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WATER DEPTH ESTIMATION WITH ERTS-1 IMAGERY

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ABSTRACT

Contrast-enhanced 9.5 inch ERTS-1 images were produced for an investigation on ocean water color. Such images lend themselves to water depth estimation by photographic and electronic density contouring.

MSS-4 and -5 images of the Great Bahama Bank were density-sliced by both methods. Correlation was found between the MSS-4 image and a hydrographic chart at 1:467,000 scale, in a number of areas corresponding to water depth of less than 2 meters, 5 to 10 meters and 10 to about 20 meters. The MSS-5 image was restricted to depths of about 2 meters.

Where reflective bottom and clear water are found, ERTS-1 MSS-4 images can be used with density contouring by electronic or photographic methods for estimating depths to 5 meters within about one meter.

1. INTRODUCTION

There are about 130,000 km of world coastline commonly plied by shipping. The continental shelves have an average slope of 2 m/km. (1) The coastal ocean area up to 20 m depth is in the order of 1,300,000 km^2, while shallow seas have more than an equivalent area in this depth range. It has been estimated that 95% of the world's coastal waters permit 70% or more light transmission per meter (70% = 5 m Secchi Depth. (2) The potential area for water depth examination by ERTS is thus very large.

Natural Color Gemini and Apollo space photography proved it was possible to see the ocean bottom in clear water at depths to 30 meters or more. Although ERTS-1 is primarily designed for terrain sensing, and does not have a blue spectral band contributing image energy equivalent to that sensed by the color film in the blue region, nevertheless a number of MSS-4 images show evidence of bottom recording in depths of 10 meters or more.

Specially processed ERTS-1 images appear capable of yielding information at image scales as large as 1:100,000, which can contribute materially to knowledge of changes in world coastal bathymetry. Most charts were originally hand-contoured from sometimes limited sounding data; many have not been revised for 10, 20 or even 50 years, and bottom topography has been altered in the interim by storms, currents and tidal action.

2. LIGHT TRANSMISSION IN SEAWATER

Maximum transmission of light in clear seawater is in the 470-480 nm blue-green spectral region. (3) Water acts as an optical filter, progressively absorbing radiant energy at longer wavelengths, until almost complete absorption occurs in the near-infrared. Maximum clear water transmission is found in the green ERTS-1 MSS-4 band (Figure 1). In coastal waters suspensions of sediment, biological matter and pollutants, according to types and concentrations, attenuate light transmission and shift the water window from the blue-green toward the longer wavelength green and yellow spectral regions. Heavy concentrations of suspended matter eventually restrict remote sensing to surface or near surface spatial and spectral information in all bands.

3. IMAGE ENHANCEMENT FOR WATER DEPTH ESTIMATION

ERTS-1 images require enhancement for this purpose. During an investigation on ocean water color several MSS-4 images of the shallow Bahama Banks were worked with, and areas of possible correlation between image density and chart depths were noted. Photographic and electronic density contouring processes were then applied.

Contrast Enhancement. ERTS-1 images are reproduced at gamma 1.0, exactly as the sensor saw the scene through the atmosphere. Ocean phenomena are normally of low contrast to begin with and, in the MSS-4 gamma 1.0 reproduction, may be further reduced to a half or fifth of true ground value by Rayleigh and Mie effects. Scene contrast can be partially restored by reprinting the image on high contrast photographic materials by carefully controlled, conventional processes. One of the images selected (Figure 2) was reproduced at gamma 2.55; densities in the original between the shallow water and deep ocean had a range of 0.52, increased during reproduction to 1.33. The enhanced contrast and improved density range of this image, when compared with the hydrographic chart at 1:1,000,000 scale, showed large areas of correlation with depth. However, the small differences in the continuous tone density scale made positive judgement of density boundaries difficult, and density-slicing was resorted to.

Photo-Optical Density-Slicing. Fourteen isodensity slices were made of the water area by an I^2S technique, each density contour being produced on a separate sheet of film. In the final registered false color composite, these were reduced for clarity to five 0.075 density contours and four 0.037 D steps, to represent the 0.52 density range in the input image.

Electronic Density Contouring. The image was processed in an I^2S Digicol electronic image analyzer. This method permits real-time density slicing under the control of the operator, with false color display of density differences, the ability to make spot density measurements, cut density profiles through the image, and to do planimetry of selected areas. As the image is converted to digital form, it can be fed into storage or computer processing. Density slice-width and placement within the density range of the input image is also possible. Black and white resolution is limited to 1000 X 1000 elements, and color to 525 X 525; however, the image area viewed by the video camera lens can be reduced to match the inherent resolution of the image, thus preserving the information content.

4. RESULTS

Figure 3 (original in color) shows groupings of the photo-optical density slices for depths of less than 2 meters and approximately 5 and 10 meters. The chart, C & GS 1112, 1:466,940 (Rev. 23 Sept. 68), was reduced to 1:1,000,000 scale for overlay and slice selection. Chart depths are in fathoms for mean low water. Water less than one meter deep is clearly separated in areas to the S. and E. of Bimini, and along the Keys to the S. These areas total about 12,500 km^2. In the S. E. corner of the image where chart depths average 4 m, however, an extensive area shows as equally shallow. This may be caused by sunglitter, although the chart warns "The charted position, size, shape and orientation of the---banks in the Bahama Islands are unreliable". Other density slices representing 4-5 m depths agree well with the chart and total about 75,000 km^2 in area. The deeper water area is confused by cloud and cloud shadow, but general correlation exists for 5-10 m. The northern end of the Bank has a well-defined shelf about 18 m deep, changing abruptly to 180 m and more. Correlation was found here for an area about 8,000 km^2, but the image density was very close to the D max of the original positive and on the borderline of detectibility.

As shown in Figure 4, very similar results were obtained with electronic image digitizing, but with the advantage of "tuning in" to the minimum separate density variations in real time.

The image of the area off Key Largo (Figure 5) was enlarged 12.5X to 1:80,000 chart scale. Tide had been rising for several hours prior to image acquisition; figures which follow are for mean low water. On the untreated enlargement, light reflected from the bottom was found on linear features about 200 m wide, in shallow water. Several circular formations, both light and dark, and 200 m in diameter also correlated with the chart. Theoretically, bulk MSS can resolve 136 m with a low contrast subject. Extensive areas 8 to 10 m deep agreed with the chart, the deepest being about 12 m. Many tone reversals were found, due to marine grasses and corals at 2-3 m, which, however, followed the depth contours quite closely.

Electronic image digitization, as shown in Figure 5, was applied to contour the enlarged image. Time has not permitted photo-optical density slicing of this image, but it is evident that either technique is an essential aid for the interpretation of image density domains related to water depth.

5. BATHYMETRIC INTERPRETATION

The Bahama Banks image was from an area where the ocean bottom is largely homogeneous and composed of highly reflective calcareous materials; the Florida Reef image has very inhomogeneous bottom. Relating density information in ERTS images to water depth must be done with caution, as many factors affect apparent water luminance and bottom reflection. Bathymetric interpretation should be done by the professional hydrographer or oceanographer, familiar with the area examined. Enhanced ERTS imagery would aid him by greatly reducing the number and length of transects required to sound a large area and by identifying areas requiring close investigation. MSS bands -4, -5 and -6 are particularly useful for this work. MSS-5 is strictly limited in water penetration, but clearly delineated, in this test, areas where chart depths were less than 2 m. Bands -6 and -7 show surface detail primarily; in several cases MSS-6 images show density differences in charted depths of one-half to 2 meters; Figure 5 shows an example.

Effects of Marine Flora. Some Caribbean regions have dense beds of marine grasses, or living corals, which modify reflectance from the bottom, and could lead to false conclusions about water depth. However, many marine algae show depth zonation tendencies related to the depth at which they can satisfy photosynthetic processes. (4,5) Knowledge of algae types, location and associated depths in a region could aid interpretation. Certain algae also require specific types of bottom. Some of the kelp families require firm holdfasts, and also expose fronds of the surface, the latter being detectible in the infrared bands as surface phenomena. Several clearly defined areas in Figure 2 to the south and east of Bimini are judged to be large algael beds at depths in the order of 4 meters.

Turbid Water. Light-colored sediments in the water can give false indications of shallow water. Near-surface turbidity normally appears similar in images of different spectral bands, but is usually identifiable by distinctive eddies and flow-lines. Turbid water currents appear to follow bottom topography in some instances.

Surface Reflectance. Large bodies of wind-generated whitecaps, individually below sensor resolution limits, become integrated as light areas, and will appear about the same order of density in all spectral bands. At high sun elevations, in relatively calm seas, many wave facets may be tilted and oriented to reflect integrated sunglitter directly into the sensor. Wave angles below 20° with sun elevations of 60° can cause this. Light areas (in the positive) will appear in all bands from this effect. Swells with wavelengths in the order of 100 meters would give similar results.

ERTS-Image Densities. ERTS image density range is primarily controlled for terrain subjects, and water areas in MSS-5, -6 and -7 positive images may be very dense and appear featureless when comparing these bands, unless examined by high-intensity transmitted light, or reprinted for the water area. Very thin cloud otherwise may be concealed by high densities in these bands, and may be mistaken in MSS-4 as a variation in water luminosity and depth.

6. CONCLUSIONS

Under favorable circumstances ERTS-MSS resolution can detect subsurface detail as small as 200 m in diameter. Enhanced and density-contoured imagery appears to permit estimation of water depth to at least 5 m within a meter or so, in the regions and at the scales assessed; and would be a valuable aid to chart revision by directing the hydrographer to areas requiring closer examination. Water depth over large areas of world coastline and shallow seas can be assessed by ERTS imagery and image processing techniques.

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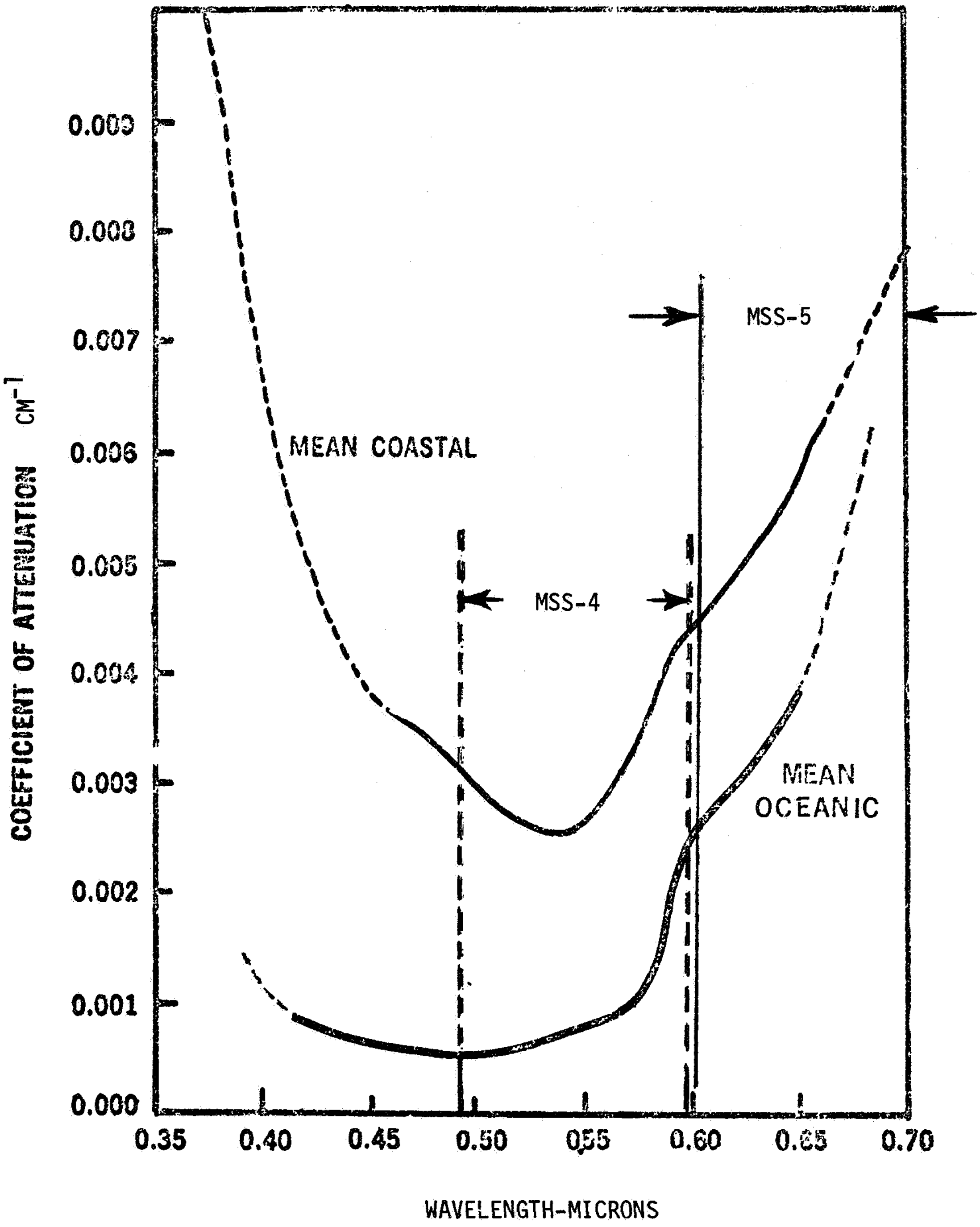

Figure 1. Light Attenuation in Ocean Water and ERTS-1 MSS-4 and MSS-5 Spectral Bands.

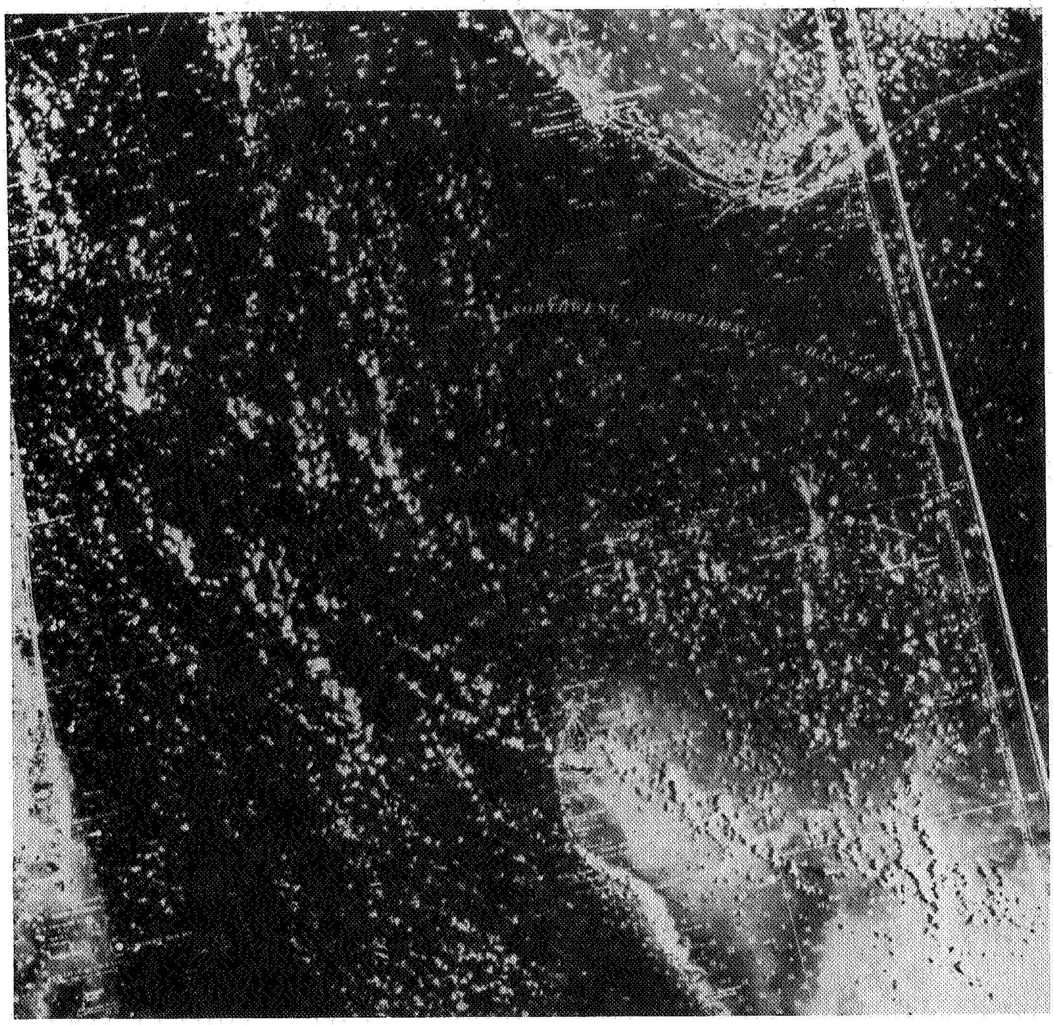

Figure 2. E-1007-15165-4. Lower Right, Great Bahama Bank with Chart Overlay. Original Scale 1:1,000,000.

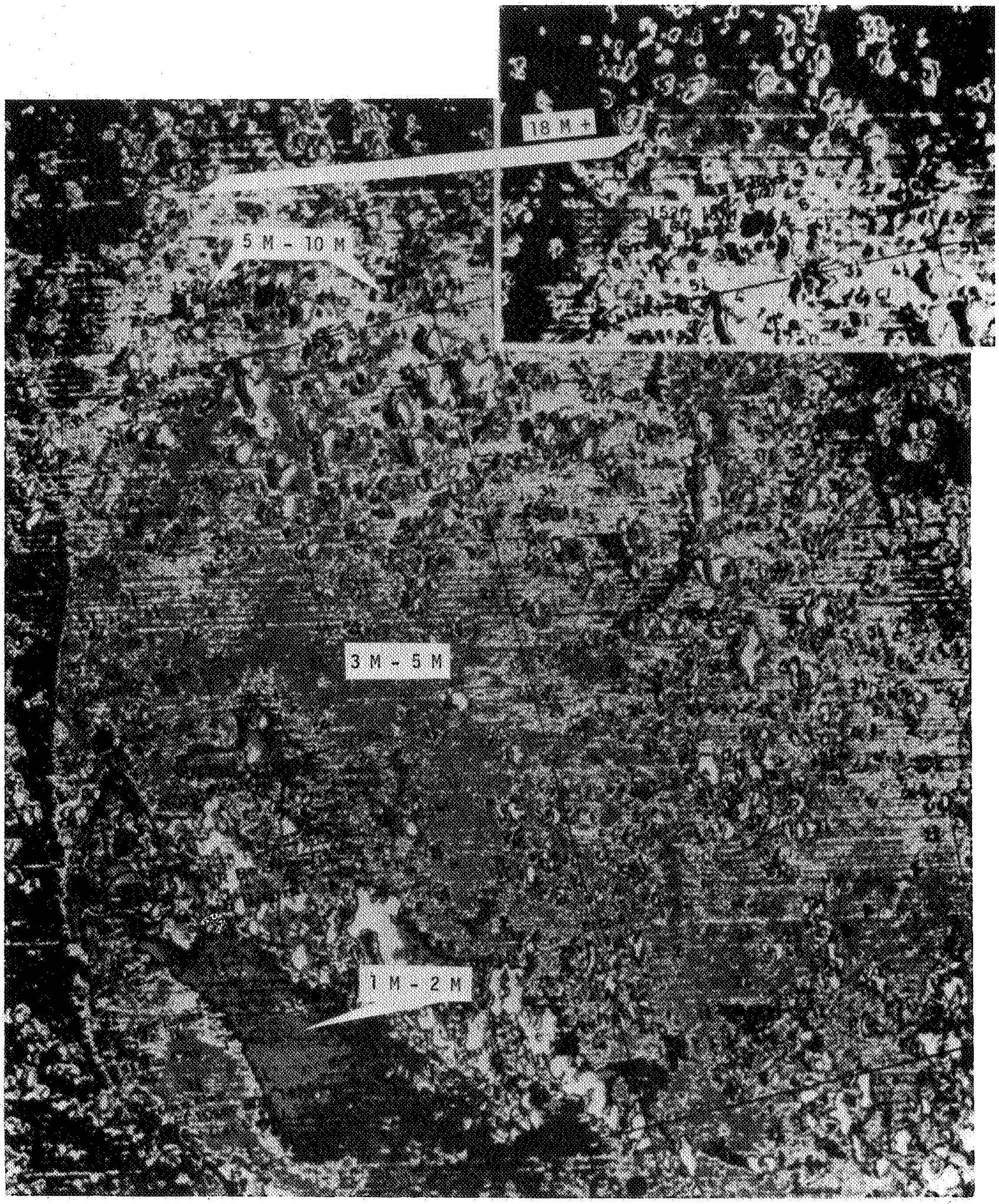

Figure 3. Photo-Optical Density Slices for Depths of 2 M or Less, 3 M – 5 M, and 5 M – 10 M. Note Enlarged Area Where Depth is 18 M or More. (Original in Color).

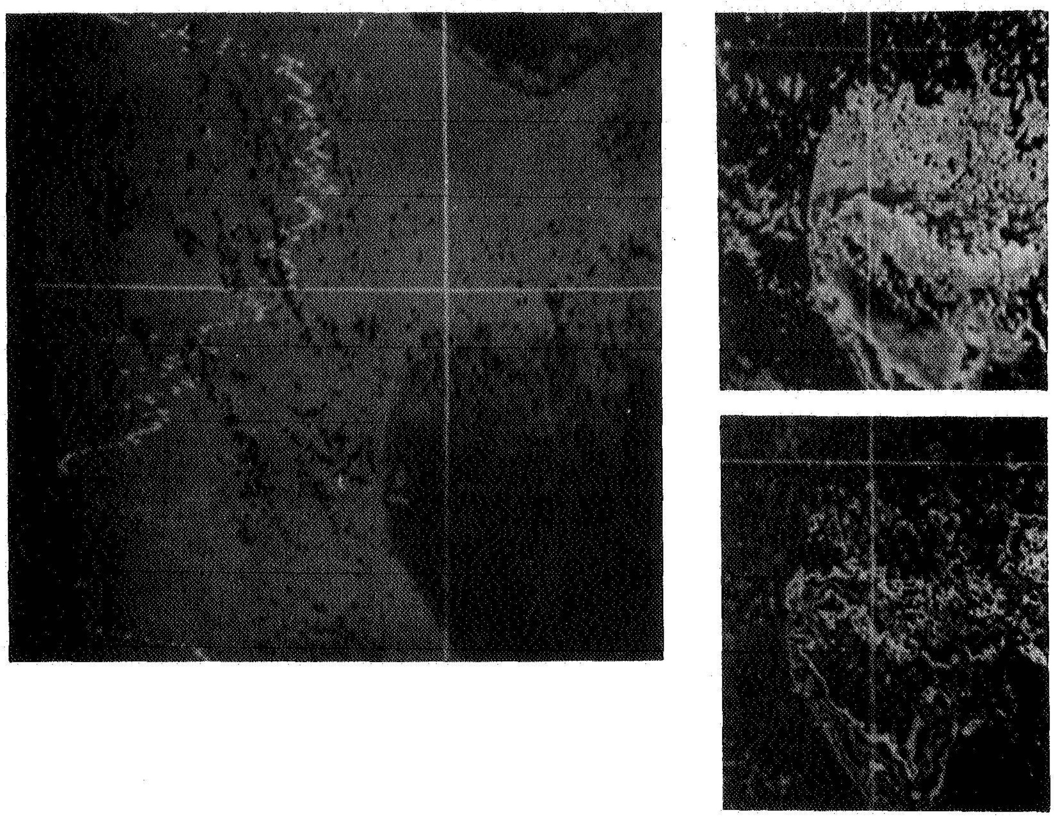

Figure 4. Electronic (Digicol) Image Density Contouring (Original in Color). The Input Image is Displayed as a Continuous Tone Negative Image on the Left. The Electronic Marker Lines Intersect Where 180 M Water Depths Begin. The Transmission Profile of the Negative Cut by the Vertical Line is Displayed to the Left as the Wavy White Curve.

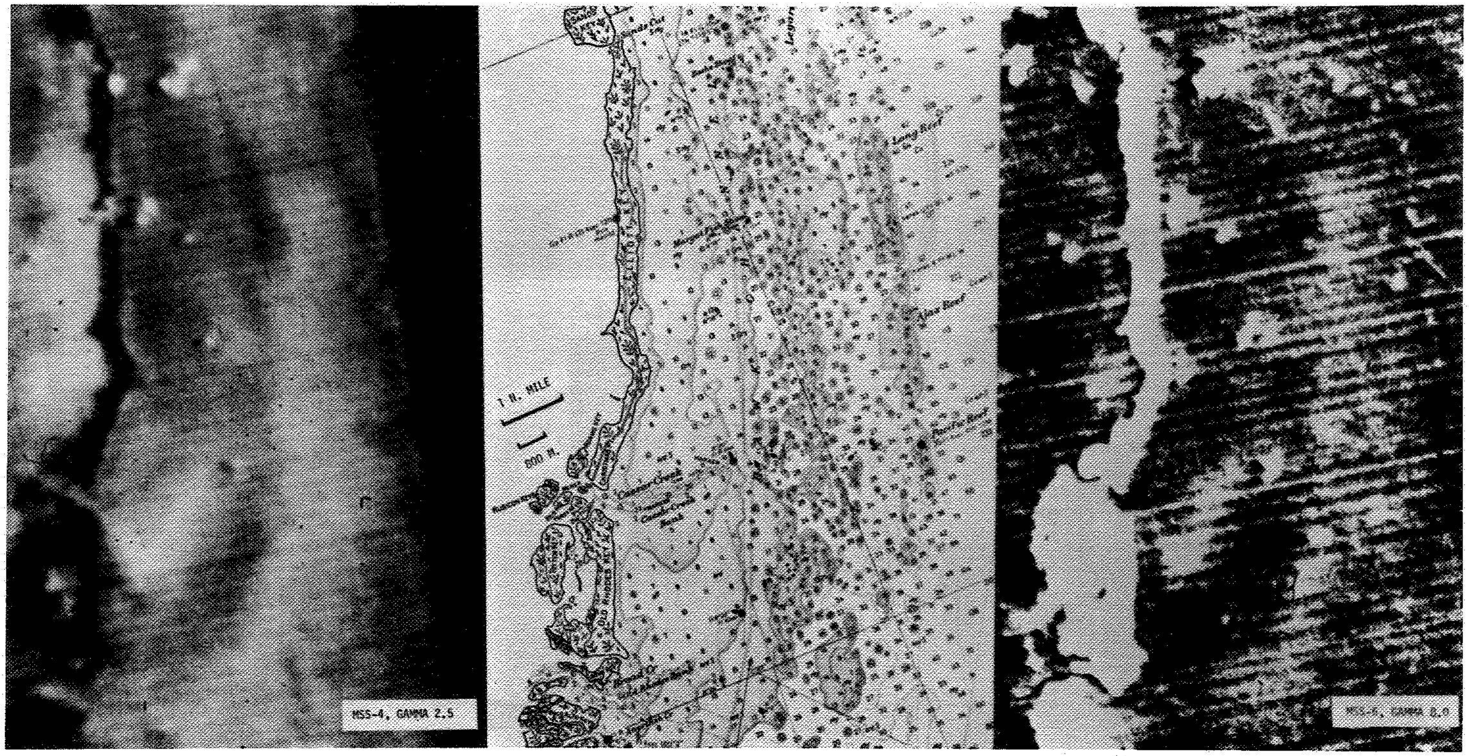

Figure 5. Section of MSS-4 and MSS-6, E-1007-15172, Enlarged 12.5X to Chart C&GS 1249, (Rev. Oct. 21, 1968) Scale 1:80,000. Area Shown is North of Key Largo Coral Reef Preserve Near Miami, Florida. White Bottom Areas in MSS-4 (Left) Near Edge of Reef Are About 200 M Wide. MSS-6 Image (Right) 700 NM-800 NM Shows Bottom on Ceasar Creek Bank, Probable Depth of 0.5 M, but Also Distinguishes Bottom Reflectance in 1 M to 2 M Depths. Chart Depths are in Feet.