and to the broad field of study of natural resources and phenomena. This paper describes the application of color photography by the U. S. Coast and Geodetic Survey and the Bureau's procedures for exposing color film and for processing color film and color prints.

The Coast and Geodetic Survey, an agency of the Department of Commerce, prepares and distributes nautical charts and related publications for maritime commerce and for navigation by all types of craft in the coastal waters of the United States. The Bureau also provides aeronautical charts for civil aviation, provides the basic geodetic surveys for the nation, and carries on extensive investigations in the earth sciences, including oceanography, seismology, and geomagnetism.

Photography and photogrammetry are used for surveys for nautical and aeronautical charts, for study of the ocean floor, for the measurement of tidal currents, for the tracking of satellites, and for the solution of many other day-to-day operating problems. At the moment, however, the primary concern is photogrammetric surveys for the Bureau's nautical charting program since it is here that color photography has found its most important and extensive application.

The Bureau first applied aerial photography to the maintenance of nautical charts in 1918. The use of aerial photography and photogrammetry has been continuous since about 1927. Over the last 30 years instruments and procedures have been developed especially for photogrammetric surveys for use in chart production and maintenance. Color photography is our most recent important addition to these procedures.

A nautical chart is made or revised from two basic types of surveys: the topographic survey of the coastline and the hydrographic survey of the adjacent waters. These two types of surveys are planned and executed conjointly. Aerial photography and photogrammetry precede the hydrography and accomplish the following:

Location of aids to navigation and land marks for charts.

Production of large-scale shoreline drawings or surveys with control stations for the hydrography, and including detailed shoreline, foreshore, and bottom information insofar as the latter is visible on the aerial photographs.

Revision of the land information on nautical chart drawings directly from the new aerial photography.

Today about 45% of the aerial photography taken for this purpose is color photography and an appreciable part of this is tide controlled, that is, the photographs are taken at exact tide stages by radio communication between tide observers and the aircraft.

One of our most important uses of the color aerial photography is to locate aids to navigation, that is, lights, day beacons, and buoys. The middle grey tone of water on panchromatic photographs does not contrast sufficiently with the aids to navigation for it to be recorded. Formerly, most of these aids had to be located by ground survey methods. Color photography, on the other hand, is excellent for this purpose because the aids to navigation are clearly recorded against the blue or green background. Many of the aids can be located or positioned in the office without even a trip to the field. In all cases the amount of field time for this purpose is greatly reduced by using color.

For hydrographic control and for charting, we require an accurate and very detailed map of the shoreline and alongshore features with as much information as possible about underwater details close to the shore. Formerly, when the dependence was solely on panchromatic photography, our field parties had to make a careful detailed ground inspection and make voluminous notes on the photographs to clarify these features. Color photography, and particularly tide-controlled color photography, eliminates much tedious field work.

Color photography penetrates the water and photographs bottom details. In parts of the Caribbean the bottom topography is recorded in depths as great as 60 or 70 feet. In northern waters this penetration is much less, 5 to 10 feet, but this is still very important. In restricted waters the low-water line, slightly submerged rocks, and other bottom details are important to the mariner. Consequently, the photogrammetric shoreline surveys preceding hydrography show as much of this information as possible. This guides and assists the hydrographer since his work is more difficult in shallow waters and since he otherwise does not have an over-all view of the bottom to guide his operations and to assist him in developing important details.

The first experience with aerial color photography by the U. S. Coast and Geodetic Survey came in 1945 with the exposure of several rolls of reversal or transparency type film using a standard cartographic camera of that period. The results of this experiment were very discouraging. The slowness and low resolving power of the emulsion and the small maximum aperture of the camera lens caused a serious underexposure and color distortion, in addition to the inherently low image-resolution of the emulsion. Some of the military experiments using faster normal-angle lenses resulted in correct exposure, but the advantages of color were still overshadowed by its failure to resolve small details which are vitally important in aerial photography. These early experiences are mentioned because they have influenced the evaluation of aerial color photography to this day. Through the years the tendency of the photogrammetrist and photointerpreter has been to think that through skillful interpretation more information can be obtained from panchromatic photographs than from color photographs. Our experience shows that this is no longer true.

In 1958, photogrammetric engineers of the Bureau re-evaluated color photography in connection with an unusual shoreline mapping problem. This research project involved the testing of two reversal and one-color negative type emulsions using a modern cartographic camera equipped with a fast anti-vignetting wide-angle lens. The results were much different this time—we were amazed and delighted with the ability of color emulsions to separate details not recorded on panchromatic photographs made with the same camera. However, a choice of the most suitable color emulsion for aerial photography was impossible because while one had a finer granular structure and gave better photographic resolution, another had a higher inherent contrast which is essential in aerial photography; also all three emulsions were too slow for use under adverse light conditions.

In 1959 additional experimental photography was made with a roll of Super Anscochrome film which was spooled especially for our test. This film was found to possess both the resolving power and required contrast and it was more than four times as fast as the other three film emulsions. Since 1959 there have been two more improved Ansco films and a new Kodak film produced which have further improved the resolution, color quality and film speed.

The Photographer and Color Film

Since accurate measurement of photographic images is essential in photogrammetry, it is important that the pictures exhibit a minimum of differential change in dimensions. Recently, color aerial films of consider-

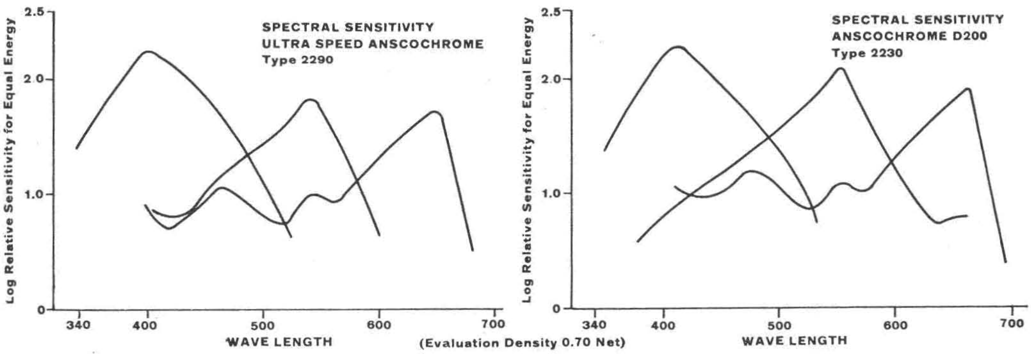

FIG. 1. Sensitivity curves for Ultra-Speed Anscochrome Aerial Film (FPC-132) and Anscochrome D-200 Aerial Film (FPC-289) used for making the aerial photographs shown in figures two to eight inclusive.

ably greater dimensional stability and low differential shrinkage have been introduced in this country by Ansco with their Plestar polycarbonate aerial film base. Further advances in the manufacture of dimensionally stable film supports for aerial photography with low differential shrinkage can be expected since the film manufacturers are well aware of the needs of photogrammetry.

The light-sensitive emulsion used for black and white photography consists of light-sensitive silver salts dispersed in a colloidal carrier such as gelatin. Such emulsions are commonly coated as a single layer or as two layers in intimate contact. Films for color photography have a more complex structure and consist of perhaps seven or more distinct layers coated separately on the film base. Three of the color film emulsion layers analyze the subject into its tricolor separation components and register their own specific portions of the visible light spectrum. Figure 1 shows the spectral sensitivity curves for Ansco Color Aerial Films types FPC-132 and FPC-289,—the ones we have found most useful for photogrammetry.

As with all photography, the prime responsibility for good quality pictures rests with the photographer. This is especially so for color film because the criteria for a proper exposure are much more sensitive than for black and white. Through experience gained by exposing several hundred rolls of color film, the U. S. Coast and Geodetic Survey has devised a highly successful method of exposure control. Table I shows in tabular form the *f*-stops required for varying conditions of light and terrain. The table applies specifically to Anscochrome 132 and 289 and must be revised for any other type of color emulsion used. The basic revision required, of course, is the ASA rating of the film. As indicated, FPC-132 and 289 are being used by the Coast and Geodetic Survey with an ASA speed of 250. This is a rate of plus 50 ASA and plus 90 ASA respectively above the manufacturer's recommendations. Film speed generally increases approximately 25% when used in aerial photography as compared with the speed of the film on the ground. The exposure tables have been made available by the Coast and Geodetic Survey as a service to other governmental agencies and to private individuals. Magnificent results have been obtained by photographers using the tables and who have had no previous experience in exposing color film.

TABLE I

COAST AND GEODETIC SURVEY EXPOSURE CHART FOR ANSCOCHROME AERIAL FILM ASA 250 (FPC-132 AND FPC-289)

DeJur Meter Readings—Camera 1/250 Second

	Lens Apertures				
	5.6	*6.3*	*8*	*11*	*16*
Light Water (Shoal)	50	75	100	200	400
Dark Water (Shoal)	15*	35	75	150	300
Medium Deep	25	40	50	100	200
Deep Water	15*	20	30	60	120
Beach	50	75	100	200	400
Light Trees	35	50	65	130	260
Dark Trees	20	30	40	80	120
Farm Land	50	75	100	200	400
City	35	50	65	130	260

Note: Readings obtained using a Weston meter should be halved.

* Meter readings lower than 20 result in underexposure.

An exposure table, revised for the color film to be used, is supplied to the photographer as a routine procedure during preparations for a photographic flight mission. The photoelectric cell component of the exposure meter is mounted outside of the aircraft body in a vertical position as near as possible to the lens of the camera. The light integrator is pointed at the target covered by the center crosshairs of the camera drift sight. Looking through the drift sight, the photographer identifies the objects on which the readings are to be taken. The two contact lead wires from the cell are brought into the aircraft so that the recording head of the meter is at a convenient angle for reading by the photographer. Five or six readings are taken at the beginning of the flight line and referred to the exposure table to determine the correct *f*-stop number. Continuous observations are made along the line and the *f*-stop adjusted accordingly. Extreme care is taken to preclude erroneous readings due to cloud light and cloud shadows on the objects. Haze conditions are countered by application of an additional correction to the *f*-stop determined from the table. Thus, whereas the absence of haze may allow an *f*-stop setting of 8, the presence of haze will require a smaller *f*-stop number such as *f*-11.

All pertinent information on meter readings, camera settings, terrain features, etc., is recorded in a flight log and returned with the exposed film to the laboratory.

Color photography in the Coast and Geodetic Survey is taken with RC-8 and RC-9 aerial cameras manufactured by the Wild Company in Switzerland. Special vignetting filters are used with the cameras to eliminate the hot spot that would otherwise form in the center of the photograph. The peach shading of the optical glass used for these filters serves to screen out the ultra-violet radiation while also depressing a portion of the blue spectrum. The camera-filter combination operates extremely well up to and at the maximum 23,000 foot altitude that can be reached by present aircraft of the Bureau. No other modification is necessary in the camera.

Laboratory Color Processing

The processing of color film to obtain either a color negative or a positive transparency is no more difficult than the normal processing of black and white film. When a positive transparency is produced, an actual time saving results because the transparency can be viewed, after drying, directly in its natural color. On the other hand, the negative that results from black and white processing, requires an additional printing step to produce the positive tones. The processing of color film, however, does require a precise maintenance of the time and temperature, and immaculate cleanliness in the laboratory. Though other equipment and procedures may yield equal results, the Coast and Geodetic Survey has found the following methods and equipment to produce excellent photographs.

After receipt from the field, the color film is processed in a Zeiss wind-rewind processing unit at 75 degrees using the standard Anscochrome 80 degree chemistry. The agitation provided automatically by the wind-rewind method eliminates the need for an additional nitrogen-burst agitation system. Table II shows the chemical treatments and the processing flow diagram. The difficulty of incorporating a step-wedge into the wind-rewind technique makes mandatory the introduction of a *p*H-meter for proper control of the chemistry. A standard Beckman hand *p*H-meter suffices for this operation. The Coast and Geodetic Survey also uses a MacBeth *p*H-meter as a control to the Beckman as a precautionary measure to insure accuracy at all times. Table III depicts the Ansco recommended *p*H levels and allowable tolerances for each chemical step. A departure from these levels may be necessary because of the chemical makeup of local water sources. The Coast and Geodetic Survey has found that the use of a forced-air-type film dryer without heat, and a dilution of the final rinse solution in the dewind tank to six parts of water to one part of rinse chemical, permits a reduction in the number of required tanks. The rinse solution also functions as the final wetting agent in the process.

The Coast and Geodetic Survey has established a procedure for making reflective-type prints on Ansco Printon material for field and office use. Printon is a reversal material possessing the high resolution and dimensional stability required for photogrammetric measurements. The prints are processed at 75 degrees using Anscochrome 80 degree chemistry. This simplifies the water temperature control problem since all laboratory operations can be performed at a single temperature. Sensitometric strips are processed along with each Printon run. The *p*H readings are taken once every morning prior to the start of operations.

Two methods are used for making the prints. The first method employs a Salzman

FIG. 2 This 1:10,000 scale view of Shark River Slough, Everglades National Park, Florida, was photographed November 5, 1962, by Coast and Geodetic Survey for hydrology studies by the Geological survey. Color photography provides data on vegetation characteristics and stream patterns that are unavailable from panchromatic aerial views.

FIG. 3 All of Key West, Florida, and the surrounding area, showing both natural and man-made underwater features, are revealed in this 1:40,000 scale photograph made in March, 1960.

FIG. 4 Hyannis Port, Massachusetts, photographed October 12, 1960, 1:5,000 scale clearly showing water line details that are measurable when stereo pairs are viewed.

FIG. 5 Exceptional detail for intelligence or engineering interpretation is shown in this 1:5,000 view of Seattle, Washington, made June 10, 1963, on Anscochrome 200 (FPC-289) film.

FIG. 6 Beltsville, Maryland, 1:5,000, photographed May 4, 1963. Note flowering dogwood trees in center of the picture.

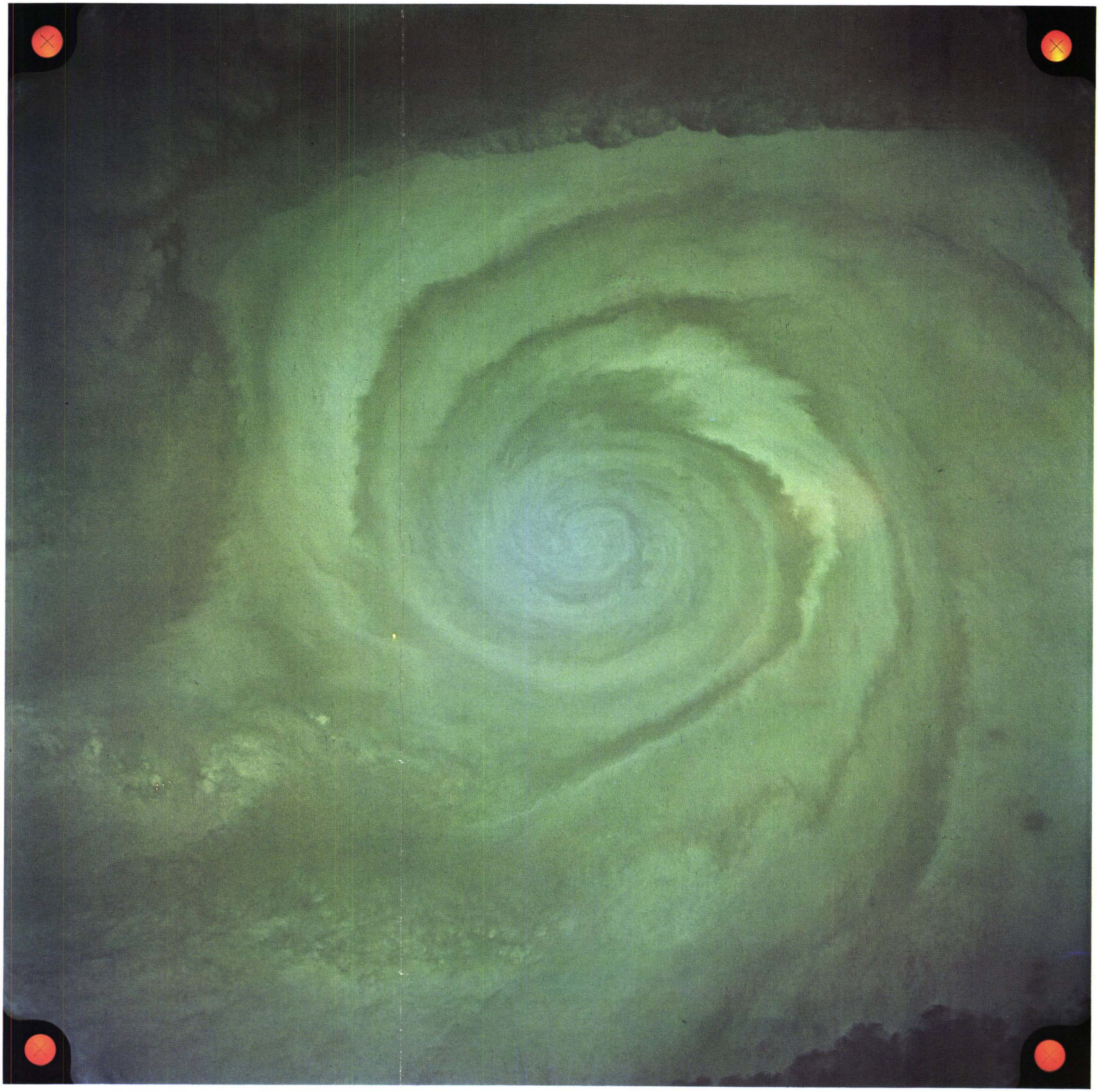

FIG. 7 Oceanographic phenomenon, the Smith-Benton Eddy, photographed (1:10,000) north of St. John's Island, Caribbean, 1960. Color photography gives tonal separation.

FIG. 8 Color photogrammetry on the ocean bottom, 14,400 feet below the surface by electronic flash exposure. One-half of a stereo pair exposed in a Coast and Geodetic Survey Edgerton camera on FPC-289 (Anscochrome 200) film near Hawaii.

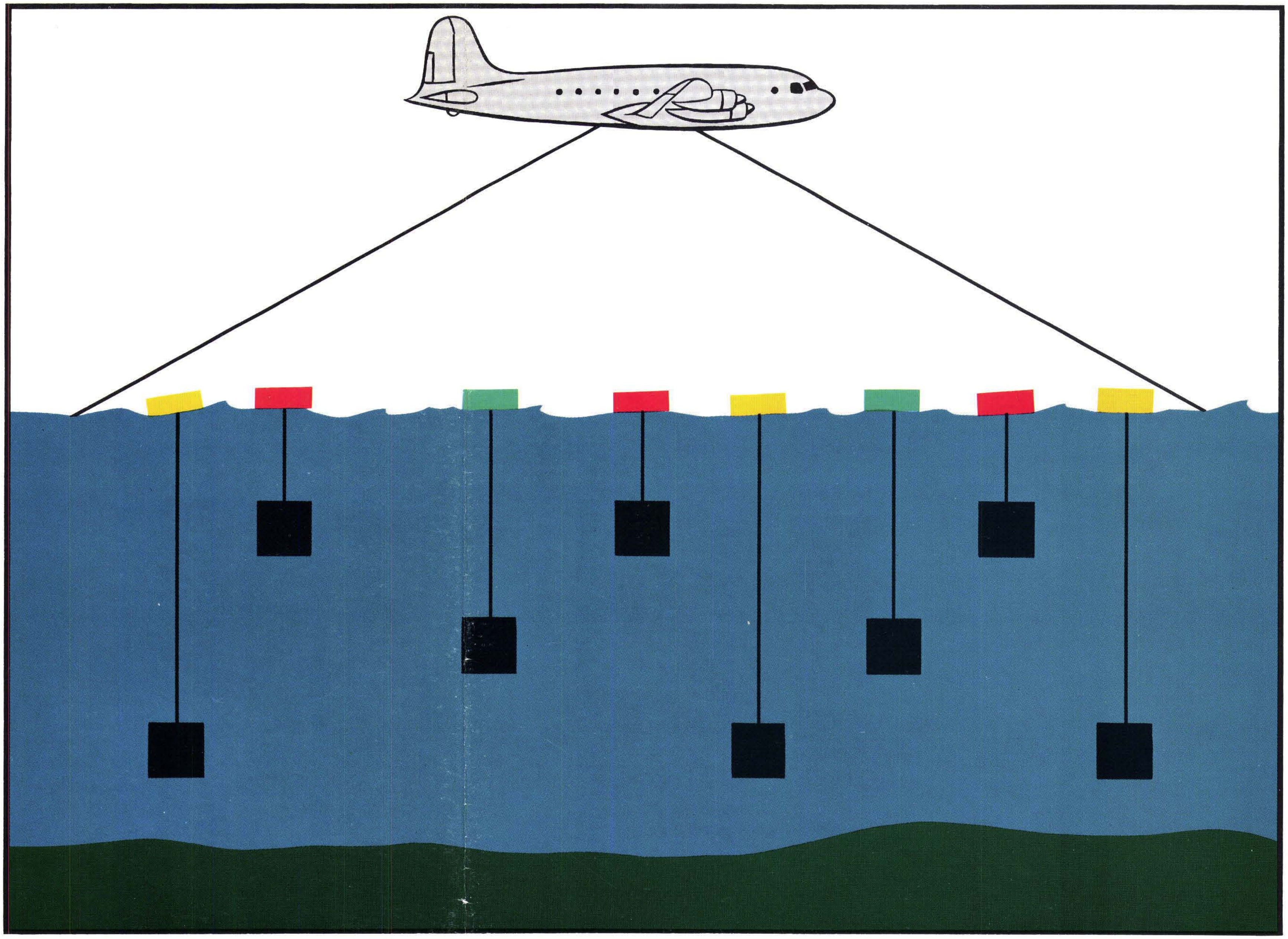

FIG. 9 Color-coded floats moved by underwater drogues traveling at different depths provide tidal current measurements by means of sequential color aerial photographs.

TABLE II

SUGGESTED PROCESSING TIME AND TEMPERATURE TABLE FOR ANSCOCHROME TYPE FILMS

	Solution	*Temperature*	*100 Ft.*
	TOTAL DARKNESS		
1)	Pre bath	75F ± 2F	6
2)	First Developer	75F ± $\frac{1}{4}$F	12
3)	Short stop hardener	75F ± 2F	5
	Wash in running water	70F – 75F	20
	Second exposure—Two complete cycles with a #2 photoflood 3 ft. from each side of the film		
	Note: Handle the wet film carefully so that no water will splatter on the hot lamp causing it to shatter.		
	ROOM LIGHT		
	Color Developer	75F ± $\frac{1}{2}$F	32
	Short stop hardener	75F ± 2F	5
	Wash in running water	70F – 75F	20
	Bleach	75F ± 2F	11
	Wash in running water	70F – 75F	10
	Fixer	75F ± 2F	6
	Wash in running water	70F – 75F	15
	Stabilizer	75F ± 2F	6
	Wash in running water	70F – 75F	3
	Final rinse	75F ± 2F	2

Note: Wash times for this process have been calculated on the basis of a $2\frac{1}{2}$ gallon /minute flow. If the water flow is less than this wash times should be increased.

rectifier equipped with an Aristo full-spectrum light source to make projection-type prints. The other technique uses a LogEtronic contact printer having a full-spectrum cathoderay tube designed to Coast and Geodetic Survey specifications. The lack of an available practical means for determining the proper exposure and color balance on the printing platen forced the Bureau to develop its own solution to the problem. This solution employs a rigid full-spectrum light source and a cone-shaped hood to cover a 9×9 transparency format. A MacBeth Quanta-Log color analyzer, using an integrating system, was then incorporated into the method. The integrating system was selected because the small size of the photographic images on the transparencies would have required multiple direct densitometer measurements to arrive at the correct color balance and exposure time. The system reduced to a few seconds the time needed to make the readings. Ninety-five per cent of the prints produced during the past year by the integrating system have been of excellent quality.

The prints are processed in a Rolor processing unit built to Coast and Geodetic Survey specifications. The unit can handle aerial prints in the square format sizes that are not used by commercial photographic organizations.

THE COST OF COLOR VERSUS BLACK AND WHITE

Color photography does not add greatly to the total cost of aerial photography for a surveying or mapping project. The largest factor in the cost of aerial photography is the cost of operating the aircraft, and this, of course, is the same regardless of the type of film emulsion used. Thus, while the laboratory processing of color film and preparation of color prints cost considerably more than black and white processing, the total cost of the photography is not greatly increased.

Figure 2 (Photo: 1589; flown November 5, 1962, at 5,000 feet; location: approximately latitude 25°32′, longitude 80°45′, in Shark River Slough, Everglades National Park, Florida) was photographed and processed by Coast and Geodetic Survey for Geological Survey's use in hydrology studies. The photograph shows the typical prairie wetland of the Florida Everglades in the Shark River Slough area under moderately high water levels which generally prevail throughout summer and fall. The areas shown of open water of up to 4 feet deep, form a braided stream pattern through the slough area. Velocities in these open areas are considerably less than one foot

TABLE III

NORMAL pH LEVELS AND RECOMMENDED TOLERANCES FOR ANSCOCHROME PROCESSING SOLUTIONS—R–1 PROCESS

Solution	*Normal Fresh pH*	*Useful pH Range*
First Developer	10.20	10.15 to 10.25
First Developer Replenisher	10.25	10.20 to 10.30
Short Stop Hardener	4.50	4.40 to 4.60
Short Stop Hardener Replenisher	4.10	4.00 to 4.20
Color Developer	10.60	10.55 to 10.65
Color Developer Replenisher	10.75	10.70 to 10.80
Bleach	5.20	5.10 to 5.30
Bleach Replenisher	5.20	5.10 to 5.30
Fixer	9.50	9.40 to 9.60
Fixer Replenisher	9.50	9.40 to 9.60
Stabilizer	6.90	6.60 to 7.20
Final Rinse	7.00	6.90 to 7.10

per second. The light yellow areas are the underlying Miami Oolite where the mat of bottom vegetation and humus has broken loose and floated away. The major vegetation of this part of the area is sawgrass (*Mariscus jamaicensis*) and is readily distinguishable in the photograph by its light blue-green color and slightly mottled appearance. Differences in tonal quality also permit separation of the two major varieties. The bay-heads and hammocks are woody vegetation, consisting of gumbo limbo (*Elaphrium simaruba*), strangler fig (*Ficus aurea*), red bay (*Tamala borbonia*), and wax myrtle (*Cero thamnus ceriferus*). These are readily distinguished as the large, darker trees in the bay heads and heads of the hammocks. The "tails" of the hammocks consist mainly of willow (*Salix*).

The photography is being used as a tool in evaluation of the hydrology of the Everglades Park. The Geological Survey is trying to determine the quantities of water necessary to maintain the present ecology of the area, and the present sources of this water. One aspect is the determination of quantities of water flowing through the relatively inaccessible Shark River Slough area. The Geological Survey hopes to accomplish this by obtaining approximate cross-sections through the slough by photogrammetry, and approximate velocities in these channels, by additional hydraulic observations and relationships. Also, by comparison of vegetation in successive flights at seasonal intervals, they should be able to assess the effect of the fluctuations in water levels during the intervening periods upon the ecology. Color photography provides the only feasible means of accomplishing all these objectives.

Figure 3 (Photograph 60S413; flown March 11, 1960; scale 1:40,000, Key West, Florida) shows the whole of Key West, Florida, and surrounding underwater features. The photograph shows the coral shelf surrounding the island and vividly illustrates the amount of underwater detail that can be furnished as a guide to the hydrographer.

Figure 4 (Photo 60S3898; flown October 12, 1960; Hyannis Port, Massachusetts; scale 1:5,000) is typical of the color photography used for shoreline mapping. Note the clarity of shoreline details and the alongshore rocks both above and below the water level. This type of photography is also taken periodically for revising the land details on nautical charts and for location of aids to navigation.

Figure 5 (Photo 63W6435; flown June 10, 1963; Seattle, Washington; scale 1:5,000) illustrates how this type of photography is invaluable to map makers and for military intelligence, as the activity of the area is so readily identified, even by an untrained interpreter. The information contained in this type of photography can be of immeasurable benefit for city planning in general and for railroad lines, dock facilities, storage tanks, street information.

Figure 6 (Photo 63S6287; flown May 4, 1963; Beltsville, Maryland; scale 1:5,000) illustrates the use of color photography in forestry surveys. Types and varieties of trees are readily identified, and diseased trees may be located even before they become visibly affected from the ground. Note that all the crowns of trees are clearly visible, and also penetration to the ground in many areas. By the use of stereo plotting, animal refuge areas may be located, and the type and amount of vegetation for survival of wild animals noted. This information is used to determine whether animal herds need thinning because their food supply is low, or whether herds may be allowed to build when a sufficient supply of food is indicated.

In addition, highway planning is simplified for the types of soil and moist areas are easily distinguished in color.

Figure 7 (Oceanography photo; north of St. John's Island, Caribbean; flown 1960; Smith-Benton Eddy; scale 1:10,000) is a photograph of an eddy pattern 1½ miles across. It was photographed from 5,000 feet above the ocean. The stereo photography showed that there was no noticeable circular motion at the time of the photography. This extremely rare oceanic feature most probably is a remnant of a current eddy which developed along the boundary between clear and turbid water masses to form the spiral pattern. The eddy was sighted while a photographic project was in progress in the vicinity of St. John's Island, near Puerto Rico.

Most often, photogrammetry is thought of as pictures from an airplane. Figure 8 illustrates that photogrammetry can also be done from the suspension of cameras from a ship. This single photograph from a stereo pair is at a depth of 14,400 feet, photographed by Coast and Geodetic Survey Ship Pioneer at 19°50.0′ N, 154°20.0′ W. It indicates volcanic lava outcroppings on the floor of the Pacific near the Hawaiian Islands. Two small, deep-sea benthonic organisms show in the photograph, and some sediment has accumulated in the depressions. We know that the ocean floor can reveal many beautiful colors. By the use of color photography, ocean bottom fish and plant life can be readily distinguished and identified.

Figure 9 illustrates the use of color photography and color coding of floating targets for tidal current measurements. In this case the color indicates the type and depth of current drogues set below the surface targets.

One of the great problems of photography over water is that of the sun spot entering the photograph and obscuring vital information. The Coast and Geodetic Survey has found that photography over water gives both better penetration and, of course, smaller sun spots if the photography is conducted before 9 o'clock in the morning and after 3 o'clock in the afternoon. The position of the sun relative to the camera must be considered very seriously whenever photographs over water are being taken. Evaluation should be made of photographic areas prior to flights. The study, which is a standard procedure in the Division of Photogrammetry, requires the plotting of the hourly trace of the sun's image at the photographic scale. Depending on the time of day, different flight lines are then drawn to preclude the appearance of the sun's spot in critical portions of the photography.

Color photography, as evident from these examples, has indeed traveled a long way along the road toward universal acceptance. Every effort is being made by the film manufacturing companies to improve their product and thereby extend the utilization of color aerial photography. We look forward to color emulsions on glass plates in the not too distant future and expect to see color photography largely replace other types for detailed mapping and interpretative studies.

A partial list of the fields of interest includes agriculture, archaeology, architecture, astronomy, biology, drainage, engineering construction, erosion, fish, game and wildlife, flood control, forestry, geography, geology, highways, hydrography, hydrology, irrigation, land management, mapping, minerology, national defense, oceanography, property line delineation, resource planning, satellite tracking, soils, tidal current surveys, traffic, transportation, and urban area analysis.*

There is still some argument that through the proper choice of filters the same or better recording of colored objects can be obtained with panchromatic emulsions. This argument is theoretically sound and it works in practice if there are only two colors to be separated and these colors are complementary or nearly so. Unfortunately, the delicate variations of colors and hues occurring in nature are too numerous and too complicated to be separated by any reasonable number of cameras equipped with color separation filters. Coastal water penetration photography is an example which illustrates the economy and practicality of color over panchromatic photography taken with special filters selected for water penetration. The color of the water in a single photograph frequently changes gradually from that of clay soil near a river entrance to green in more clear inshore areas, then through the blue-greens to the blue and finally to the blue-violet. This range covers a large portion of the visible spectrum and therefore makes color photography the logical choice.

Many photointerpreters today are discovering that contrary to what they have believed for many years, the world outside is not made up of grey tones, but is in full color.

* See also "Values and Uses of Photogrammetry." PHOTOGRAMMETRIC ENGINEERING, Vol. XXIX, No. 1, p. 146.