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DERIVATION OF SHALLOW OCEAN BOTTOM REFLECTANCE VALUES
FROM COLOR AERIAL PHOTOGRAPHY

Donald J. Gerson, Lynn K. Fehrenbach,

Kenneth R. Piech, and David W. Gaucher

JUN 17 1981

I. ABSTRACT

An alternative to the field survey method of acquiring hydrographic data is described. The technique involves the use of digitized color aerial photography in the derivation of the percentage of reflectance of shallow ocean bottom materials. These spectral reflectance values can then be used in an algorithm for calculating water depths. The reflectances that were derived in this study show a close relative comparison to ground truth information. After a discussion of the causes of discrepancies between derived and actual reflectance values, it is concluded that this method of data acquisition merits further investigation due to its high geometric fidelity, its simplicity, and its cost and time-saving benefits.

II. BACKGROUND

Collection of data for hydrographic charting purposes is expensive, time-consuming, and in some cases, very difficult to accomplish. Conventional methods of shipboard data collection have progressed over the years to the present, highly sophisticated sounding techniques which often utilize sonar arrays and onboard computers. Shallow-water hydrographic data, however, must still be collected by sounding boats which make use of precision fathometers, and which can obtain only one depth profile per survey line. This data collection method is accurate enough in good weather conditions, but is extremely time-consuming in relation to the volume of data that is recorded. Even though new shipboard methods are presently under development, lengthy traverses across the area being surveyed will still be necessary in order to ultimately produce accurate and comprehensive charts.

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New aerial data collection methods, including multispectral scanners and laser sounders mounted on aircr ft, are now being developed for hydrographic charting. These systems show excellent promise and, within their depth capability, could become standard data acquisition systems of the future. Being expensive and unique, however, their availability will be initially limited. Moreover, interpretation of the data obtained from these sensors can require extensive analysis.

An earth-orbiting observation platform, LANDSAT, collects imagery which has previously been used in certain hydrographic analyses. Because the wavelengths associated with spectral Bands 4 and 5 can record solar radiation reflected from surfaces below water level, LANDSAT has been particularly useful in relatively shallow, clear water studies. Features which lie at depths of 30 - 40 meters have been mapped in some areas using various band combinations of LANDSAT's multispectral scanner (MSS) imagery.

An algorithm has been developed[1] cooperatively by the Environmental Research Institute of Michigan (ERIM) and the Defense Mapping Agency (DMA) to derive water depths through the interpretation of LANDSAT data and/or airborne remotely sensed MSS data. This method makes use of the fact that apparent shallow ocean bottom reflectances are exponentially attenuated when energy is propagated through water. In order to perform water depth calculations, it is necessary to determine (1) the reflectance of bottom materials, (2) the extinction coefficient of the intervening water column, (3) the bottom reflectance measured at the surface of the water, and (4) surface reflectance in deep water.

The application of the aforementioned algorithm to ocean mapping is of real importance. The use of LANDSAT allows large hydrographic survey areas to be covered with moderate resolution, and the use of airborne MSS data provides even greater mapping precision; but there are problems with both of these sources.

First, the algorithm assumes a knowledge of bottom materials; this is not always possible, however, without the availability of previously collected ground truth information. Secondly, the resolution of LANDSAT is such that varying bottom reflectances can result in a misrepresentation of the true bottom reflectance for a given pixel, and thus result in a miscalculation of the water depth. Lower altitude aerial scanner systems, which have much higher resolutions, can provide more accurate bottom reflectance information at the expense of large areal coverage.

III. THE REFLECTANCE DERIVATION METHOD

The proposed solution to the existing problem is to utilize color aerial photography to obtain shallow ocean bottom reflectance values. The procedure for extracting bottom reflectance percentages in the red, green, and blue bands from aerial photography is the subject of this paper. A value of this method lies in the fact that these derived reflectances could be used in ERIM/DMA's water depth algorithm, and hence could become an integral part of hydrographic charting through remote sensing techniques.

The method for determining reflectance values from color aerial photography was developed jointly by personnel at SCIPAR, Inc. in Buffalo, N.Y. and DMA. It requires that a calibrated 21-step wedge be exposed on the leader of each roll of film. This wedge is to be used in the derivation of a set of D-log E curves (one set of characteristic curves per roll) (Figure 1), and serves as a control in the film processing. A second requirement for the SCIPAR/DMA technique is that an area of known spectral reflectance must appear in each frame that is selected, or in reasonably adjacent frames that were exposed under identical conditions. This known reflectance, the exposure values of each resolution element within the area being analyzed (calculated from microdensitometer scans of the scene), and the calculated exposure at the point of maximum density on the image are used to derive alpha and beta in the relationship:

3

$$R = \frac{E - \beta}{\alpha} \tag{1}$$

This equation is used to determine total spectral reflectance from exposure values, where

R = Reflectance

E = Exposure of pixel

α = Slope of the reflectance-exposure curve for the scene; to be determined from the area of known reflectance.

β = Zero intercept of the reflectance-exposure curve for the scene; to be determined from the area of maximum density.

This derivation of reflectance values is done over the entire area of interest in each spectral band corresponding to the separate dye layers within the film.

IV. THE FIELD EXPERIMENT

The hydrographic data collection for this experiment was conducted in the summer of 1980 in an area that DMA calls the Bahamas Photobathymetric Calibration Range (Figure 2). The objective of DMA's survey operations in this area was to measure and define the physical and spectral characteristics of selected submerged features on the northwest Bahamas shelf. These recordings will be used in the analysis and evaluation of various remote sensor systems for hydrographic application. The Bahamas were selected as DMA's test site because of the presence of clear, tropical water, large assortments of bottom cover types, proximity to the U.S., and the extensive background of scientific studies concerning the biology and geology of the Bahamas shelf itself.

For this particular experiment, calibration wedges were exposed on the leaders of each roll of film prior to field activities. Aerial photography and hydrographic survey data from the areas depicted in Figure 3 were collected, but application of the SCIPAR/DMA method for reflectance determination is limited to use of the data from "Nix Olympica" (a feature which lies in the upper right corner of Figure

4

3.) Figure 4 is an aerial photograph of Nix Olympica, and descriptive information concerning this site can be found in Figures 5a and 5b.

A sounding transect was made by DMA's survey ship between two yellow bottom markers which can be seen in Figure 5b. A calibrated photometer was attached to the hull of the ship, and bottom reflectance data were recorded digitally on board during this transect. The data thus obtained were used as ground truth for surface observed bottom reflectances derived from aerial photography that was flown at the same time as the transect, and for verification of bottom depths in the study area. Due to the nature of the digital recording method, only two discrete photometer observations were obtained, each representing an integrated circular area of about 5-13 feet in diameter at the bottom depending on water depth. Analog reflectance data (Figure 6) were also obtained in this same area using a calibrated photometer which was carried by scuba divers between the markers at about one meter above the bottom and again at just below the water's surface. The manually smoothed and digitized near surface data are shown in Figure 6. Considerable descriptive data regarding bottom characteristics were also .obtained for other purposes, and may be used for future evaluation of this procedure; but the present effort concerns only the derivation of bottom reflectances.

V. DIGITAL IMAGERY

A 2.5cm x 2.5cm area on a color aerial photograph was digitized on a Perkin-Elmer Micro 10 microdensitometer using red, green, and blue filters to obtain spectral densities for each dye layer in the film. The density wedge which had been exposed on the film's leader was similarly scanned. Areas of maximum density in each spectral band (red, green and blue) which were located on the same frame as the 2.5cm x 2.5cm area (though not necessarily within the digitized area) were manually scanned on the microdensitometer. These densities were then

converted to exposure values for each dye layer by using the D-log E curves derived from the calibration wedge. Thus the "β" values for each spectral band were obtained for use in Equation (1). Next, the area of known spectral reflectance (in this case, a portion of the survey ship which was located within the scene) was similarly scanned and its densities converted to exposures. Using the relationship:

$$\alpha = \frac{Ek - \beta}{Rk} \tag{2}$$

where Ek and Rk are the known exposures and reflectances respectively, the values of "α" for each band were derived. The reflectances of the digitized arrays were then determined by a simple computer program using Equation (1). In order to display the resultant image, these reflectances were converted to "pseudodensities" using the equation

$$Dp \text{ (Pseudodensity)} = 127.5 \log_{10} R \quad \text{where} \quad 1 \leqslant R \leqslant 100 \tag{3}$$

Figure 7 shows the image after the algorithm and Equation 3 have been applied.

The reflectance measurements obtained by this method each represent a 6 inch by 6 inch ground area, and are therefore much more highly resolved than the ground truth data. They are summarized in Figure 8.

VI. DISCUSSION

The utilization of color photography for derivation of reflectances has many benefits, but also introduces several problems in interpretation. The benefits are fairly obvious; it is a relatively inexpensive means of data acquisition, the necessary equipment is readily available, and very high spatial resolution can be obtained.

The problems with interpretation involve a number of factors. Comparison of data acquired as ground truth in this experiment requires that corrections be made

6

for losses or gains in radiation due to the effects of the air-water interface. There is a loss of approximately 4% of the reflected energy each time light passes through this interface due to transmittance interactions. There is also a gain in scattered light reaching the camera due to reflectance off the water's surface. This additional energy can be estimated from the mean deep water signal, where no bottom reflectance is sensed by the camera. Specular reflectance can be avoided if the photography is taken at relatively low sun angles and under calm wave conditions; but otherwise, it could be a severe problem. Cloudy conditions should also be avoided since the sea surface will reflect scattered light from the clouds. Another problem, which is not easily correctable or even predictable at present, is that of angular variation in bottom reflectance across the photography. Extensive tests have been done to determine directional reflectance variation of land materials, but little is known about these effects on ocean bottom materials.

Additional problems exist with the photography itself. One of these is the possibility of variations in processing characteristics due to the length of the rolls of film being used. The wedge, which is exposed on the film leader and used for control, may no longer be valid near the end of the roll. This could be compensated for by exposing several wedges at equally spaced intervals along the length of the roll. Another problem is due to differences in the color components of the light being used to expose the wedges and the images. There is an asymmetry in film processing[2] due to the fact that the developing chemicals enter the emulsion stack through the process of diffusion from only one side of the film, and leave by the same route. This action causes a chemical concentration gradient through the emulsion so that the processing of each layer is somewhat dependent on the processing of previous layers. The grey wedge used for calibration may not, therefore, be processed in the same manner as the non-grey, color images on the same roll. The solution to this disparity would be to use wedges whose colors

7

match as closely as possible the imagery to be analyzed. One additional problem that should be considered is related to the spectral dye sensitivity. The maximum sensitivity of each dye layer falls within the intended spectral range, but each dye layer will still have some sensitivity to light outside that range. When the film is digitized, this effect will cause some error in the color separation values. For the imagery used in this experiment, this effect is believed to be minimal. It is possible, however, to compute the correct values by using linear combinations of the three densities[2].

From the above, it can be readily seen that there is a tradeoff between the inexpensive and simple acquisition of data and the complications which may arise in its precise interpretation. The interpretation is very simple without the many corrections cited, and it is therefore up to the user to decide how far the corrections should be taken.

VII. RESULTS

As can be seen by comparing Figures 6 and 9, the relative values of the photographically derived reflectances are very similar to the analog ground truth data. There are rather large absolute value differences, however, most of which have been accounted for in the previous section. Matching points are compared in Table 1. Corrections were not applied to the derived data; that will be left to future work.

There are some potential problems involved in trying to compare the analog data with the derived data. First, the analog data were obtained by a scuba diver swimming just below the surface of the water while carrying a photometer which was tethered to the research vessel. This means that the data were collected in a format that is time-dependent rather than distance-dependent. A problem could thus arise in the correlation between time and distance if the diver were not swimming at a constant speed. Secondly, any tilting of the photometer from the

8

vertical would cause a change in the size, shape, and location of the area being surveyed and in the length of the water column attenuating the bottom signal. Finally, it is also possible that the diver did not swim a precisely straight line between the bottom markers. It is for these reasons that a statistical comparison between the analog and derived data was not attempted. It is obvious, however, that the geometry of the photographically derived data is more precise than the diver data.

There are also potential errors which may be encountered in the preparation and execution of the reflectance derivation method itself. The determination of alpha and beta in the reflectance equation require very precise measurements of density and precise knowledge of spectral reflectances. It also requires the assurance that the area chosen for beta represents a zero reflectance.

VIII. CONCLUSIONS AND RECOMMENDATIONS.

It can readily be concluded that the method described in this paper produces excellent relative results, but that absolute reflectance values show some discrepancies which must be eliminated. These adjustments will require additional study. It can also be concluded that this method provides geometric resolution and fidelity that exceeds other available techniques. For example, LANDSAT MSS data have a pixel size of 80 x 57 meters; and, when collected at an altitude of 1500 feet, the airborne MSS data has a resolution of approximately 1.1 meter pixels. The photography, however, has a resolution of approximately .15 meters on the ground when scanned with a microdensitometer with a 50 micrometer aperture. The photography is also free of the distortions commonly associated with MSS data. This added detail is important because it can aid in the determination of bottom types by using texture analysis and pattern recognition techniques.

The method shows great potential since a very limited amount of ground truth can be extended considerably in areal coverage. It could be used, for example,

with the Hydrographic Airborne Laser Sounder (HALS) for expanding information content within a survey area.

For maximizing the usefulness of this method, several recommendations need to be made. The first is to analyze the problems cited in Sections V and VI and to determine methods of applying corrections to the processed digital data, which will ultimately add to the accuracy of the results. The second recommendation is to repeat the field experiment, with subsequent data acquisition designed specifically for testing this algorithm. For example, calibrated test panels should be photographed in each image sequence in order to eliminate the problem of finding "ground" objects of known spectral response within a scene composed almost entirely of water. In addition, photometric data should be acquired from a hull mounted photometer that produces digital output and can survey a large area rather than make only a straight line scan.

The method described in this paper thus appears to be a simple, effective way to derive shallow ocean bottom reflectance values from color aerial photography. Even though more work needs to be done to improve the accuracy of the algorithm, the potential utilization is so extensive that this additional effort should be made. In the future, the method may be used to greatly improve the extent and cost effectiveness of hydrographic data acquisition.

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Donald J. Gerson received a B.A. in Meteorology at New York University in 1956, an M.S. in computer science at the University of Maryland in 1975 and has done additional graduate work at the University of Maryland in computer science. He was an Oceanographer for the U.S. Naval Oceanographic Office from 1956-1978 and has been a mathematician at the Defense Mapping Agency since 1978. His specialties have included methods of observation of Arctic sea ice, studies of ice growth and ice drift which included extensive Arctic field work. More recent projects have included digital image processing, pattern recognition, image normalization, and remote sensing of various oceanographic parameters including ice, thermal fronts and bottom characteristics. He has presented several papers at scientific meetings and is the author of many technical reports and journal articles on these subjects. Mr. Gerson was United States Representative to the World Meteorological Organization's Working Group on Sea Ice. He is listed in Who's Who in the East, is a Fellow of the Explorer's Club, and a member of The Arctic Institute of North America, IEEE, SPIE, and Sigma Xi.

Lynn K. Fehrenbach received a B.A. in Psychology from Emory University in 1973, and later did graduate work in Geography at the University of Georgia. She is presently employed as a Cartographer/Photogrammetrist by the Defense Mapping Agency's Hydrographic/Topographic Center in Washington, D.C., and teaches a course in remote sensing at the George Washington University. For the past two summers she was in charge of the field operations and hydrographic data collection associated with a techniques improvement project at DMA.

Kenneth Piech received his Ph.D. from Cornell University where he was a National Science Foundation Fellow. He has conducted research in optical physics, digital image exploitation, multispectral image analysis techniques, and application of these techniques to reconnaissance and image exploitation problems. Dr. Piech has served as a Skylab Principal Investigator on programs to utilize multispectral image analysis techniques for study of eutrophication in the Great Lakes and for analysis of laser beam propagation through the atmosphere. He is the author of two patents related to processes for normalization of reconnaissance imagery; one of these techniques is currently being implemented for operational use in the national community. Dr. Piech is the author of approximately fifty technical papers, articles, and reports and is an editor of a book summarizing the Skylab Earth Resources Experiment Program. He is listed in Who's Who in Engineering and American Men of Science and is the recipient of the 1973 Award from the American Society of Photogrammetry for the outstanding technical publication on photographic interpretation. He has served as Charman of the Engineering Applications Committee of the American Society of Photogrammetry and as an officer of that Society's Hydrospheric Sciences Committtee.

David Gaucher has an extensive background in the development of image exploitation and multispectral image analysis techniques. His eighteen years of experience include two and a half years spent at Rome Air Development Center as an off-site representative demonstrating the application of photometric interpretation techniques and performing special target analyses using multispectral properties of targets measured from reconnaissance imagery. Mr. Gaucher has played a major role in remote sensing analyses of forest defoliation due to insect infestations in support of the U.S. Forest Service,

vegetation stress caused by SO_2 emissions for the New York State Energy Research and Development Authority and the Environmental Protection Agency, and quantitative analysis of thermal discharges from power plants for NYSERDA. In recent years, he has been a principal contributor to programs for Rome Air Development Center, Defense Advanced Research Projects Agency, Defense Mapping Agency, and National Photographic Interpretation Center involving material identification using black and white reconnaisance photography. He served as project engineer on a recently completed RADC program to develop advanced techniques to detect camouflaged vehicles using multispectral analysis techniques. Mr. Gaucher is an honor graduate from the U.S. Army Image Interpretation School and holds a B.A. in geography from Syracuse University at Utica, New York.

Table 1. Comparison of Matching Points, Reflectance

Point	Analog Photocolor Data			Digital Color Graphic Data		
	Red	Green	Blue	Red	Green	Blue
a	.5	9.5	12.	1.7	6.7	6.9
b	.3	4.0	4.5	.92	3.2	3.4
c	.42	6.0	7.5	1.9	5.5	5.6
d	.3	4.0	4.0	1.4	3.7	3.8
e	.45	5.7	6.0	1.3	4.0	4.2
f	.40	5.0	5.0	1.1	3.6	3.7
g	.37	5.0	6.3	1.3	4.5	4.7
h	.35	5.7	7.0	1.0	4.0	4.2
i	.25	4.2	5.2	.62	2.5	2.9
j	.10	4.5	5.0	.75	3.0	2.9
k	.08	2.6	3.5	.39	1.8	2.5
l	.09	3.8	5.0	.57	2.2	2.8
m	.09	4.0	5.0	.67	2.4	3.0
n	.10	3.7	4.5	.47	1.8	2.5
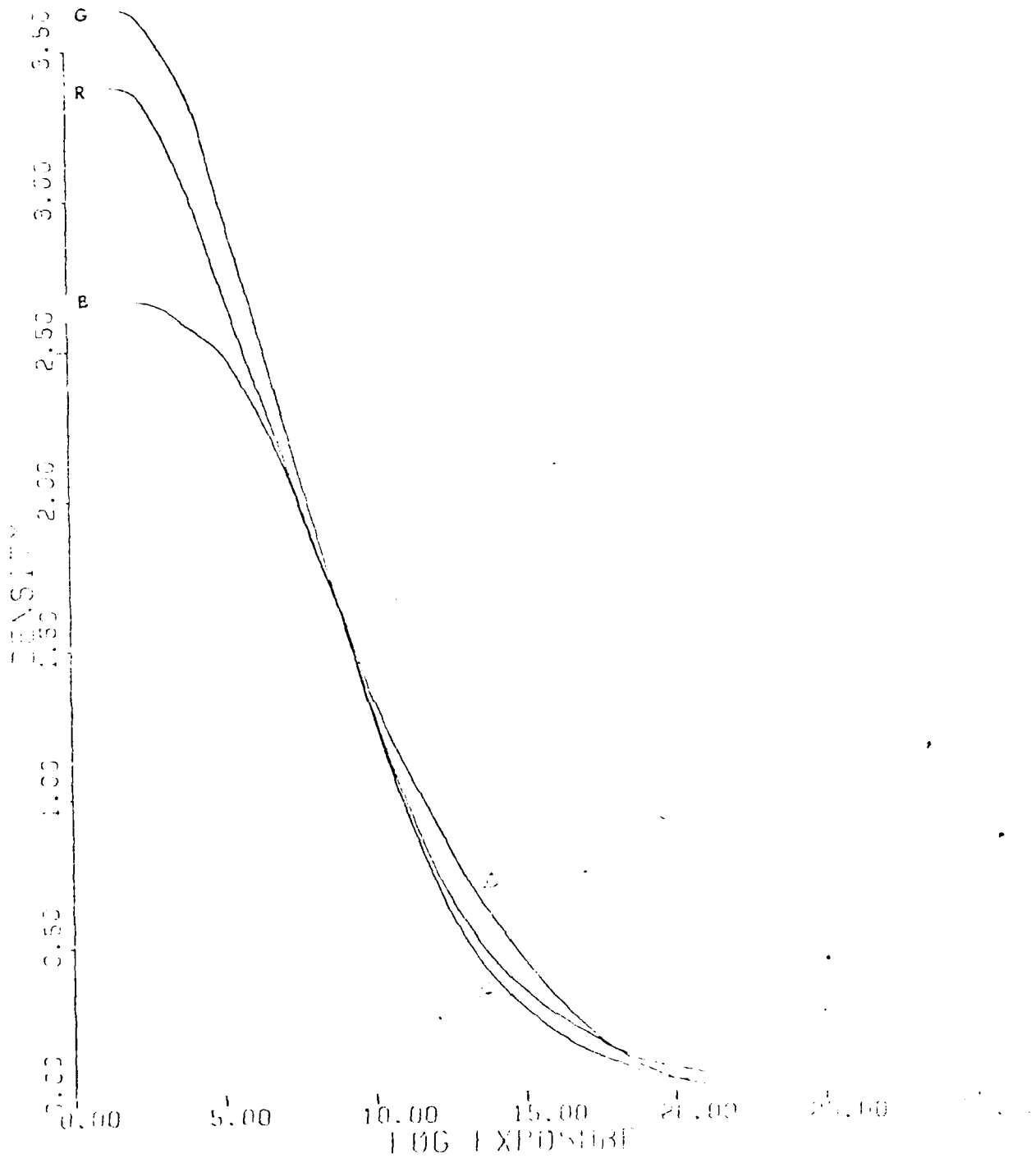
Figure 1. D LOG E CURVES

BAHAMAS PHOTOBATHYMETRIC CALIBRATION RANGE

Figure 2

Great Isaac

Hens & Chickens

26 00'N

79 00 W

Little Isaac

No Cy me Middle ic
Each Isaac

N Rock

N. Bimini

N

S. Bimini

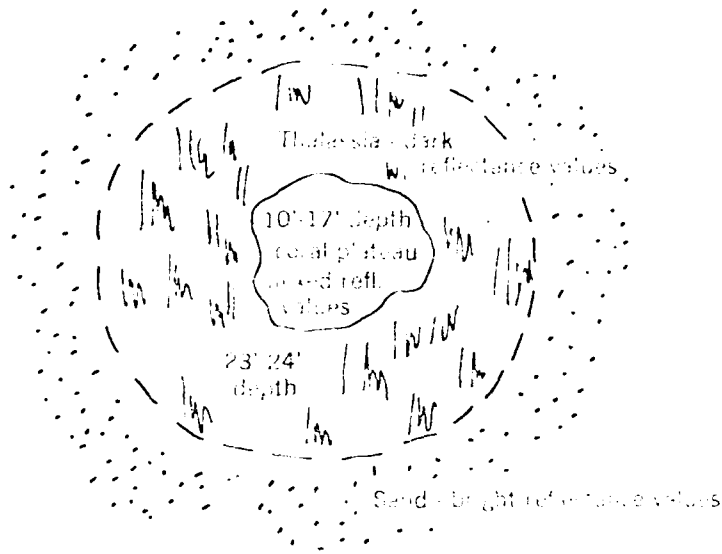79 00 W

00 N
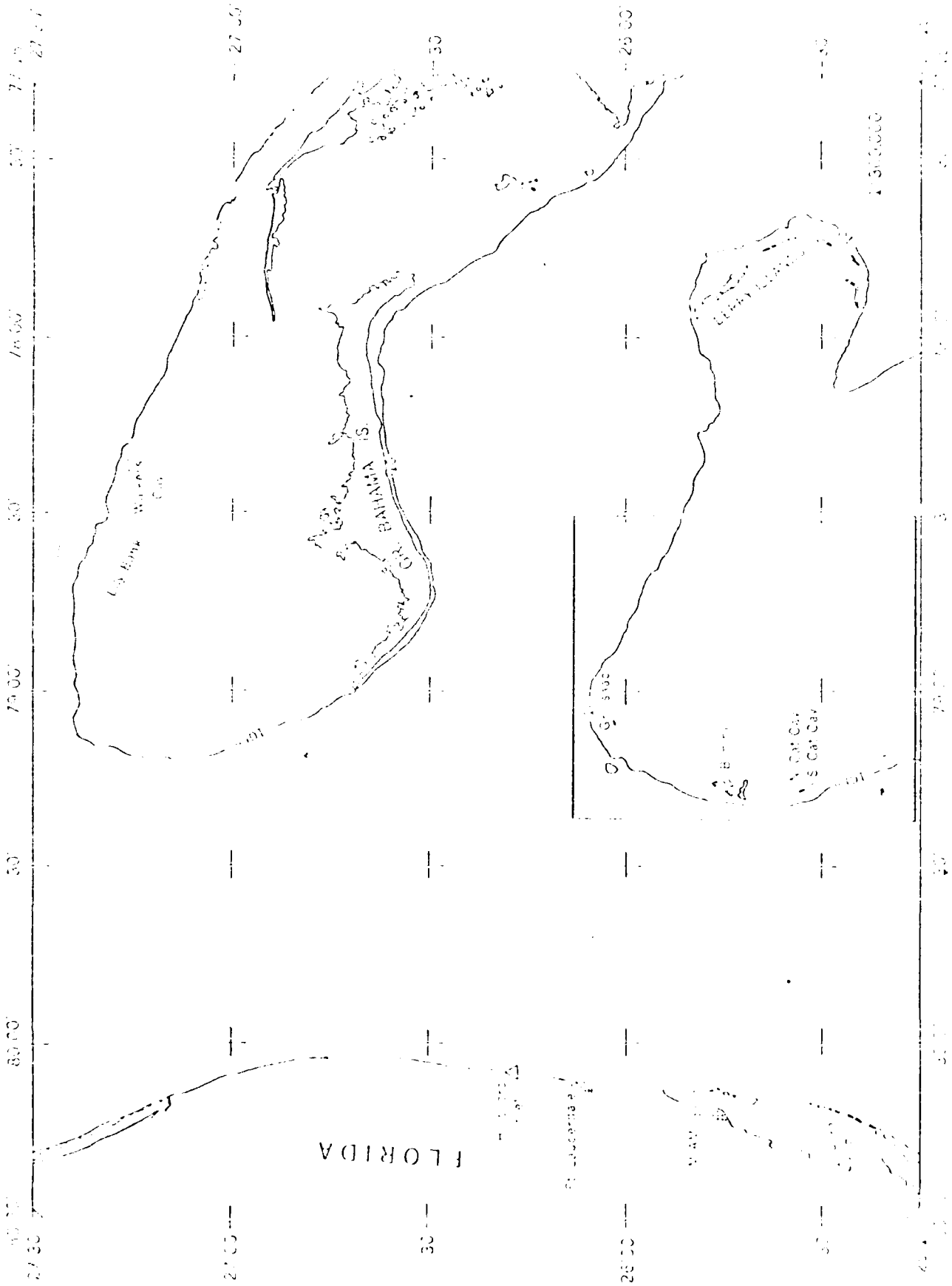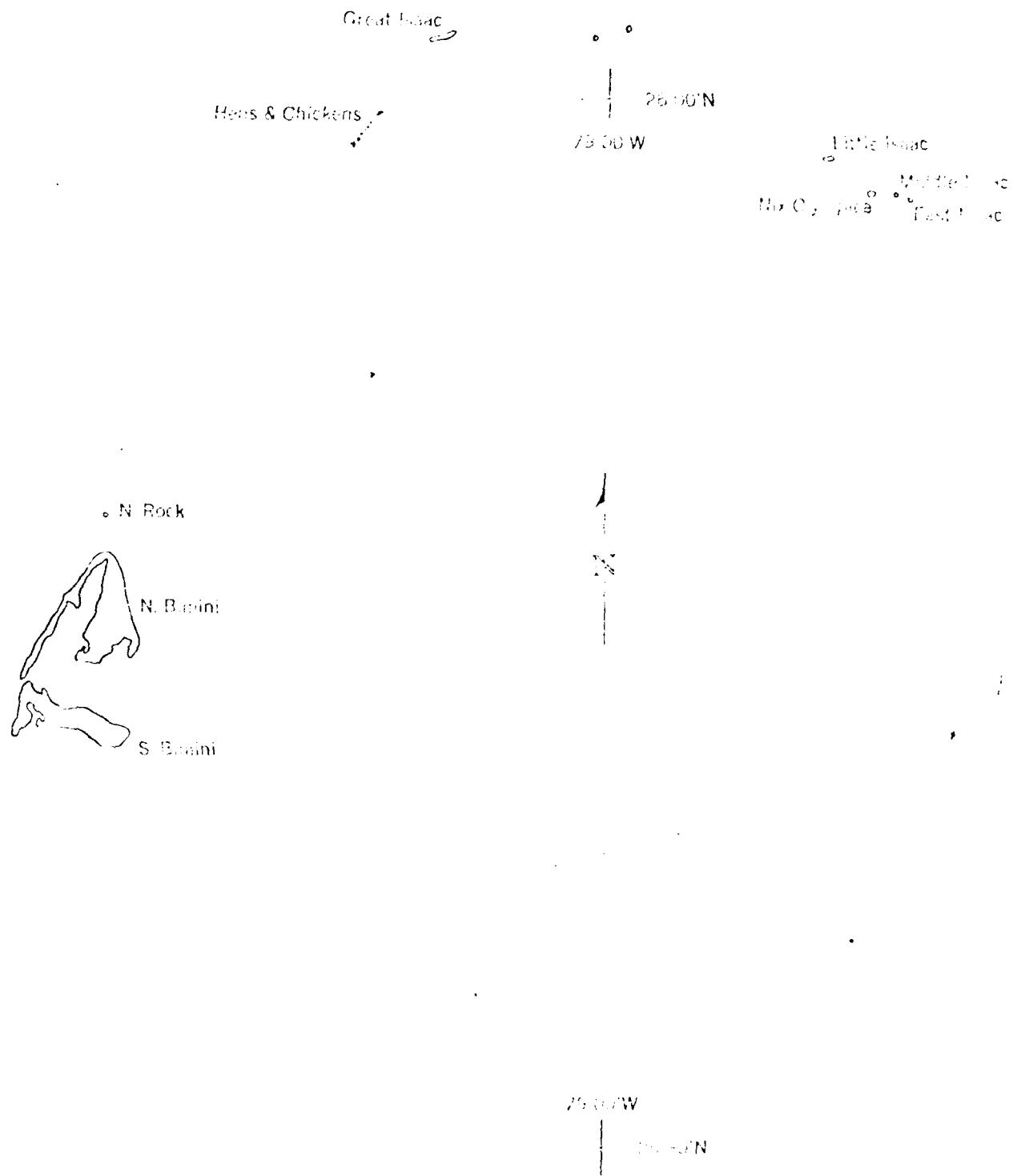
Figure 3   AREAS OF DATA ACQUISITION
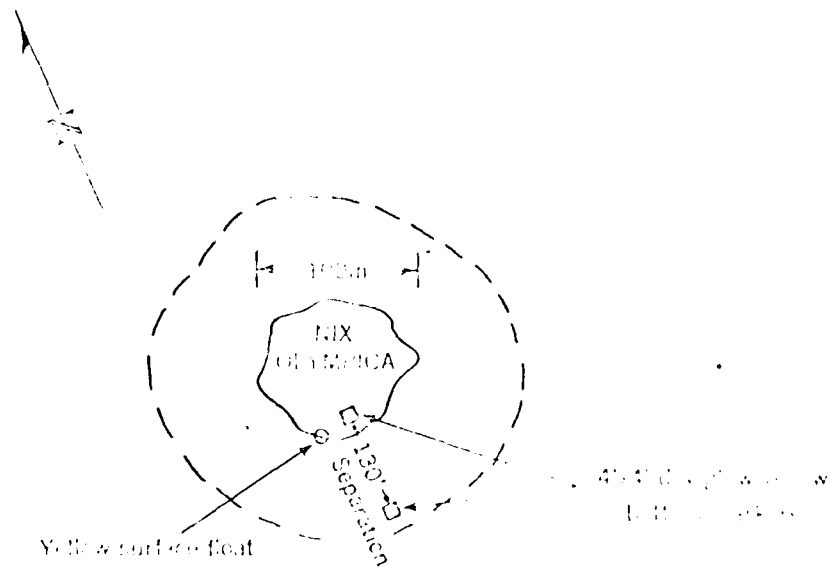
Figure 5b   NIX OLYMPICA - DIMENSIONS
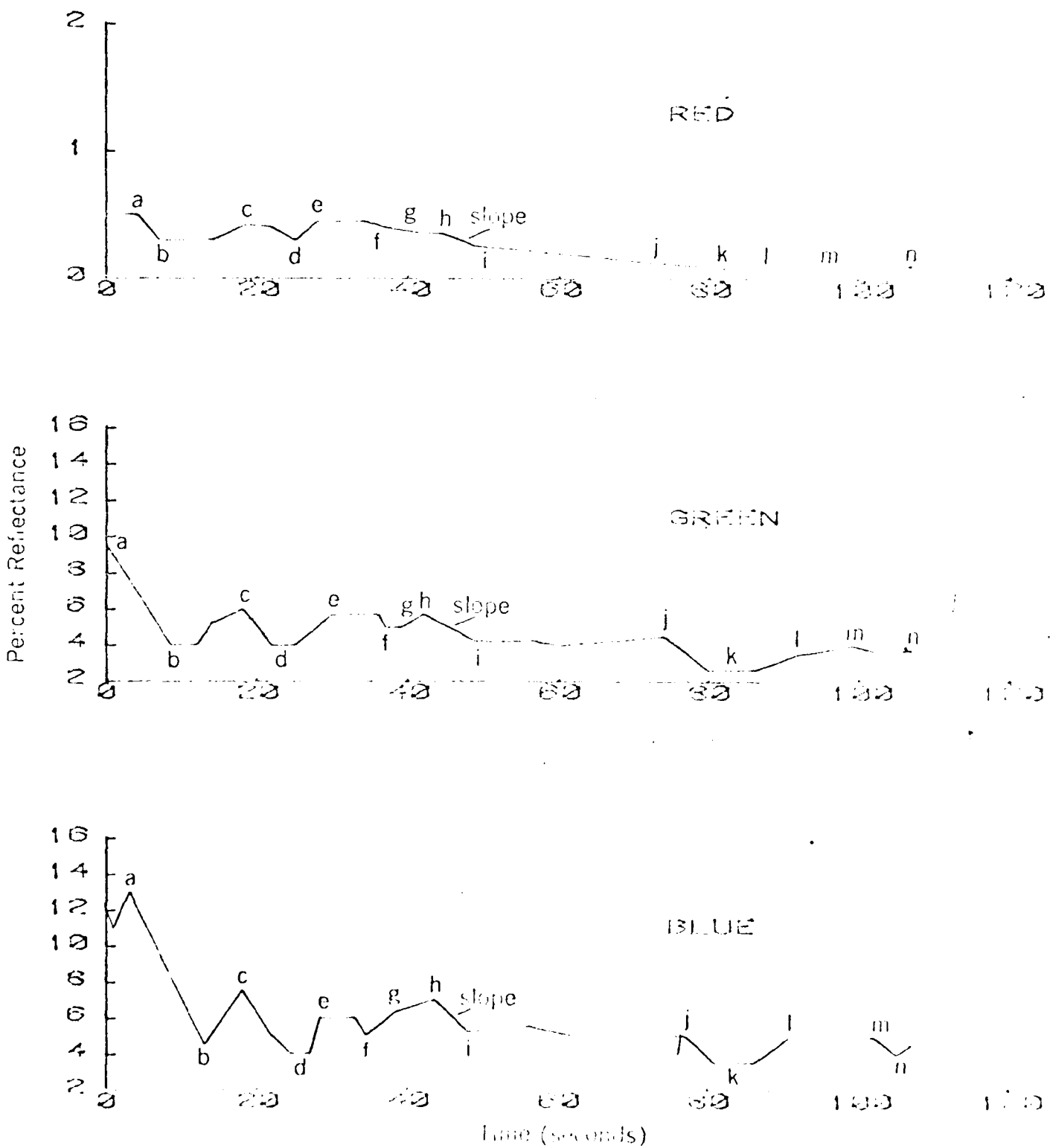

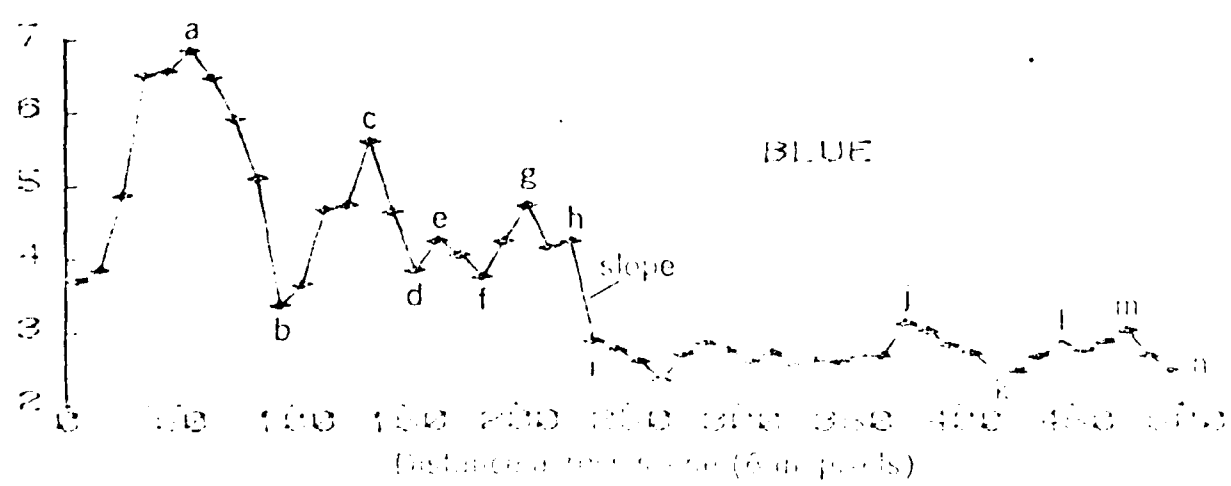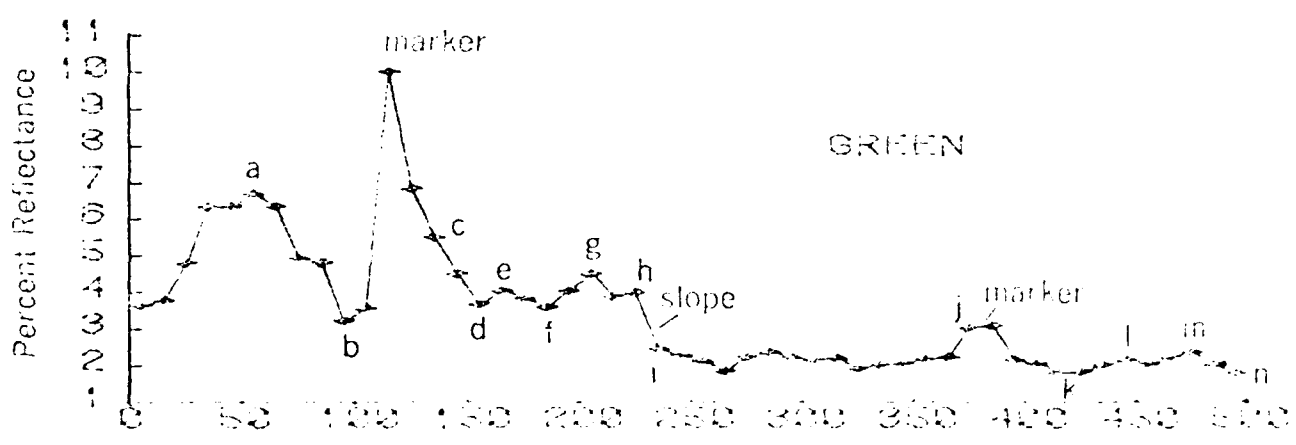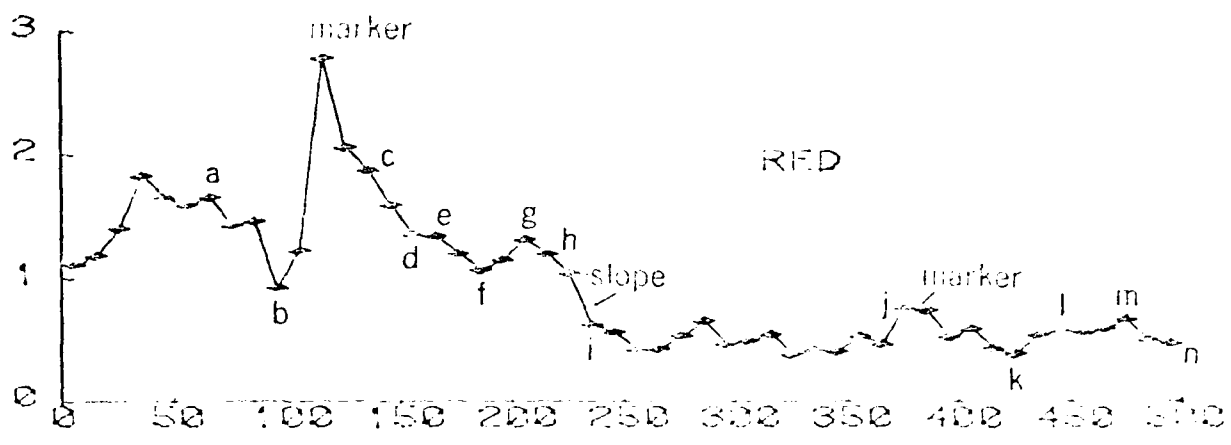Figure 5   DESCRIPTIVE DATA OF NIX OLYMPICA

Figure 6. ANALOG REFLECTANCE DATA

Figure 8. AVERAGE DERIVED REFLECTANCES

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