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Paper M 15

# BIOMASS IN THE UPWELLING AREAS ALONG THE NORTHWEST COAST OF AFRICA AS VIEWED WITH ERTS-1

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Light penetration in water is affected by plankton, algae, and dissolved and suspended matter. As a consequence, the composition of backscattered light from below the air-sea interface is determined by the nature of the constituents in the water column. In contrast to the absorption spectrum of chemically pure chlorophyll in solution, algae suspensions absorb and scatter light more uniformly throughout the visible part of the electromagnetic spectrum. Because of their spectral absorption and scattering properties plankton concentration can be estimated by measuring the spectral backscattered radiance over water. Our experiments using this approach were performed in upwelling regions along the North-West Coast of Africa.

The North-West Coast of Africa was chosen for several reasons:

1. From the oceanographic point of view knowledge of the NW Coast of Africa is very poor.
2. We are collaborating with the CINECA program which is an international oceanographic cooperation providing access to multiship cruises for ground truth.
3. Climatological conditions favor space observations.

4. No river discharge appears in the upwelling area thus changes in sea color are produced by plankton organisms.

A typical analysis of wind speed and direction for the test site is shown in Fig. 1. These data were obtained during 1967 onboard the H. M. S. "Hydra".

The Alize, blowing in a northeast direction along the coast of Spanish Sahara and Mauritania is predominant the whole year. As a consequence of this wind system, the Canary Current is present during much of the year in a southwest direction. Wind stress and the geostrophic sloping of the isotherms leads to upwelling in the near coastal zone especially at Cape Sim, Cape Ghir, Cape Juby, Cape Blanc, and Cape Verde. The euthrophication of the productive layer by increased nutrient transport from the deeper layers causes extremely high concentrations of chlorophyll. Since the adjacent regions are arid, visibility through the atmosphere favor observation by satellite. Fig. 2 shows a composite of data for the reflected solar energy between 0.7–1.1 μm as collected by channel 7 of the MSS. The frames were obtained during ERTS-1 overpass of the NW Coast of Africa between 32°N and 10°N. The area covered includes Morocco, Spanish Sahara, Mauritania, Senegal, Gambia, Portuguese Guinea, and Guinea.

The following color composites of channels 4, 5, and 7 give evidence of the types of climatic conditions encountered in the test site. The northern boundary of the test site includes the region of the Anti Atlas mountains in Morocco. Figure 3 shows the coast of Morocco south of the upwelling areas of Cape Sim and Cape Ghir. From studies made using data gathered from the satellites Nimbus 2, 3, and 4 and our recent analysis of NOAA 2 data, this slide shows the northern limit of the cloud free region of the test site. Part of the test site includes arid regions or desert. Figure 4 shows part of Senegal south of Cape Blanc with the Island Tidra included. The area shown in this figure is also part of an ongoing program to study the chemical impact of eolian dust from the Sahara on the nutrient budget of the ocean. The ERTS-1 imagery was used to determine the geographic path of the transported sand. The results of this part of the study will be discussed in thesis form.

The only important river discharge in the test site is from the Gambia River which is shown in Figure 5. The river discharge is to the south in agreement with the movement of the Canary Current. The shifting of the river mouth from north to south, in evidence by closer analysis of the figure, is probably a long term evolutionary process resulting from the Canary Current.

The chlorophyll distribution as obtained from direct measurements aboard research vessels during August 1972 is shown in Fig. 6. This area was investigated by the Spanish R. V. "Cornide de Saveedra" in the North and the British R. V. "Discovery" in the South. The concentration of chlorophyll in the outer section near the Canary Islands is representative of the open ocean with values around 0.5 $\mu g \cdot l^{-1}$. High chlorophyll concentrations were found in the upwelling area near Cape Juby with values above 8 $\mu g \cdot l^{-1}$. Thus, the chlorophyll concentration for this test site ranges over two orders of magnitude. In plankton blooms maximum concentrations were found up to 16 $\mu g \cdot l^{-1}$. Generally speaking, the whole coastal area shows eutrophication with chlorophyll concentrations above 0.5 $\mu g \cdot l^{-1}$ which is still one order of magnitude higher than in the open ocean.

Maximum gradients of chlorophyll concentration were always found to be close to the coast with highest concentration near Cape Juby. Fig. 7 shows the display of channel 4 from the MSS during the operation of "Cornide de Saveedra" in this area. The gray scale indicates increased plankton concentration as evidence by backscattered light in the 0.5-0.6 μm region of the MSS. Channel 5, 6, and 7 showed neither cloud contamination nor sun glint. For more details, part of the encircled area was investigated with grid print maps from the digital values found on computer compatible tapes.

To derive the position of the coastline with the radiance measurements, we established the frequency histogram of all data. The total picture consisted of 585 lines with 810 samples per line with 47,380 points. An average gray level was 1.14 milliwatts/$cm^2$/steradian. The frequency histogram for channel 4 is shown in Fig. 8, where all data were normalized to the maximum of 100.

The two maxima in the frequency distribution indicate the different gray levels for water and the adjacent continent. The high radiance of 1.17 to about 1.56 mw/$cm^{-2}$/$ster.^{-1}$ (i.e., 60 to 80 digital units) corresponds to an albedo of from 0.254 to 0.339 and shows the reflective properties of the desert region. Gray levels between 0.51 and 0.98 $mw/cm^{-2}/ster.^{-1}$ (i.e., 26 to 50 digital units) correspond to albedo levels of 0.110 to 0.213 and can be assigned to the radiance of the ocean. The frequency distribution shows that gray levels greater than 0.98 $mw/cm^{-2}/ster.^{-1}$ (albedo equals 0.213) are caused by the coastal features or the continent. Consequently we developed a threshold level for the position of the waterline to be indicated by radiances less than 0.98 $mw/cm^{-2}/ster.^{-1}$.

Fig. 9 shows a computer printout where characters were assigned to the radiance. Only every 12th line was used with a sample spacing of 12. The gradient visible by the assigned character 0 shows the positon of the coastline. The region near Cape Juby shows high radiance caused by plankton. The transportation of plankton within the Canary Current can be seen by the symbols 0 and 8. Radiance less than 0.61 $mw/cm^{-2}/ster.^{-1}$ had no assigned symbol. The offshore area in the northwest corner of the display indicated low radiance and consequently low concentration of plankton organisms.

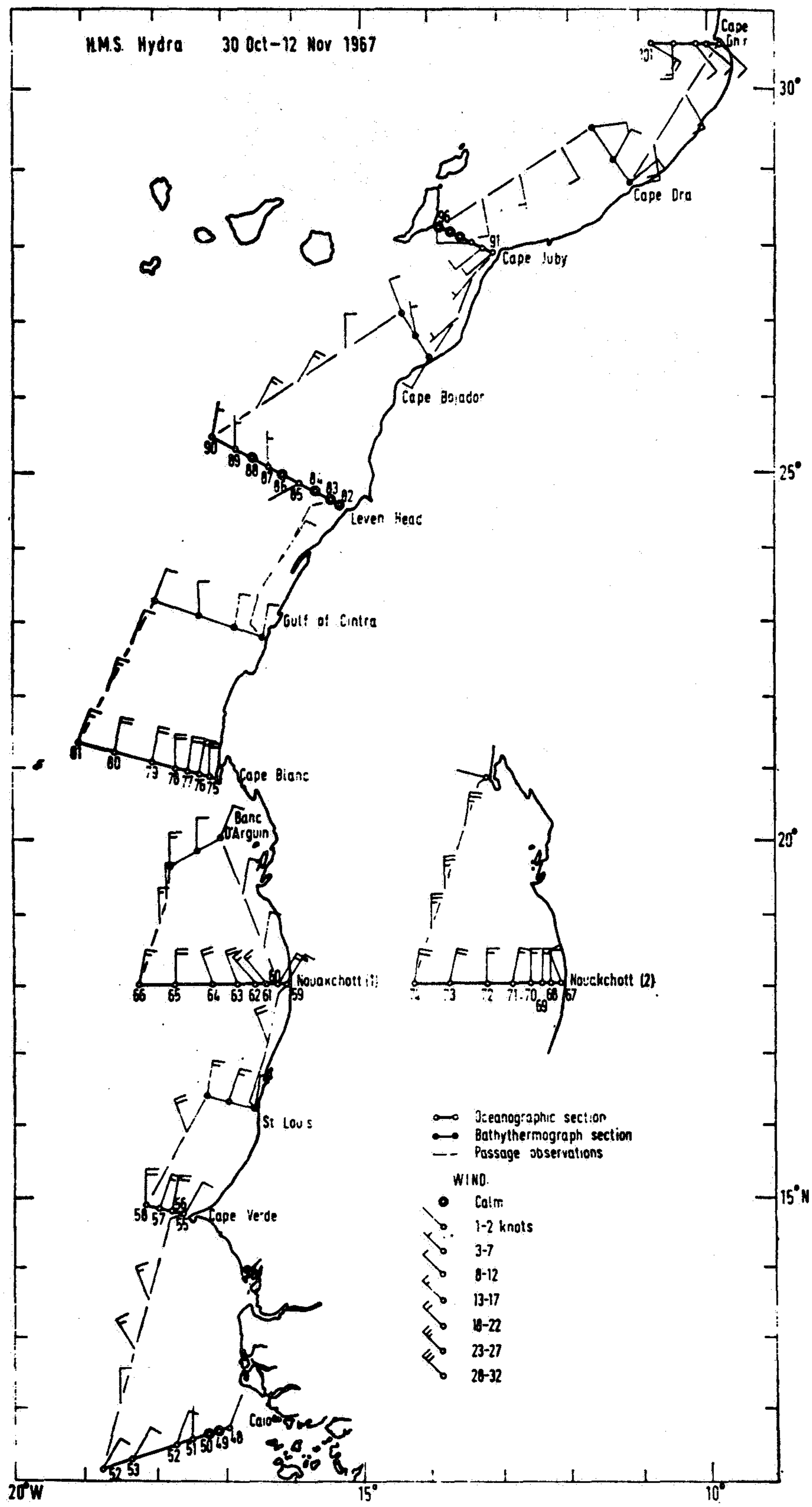
Fig. 10 gives the analysis of the total values as obtained from the generated grid print map over an area of 30 km. The isolines of radiances were smoothed over about eight grid points. The position of the coastline was established by the maximum gradient at the interface between continent and ocean. The nearest isoline to the coast was three grid print points from the coast which corresponds to a distance of about 300 meters. This should avoid the most important influence of the bathymetry near the coastline.

Oceanic regions with high productivity have a thin eutrophic layer and consequently the photo-penetration depth is very shallow. Readings with the Secchi disc in the upwelling area showed only five meters. This can be explained by the light attenuation of plants. Highest radiance can be found in the near coastal waters where upwelling is expected to be strongest. Repeated coverage with ERTS showed that the plankton bloom are not persistant. They change their size and their location.

Continuous recordings of chlorophyll concentrations during the ground truth program in the upwelling area along the NW Coast of Africa showed similar patterns as derived with ERTS-1.

The recordings parallel to the coast showed periodic variations in the chlorophyll concentration which showed the same spacing as the periodicity observed with ERTS-1 data. In other words, we detected the real distribution structure of plankton with ERTS-1 as it could never be investigated with the conventional method or even multiship cruises.

We were asked to stress the economical point of view in our investigations. A very simple calculation will demonstrate the advantage of satellite information for the research in upwelling regions. Dr. W. Fisher from the United States Geological Survey estimated the cost per $km^2$ in the image to be less than 3 cents. The analyzed frame would cost about $324. Including computer time we can estimate the total amount for the satellite coverage to be $1,000. The information obtained with the ship was in the order of $30,000 or roughly 30 times more expensive. I think that this estimate and the presentation of data show the high potential and the inexpensive acquisition of information obtained with the satellite in our studies. It is desirable that NASA focus more on the activity in spacecraft oceanography.



H.M.S. Hydra 30 Oct–12 Nov 1967
Cape Ghir
30°
Cape Dra
Cape Juby
Cape Bojador
25°
Leven Head
Gulf of Cintra
Cape Blanc
Banc D'Arguin
20°
Nouakchott (1)
Nouakchott (2)
St Louis
15°N
Cape Verde
Oceanographic section
Bathythermograph section
Passage observations
WIND
Calm
1-2 knots
3-7
8-12
13-17
18-22
23-27
28-32
20°W
15°
10°


Figure 1

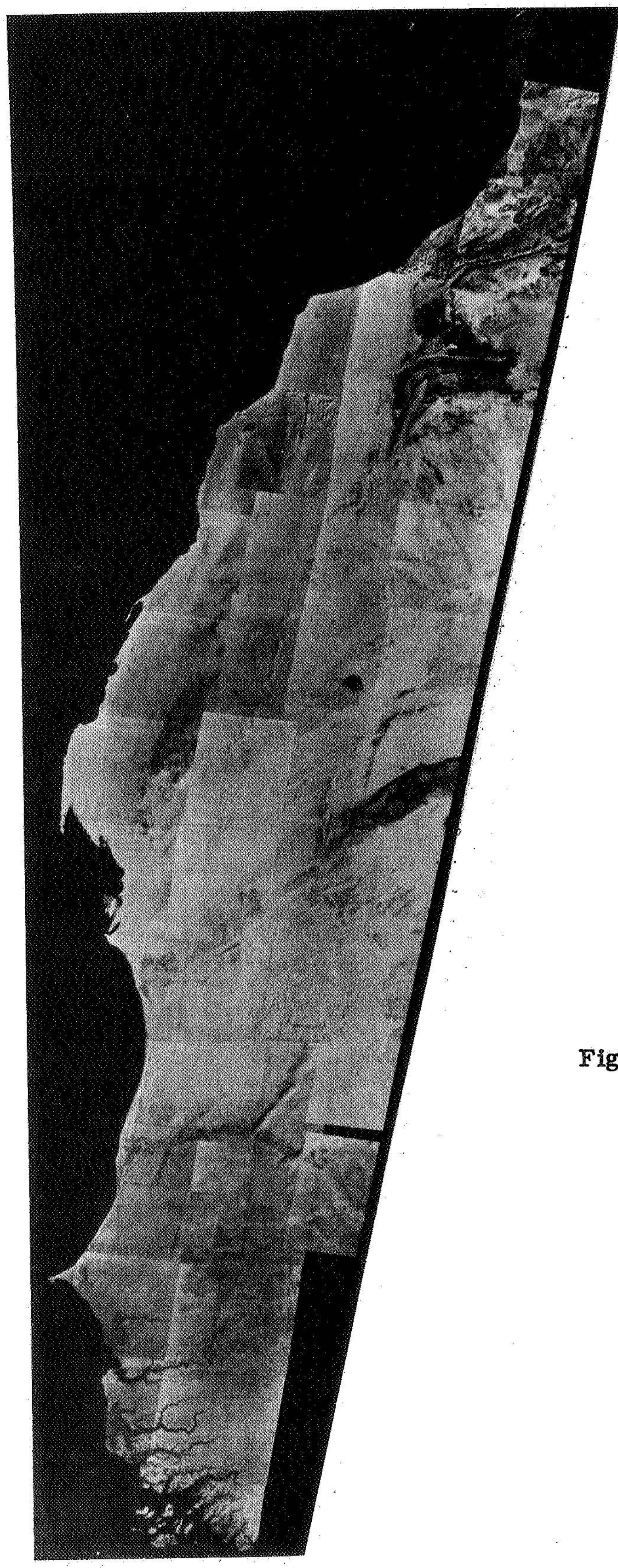
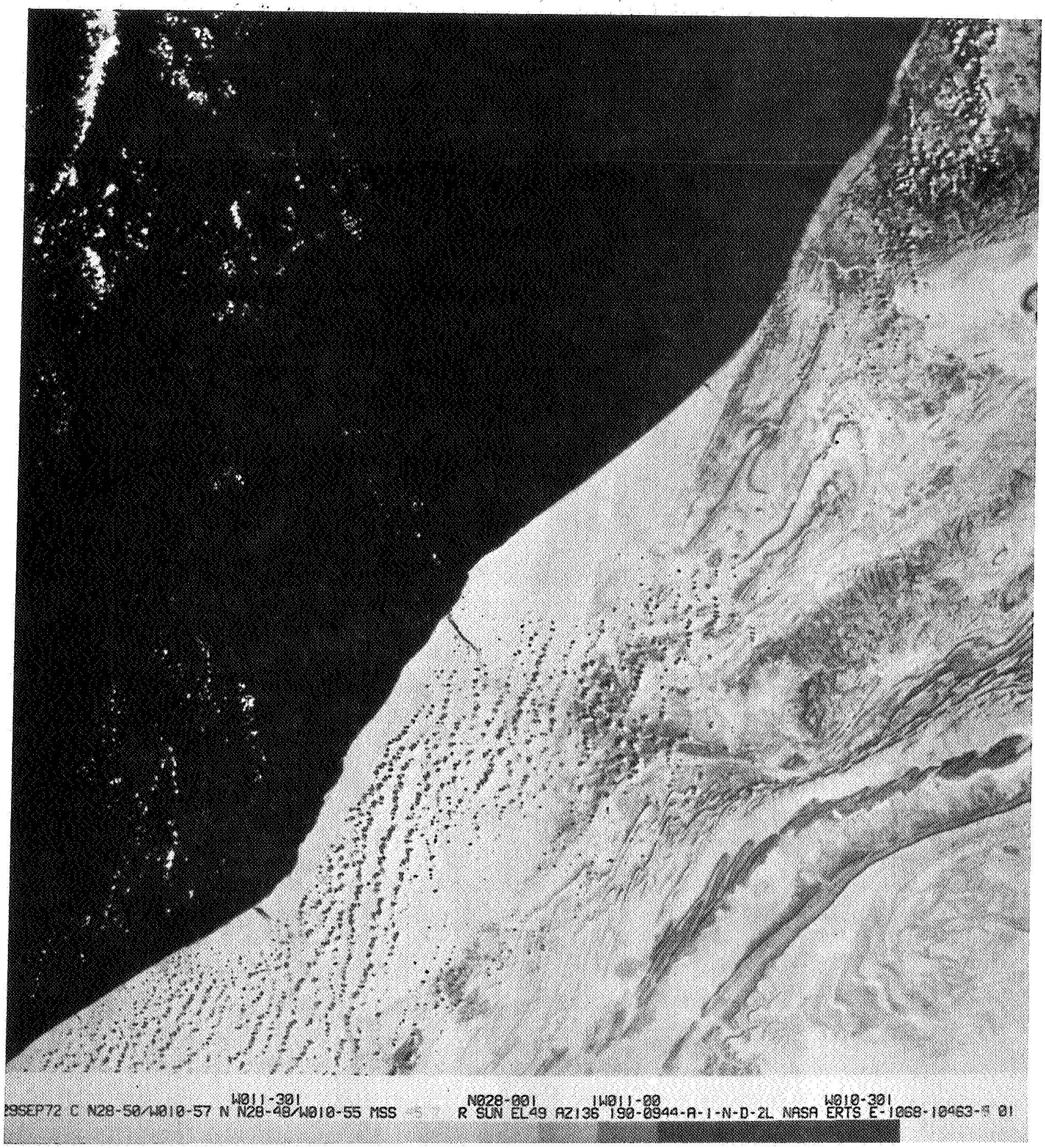


Figure 2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N028-001
IW011-00
W010-301
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R SUN EL49 AZ136 190-0944-A-1-N-D-2L NASA ERTS E-1068-10463- 01

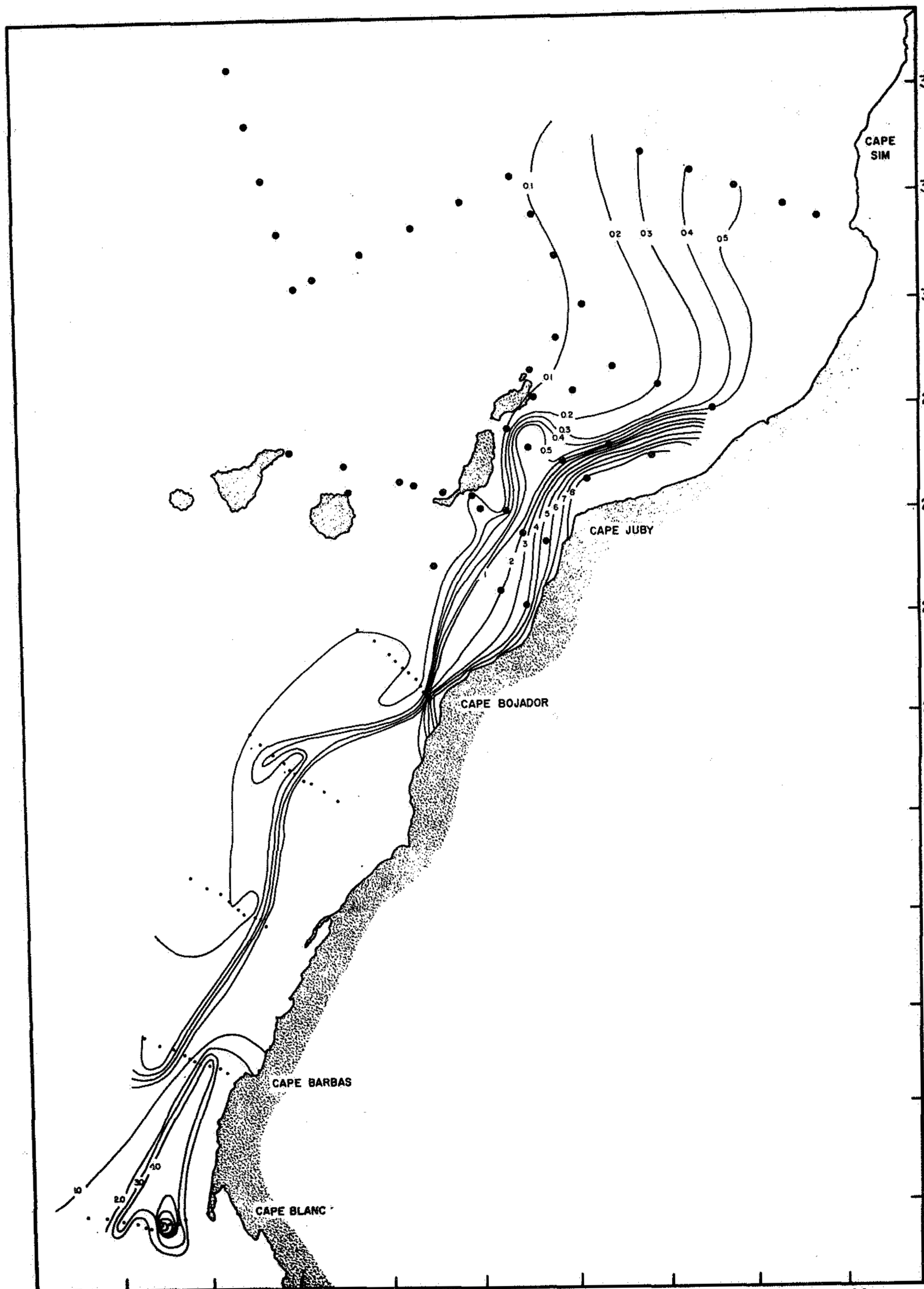
Figure 3


W017-001
W016-301
W016-001
C N20-05/W016-16 N N20-02/W016-14 MSS R SUN EL45 AZ141 189-1474-G-1-N-D-2L NASA ERTS E-1106-110

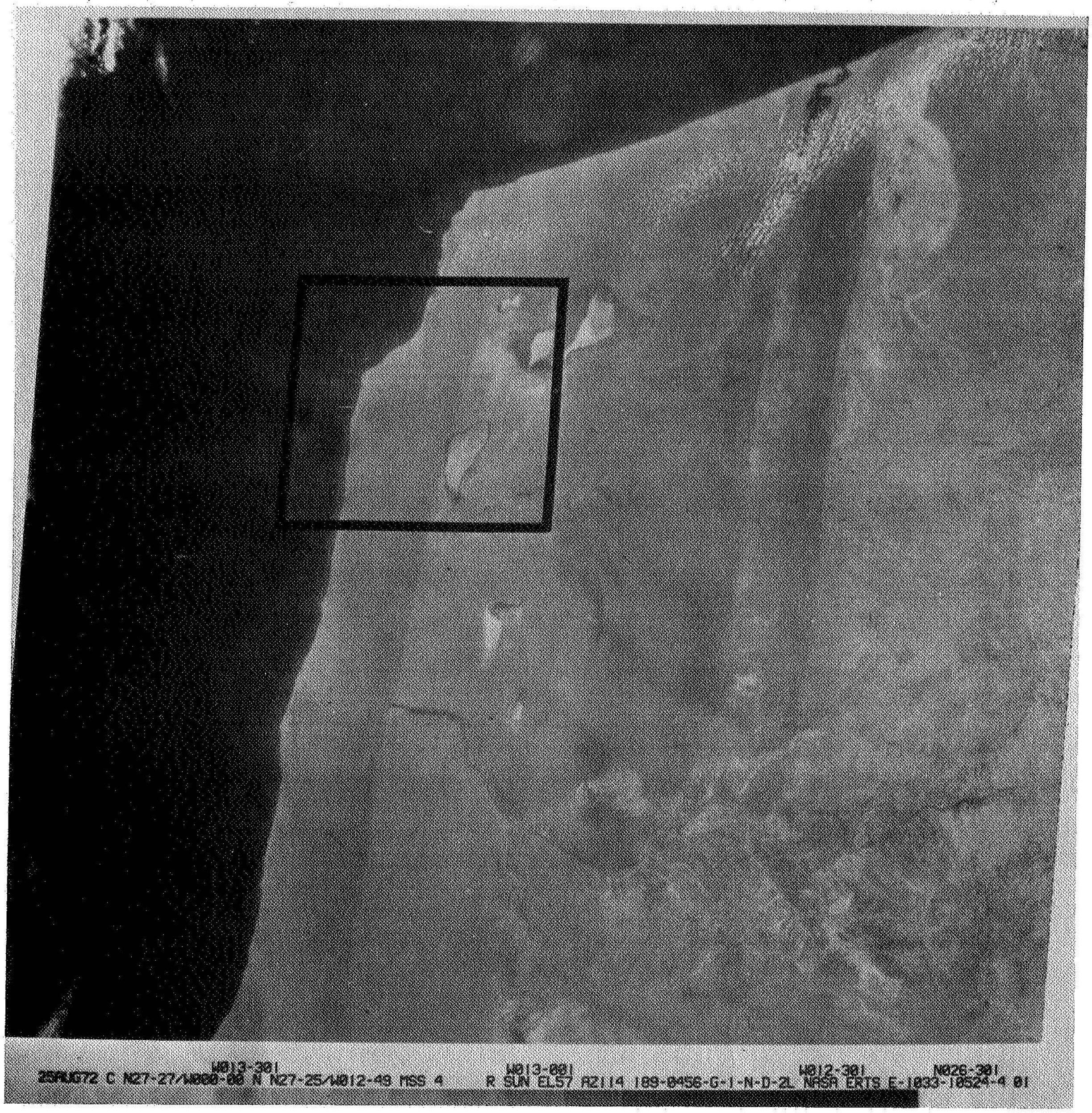
Figure 4


1W016-30
W016-001
W015-301
SEP72 C N15-59/W015-47 N N15-57/W015-42 MSS R SUN EL55 AZ120 188-0958-A-1-N-D-2L NASA ERTS E-1069-10560-5

**Figure 5**



CAPE SIM
CAPE JUBY
CAPE BOJADOR
CAPE BARBAS
CAPE BLANC
32°
31°
30°
29°
28°
27°
26°
25°
24°
23°
22°
21°
19°
18°
17°
16°
15°
14°
13°
12°
11°
10°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W013-001
R SUN EL57 AZ114 189-0456-G-1-N-D-2L NASA ERTS E-1033-10524-4 01
W012-301
N026-301

Figure 7

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TOTAL PICTURE SIZE =    565 LINES,    810 SAMPLES/LINE

SECTION    2 OF SEGMENT    2 CHANNEL   4
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  SUN EL57 AZ114 189-0456- -1- D-
 NASA ERTS E-1033-10524-                    0 G-
06|W013-30N*W013-00|27W012-30||-W012-00|
/+N028-00=M N027-30=>6N027-00=
11=NC28-007,N027-30=D(N027-00=2 W012-00=
-1W013-30|8PW013-00|Y,N026-30|RZW012-30|

FREQUENCY DISTRIBUTION     SL=   1    SS=   1    NL=  565    NS=  810    HISTUP=  255   HISTLW=

AVERAGE GRAY LEVEL = 58.2024   STANDARD DEVIATION = 18.4267 NUMBER OF POINTS =  473850

                    FREQUENCY HISTOGRAM - NORMALIZED TO MAXIMUM = 100   (LEVELS WITH ZERO FREQUENCY OMITTED)
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| GRAY | FREQ | PERCENT |
|---|---|---|
| 0 | 364 | 0.076 |
| 2 | 3 | 0.000 |
| 3 | 3 | 0.000 |
| 7 | 1 | 0.000 |
| 8 | 4 | 0.000 |
| 10 | 1 | 0.000 |
| 11 | 3 | 0.000 |
| 12 | 3 | 0.000 |
| 13 | 1 | 0.000 |
| 14 | 2 | 0.000 |
| 15 | 2 | 0.000 |
| 16 | 2 | 0.000 |
| 17 | 1 | 0.000 |
| 18 | 1 | 0.000 |
| 19 | 1 | 0.000 |
| 22 | 1 | 0.000 |
| 23 | 3 | 0.000 |
| 24 | 1 | 0.000 |
| 25 | 15 | 0.003 |
| 26 | 1355 | 0.285 |
| 27 | 1767 | 0.370 |
| 28 | 4702 | 0.992 |
| 29 | 16862 | 3.562 |
| 30 | 15307 | 3.230 |
| 31 | 8641 | 1.823 |
| 32 | 16137 | 3.405 |
| 33 | 20536 | 4.333 |
| 34 | 21661 | 4.571 |
| 35 | 12655 | 2.670 |
| 36 | 3163 | 0.665 |
| 37 | 4347 | 0.917 |
| 38 | 3040 | 0.641 |
| 39 | 3870 | 0.816 |
| 40 | 3488 | 0.736 |
| 41 | 2274 | 0.479 |
| 42 | 1278 | 0.269 |
| 43 | 660 | 0.139 |
| 44 | 2371 | 0.500 |
| 45 | 736 | 0.155 |
| 46 | 1108 | 0.233 |
| 47 | 241 | 0.050 |
| 48 | 330 | 0.069 |
| 49 | 403 | 0.085 |
| 50 | 113 | 0.023 |
| 51 | 333 | 0.070 |
| 52 | 301 | 0.063 |
| 53 | 394 | 0.083 |
| 54 | 1074 | 0.226 |
| 55 | 751 | 0.158 |
| 56 | 692 | 0.146 |
| 57 | 1353 | 0.285 |
| 58 | 1769 | 0.373 |
| 59 | 2380 | 0.502 |
| 60 | 8394 | 1.771 |
| 61 | 1271 | 0.268 |
| 62 | 16432 | 3.467 |
| 63 | 7128 | 1.504 |
| 64 | 45866 | 9.679 |
| 65 | 41983 | 8.859 |
| 66 | 15729 | 3.319 |
| 67 | 23043 | 4.862 |
| 68 | 12980 | 2.739 |
| 69 | 8334 | 1.758 |
| 70 | 8571 | 1.808 |
| 71 | 16139 | 3.405 |
| 72 | 7410 | 1.563 |
| 73 | 17725 | 3.740 |
| 74 | 14587 | 3.078 |
| 75 | 9534 | 2.012 |
| 76 | 12169 | 2.568 |
| 77 | 12862 | 2.714 |
| 78 | 4673 | 0.986 |
| 79 | 3976 | 0.839 |
| 80 | 6310 | 1.331 |
| 81 | 1829 | 0.385 |
| 82 | 2803 | 0.591 |
| 83 | 4693 | 0.990 |
| 84 | 518 | 0.109 |
| 85 | 1582 | 0.333 |
| 86 | 895 | 0.188 |
| 87 | 2458 | 0.518 |
| 88 | 458 | 0.096 |
| 89 | 870 | 0.183 |
| 90 | 841 | 0.177 |
| 91 | 1035 | 0.218 |
| 92 | 123 | 0.025 |
| 93 | 518 | 0.109 |
| 94 | 731 | 0.154 |
| 95 | 39 | 0.008 |
| 96 | 240 | 0.050 |
| 97 | 261 | 0.055 |
| 98 | 476 | 0.100 |
| 99 | 17 | 0.003 |
| 100 | 217 | 0.045 |
| 101 | 223 | 0.047 |
| 102 | 331 | 0.069 |
| 103 | 60 | 0.012 |
| 104 | 168 | 0.035 |
| 105 | 36 | 0.007 |
| 106 | 97 | 0.020 |
| 107 | 101 | 0.021 |
| 108 | 88 | 0.018 |
| 109 | 24 | 0.005 |
| 110 | 12 | 0.002 |
| 111 | 50 | 0.010 |
| 112 | 42 | 0.008 |
| 113 | 21 | 0.004 |
| 114 | 11 | 0.002 |
| 115 | 25 | 0.005 |
| 116 | 16 | 0.003 |
| 118 | 10 | 0.002 |
| 119 | 13 | 0.002 |
| 120 | 13 | 0.002 |
| 122 | 12 | 0.002 |
| 123 | 12 | 0.002 |
| 124 | 7 | 0.001 |
| 125 | 9 | 0.001 |
| 126 | 12 | 0.002 |
| 127 | 8 | 0.001 |
| 128 | 2 | 0.000 |
| 131 | 1 | 0.000 |
| 144 | 1 | 0.000 |
| 148 | 1 | 0.000 |
| 164 | 1 | 0.000 |
| 170 | 1 | 0.000 |
| 194 | 1 | 0.000 |
| 195 | 5 | 0.001 |
| 196 | 1 | 0.000 |
| 197 | 2 | 0.000 |
| 199 | 2 | 0.000 |
| 201 | 2 | 0.0[illegible] |
| 202 | 1 | 0.0[illegible] |
| 206 | 1 | 0.000 |
| 211 | 2 | 0.000 |
| 212 | 7 | 0.001 |
| 214 | 1 | 0.000 |
| 215 | 1 | 0.000 |
| 217 | 4 | 0.000 |
| 218 | 7 | 0.001 |
| 220 | 3 | 0.000 |
| 221 | 6 | 0.001 |
| 222 | 1 | 0.000 |
| 224 | 1 | 0.000 |
| 230 | 9 | 0.001 |
| 234 | 1 | 0.000 |
| 239 | 1 | 0.000 |
| 240 | 39 | 0.008 |
| 241 | 10 | 0.002 |
| 242 | 12 | 0.002 |
| 243 | 12 | 0.002 |
| 244 | 2 | 0.000 |
| 246 | 1 | 0.000 |
| 247 | 4 | 0.000 |
| 248 | 2 | 0.000 |
| 253 | 1 | 0.000 |
| 255 | 73 | 0.015 |

Figure 8

```
TOTAL PICTURE SIZE =     585 LINES,     810 SAMPLES/LINE

SECTION    2 OF SEGMENT    2 CHANNEL    4
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  SUN EL57 AZ114 189-0456- -1-  D-
 NASA ERTS E-1033-10524-                           R G-
6a|W013-30M"W013-00|2?W012-30||.W012-00|   ********   ********
/+N028-00=H N027-30=>6N027-00=  ********   ********   ********
II=N028-00?,N027-30=0(N027-00=2 W012-00=   ********   ********
-?W013-30|aPW013-00|Y,N026-30|RZW012-30|   ********   ********

NGRY = 7  GRVAL =   31  33  35  37  39  41  45     GRCHAR =  *8XIO$

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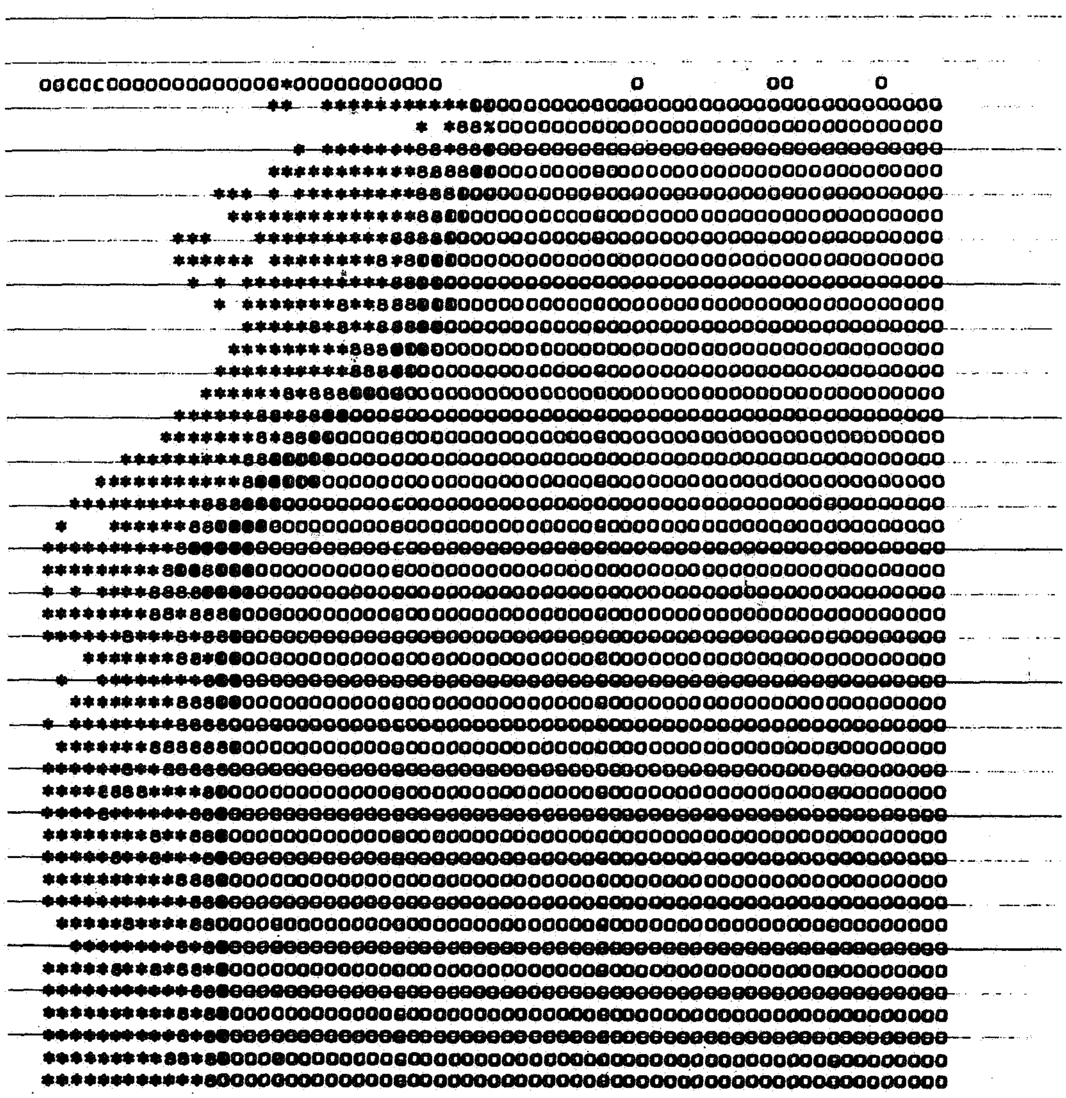

Figure 9

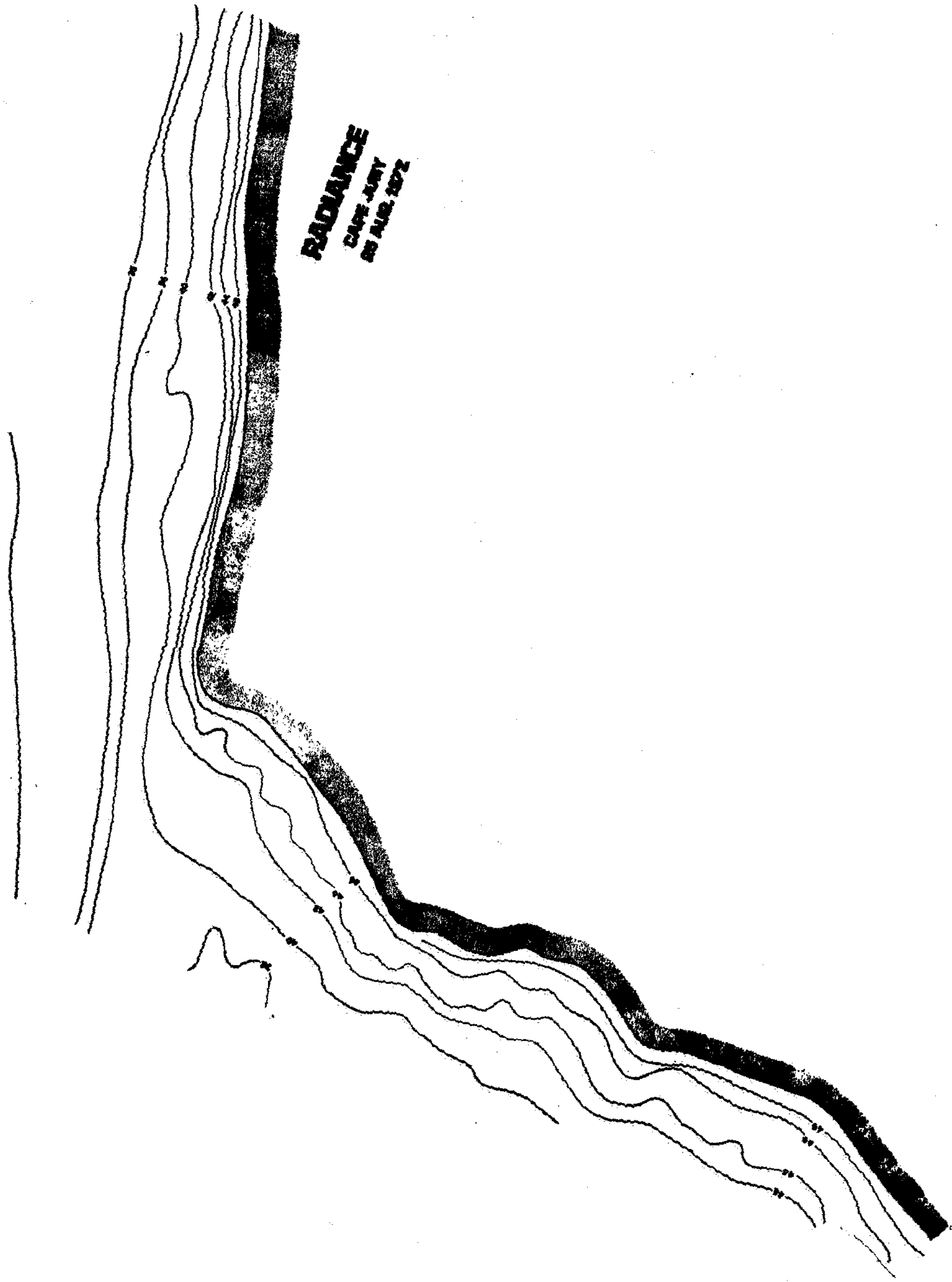


Figure 10