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.

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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 concen-

trations 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 measure-

ments, 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.
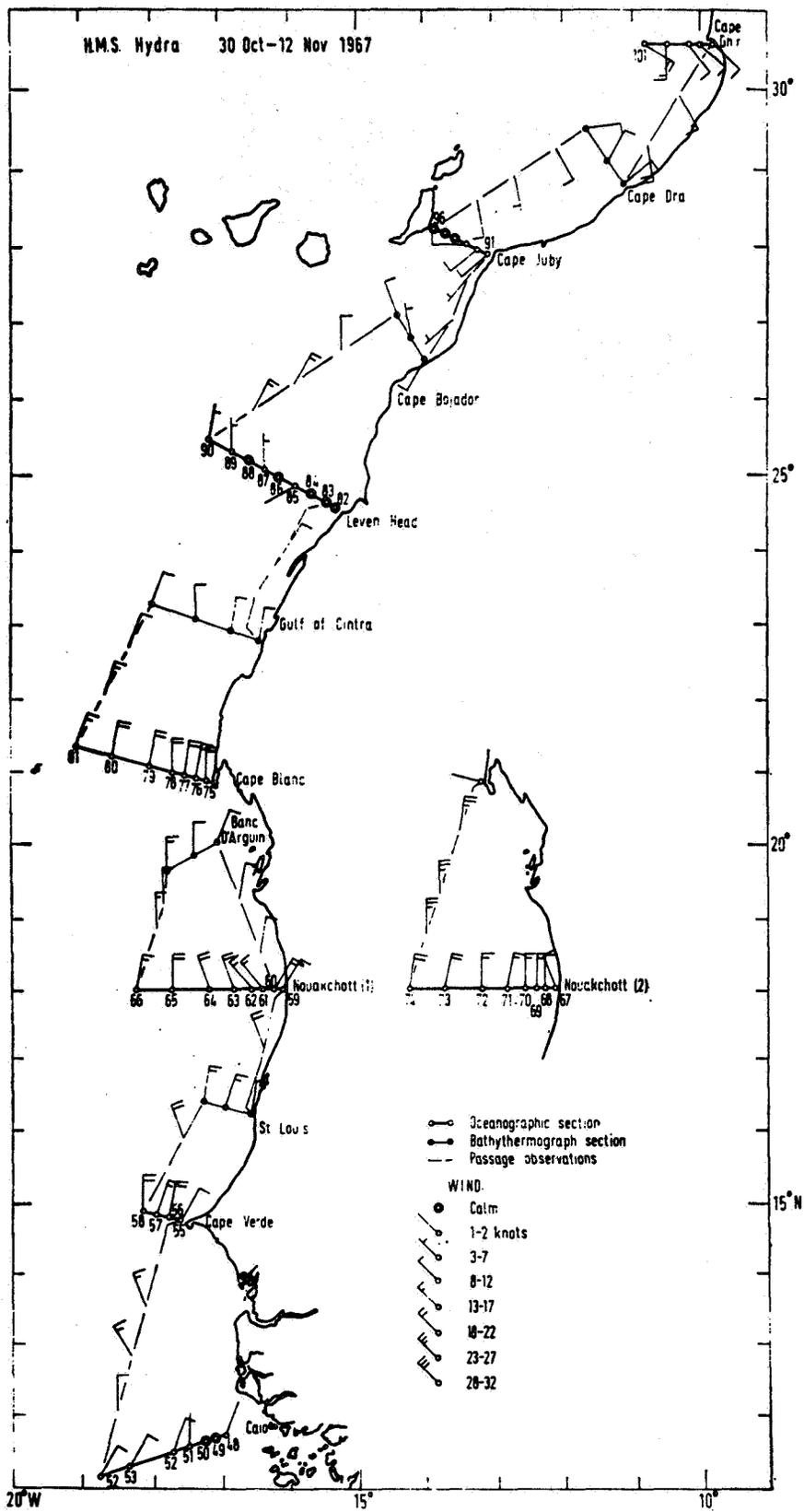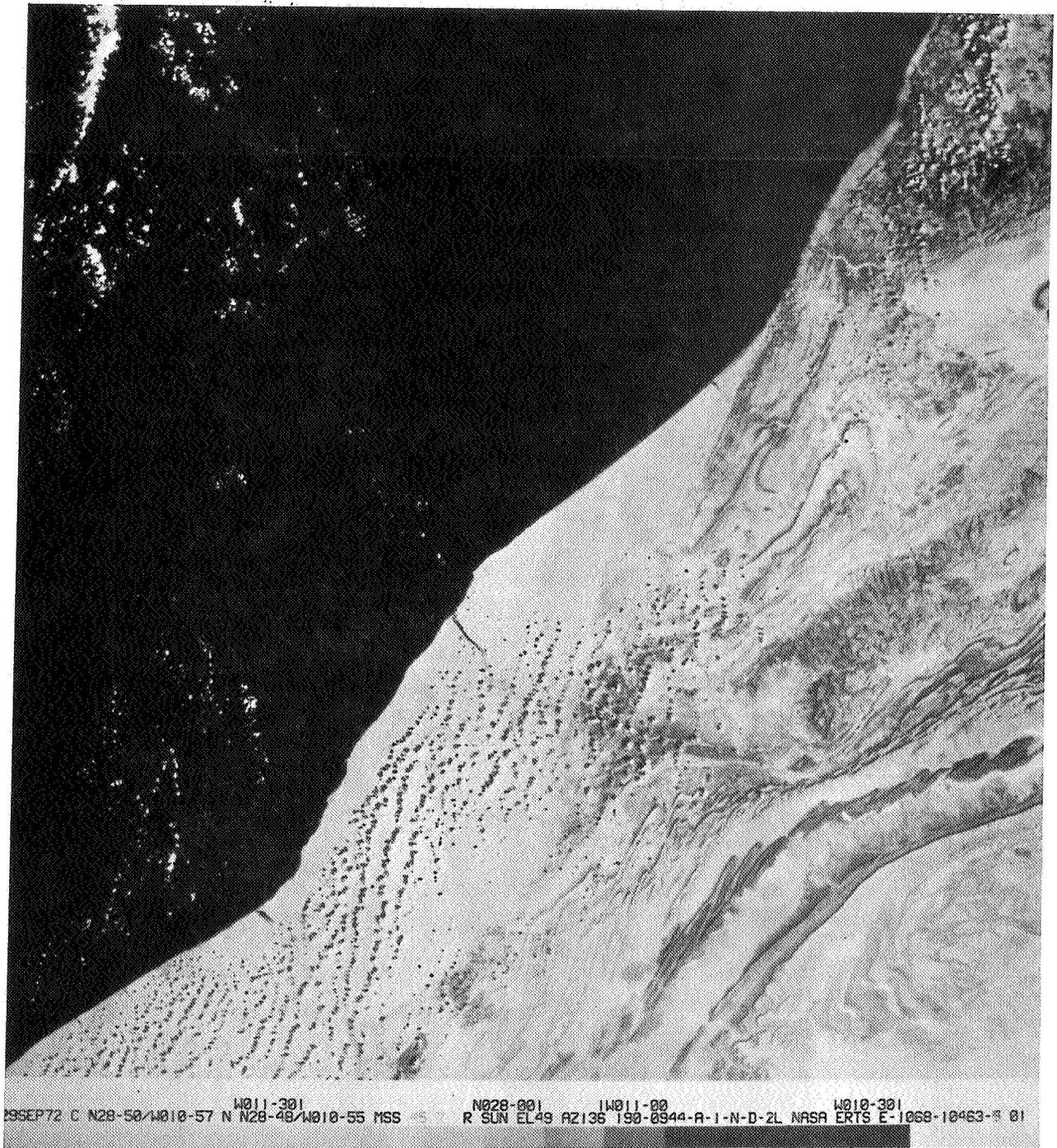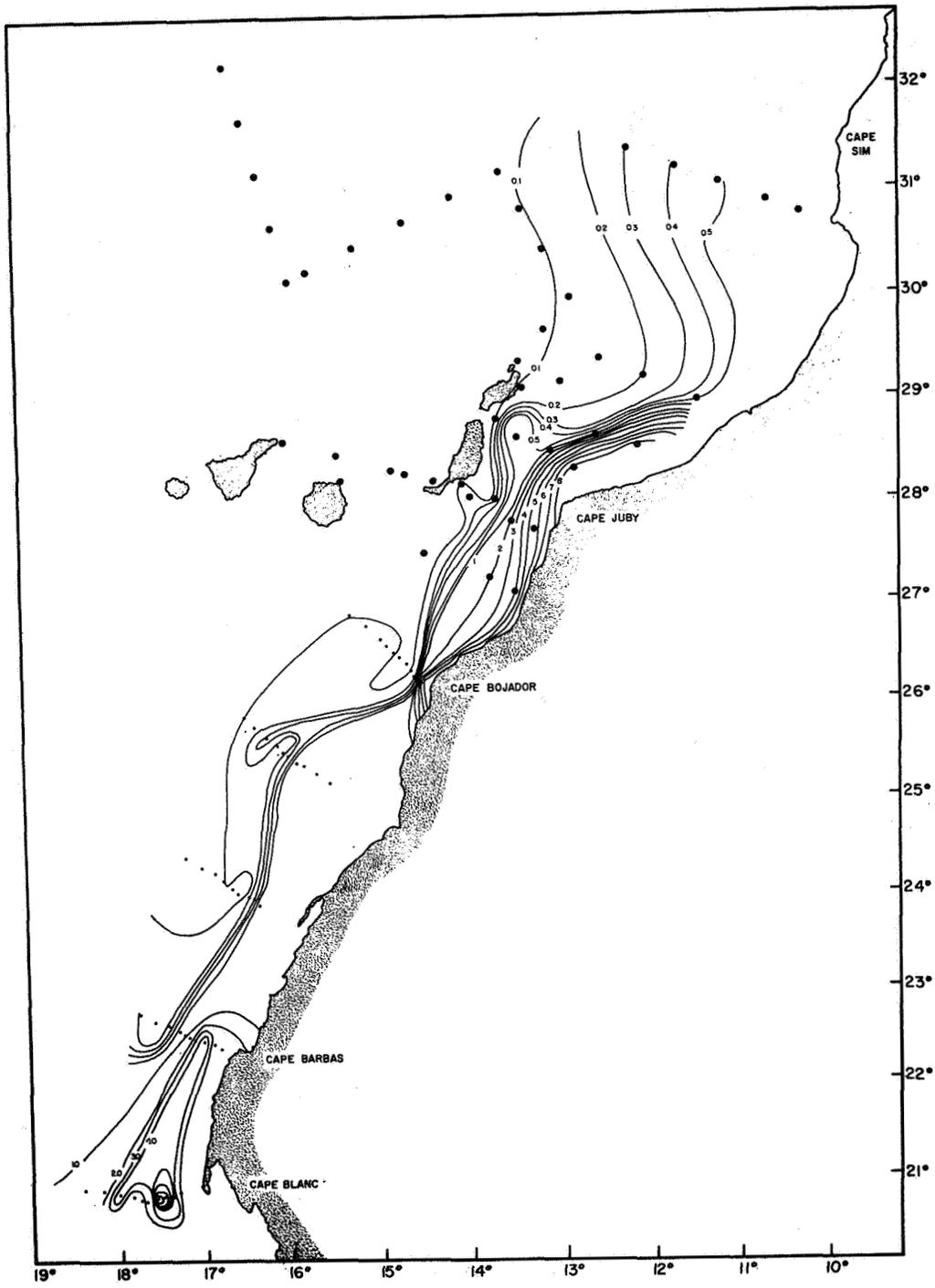
Figure 1

Figure 2

Figure 3

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W017-001　　　　　　　　　　　W016-301　　　　　　　　　　W016-001
06NOV72 C N20-05/W016-16 N N20-02/W016-14 MSS 5　R SUN EL45 AZ141 189-1474-G-1-N-D-2L NASA ERTS E-1106-110

Figure 4

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SEP72 C N15-59/W015-47 N N15-57/W015-42 MSS   R SUN EL55 AZ120 188-0958-A-I-N-D-2L NASA ERTS E-1069-10560-8 01

Figure 5

CAPE SIM

CAPE JUBY

CAPE BOJADOR

CAPE BARBAS

CAPE BLANC

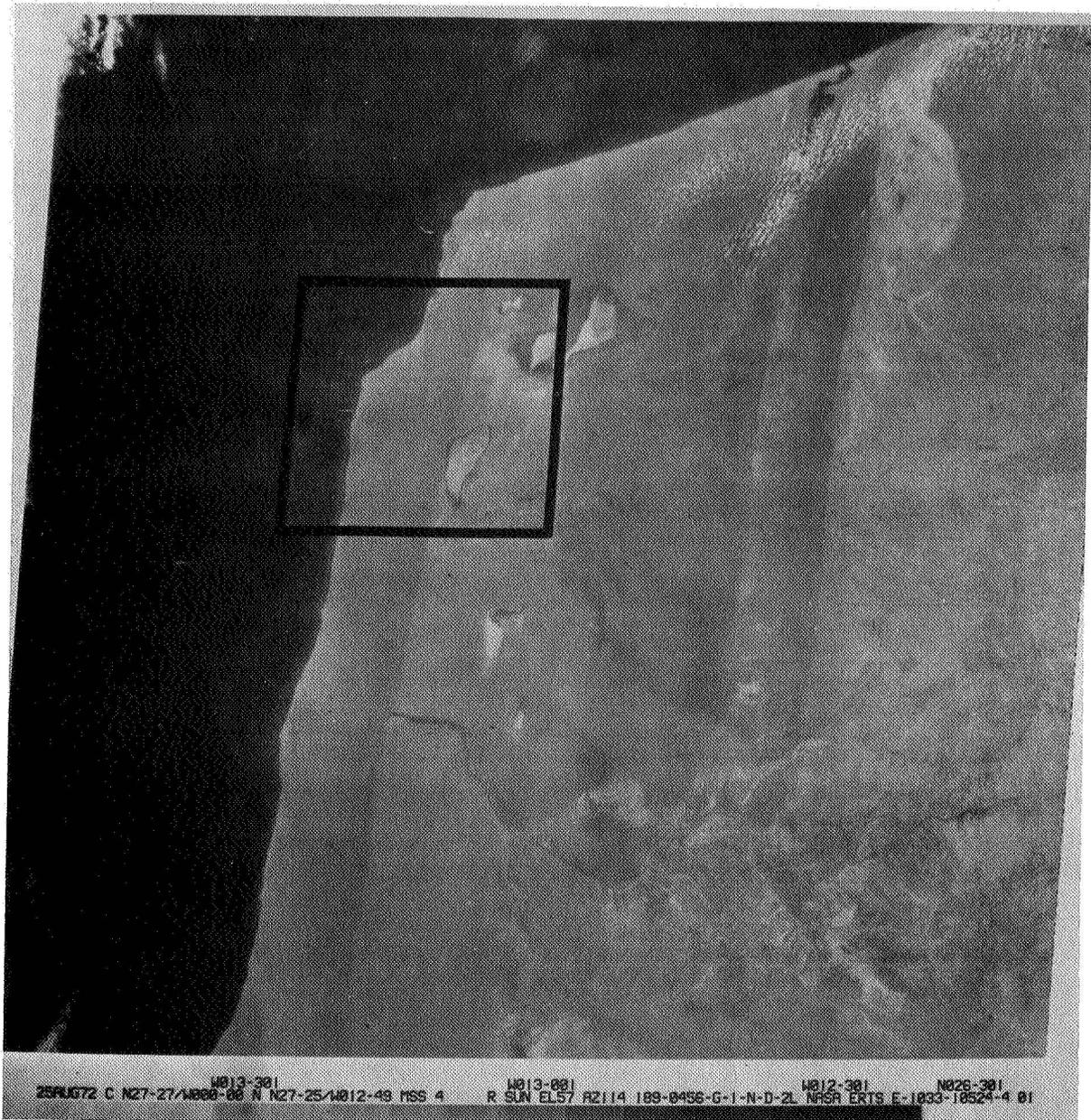1397

Figure 7

Figure 8

TOTAL PICTURE SIZE =   585 LINES,   810 SAMPLES/LINE

SECTION   2 OF SEGMENT   2 CHANNEL   4
1033-1052400 2 4<-A / 4D   SI112407 X<Y
25AUG72 C N27-27/W012-53 N N27-25/W012-49
    SUN EL57 AZ114 189-0456- -1- D-
NASA ERTS E-1033-10524-   R G-
68|W013-30M"W013-00|27W012-30||.W012-00| HHHHHHHH HHHHHHHH
/+N028-00=H N027-30=>6N027-00= HHHHHHHH HHHHHHHH
II=N028-00?,N027-30=0(N027-00=2 W012-00= HHHHHHHH HHHHHHHH
-?W013-30|BPW013-00|Y,N026-30|RZW012-30| HHHHHHHH HHHHHHHH

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

START LINE = 1   START SAMPLE =   1   LINE SPACING 12   SAMPLE SPACING

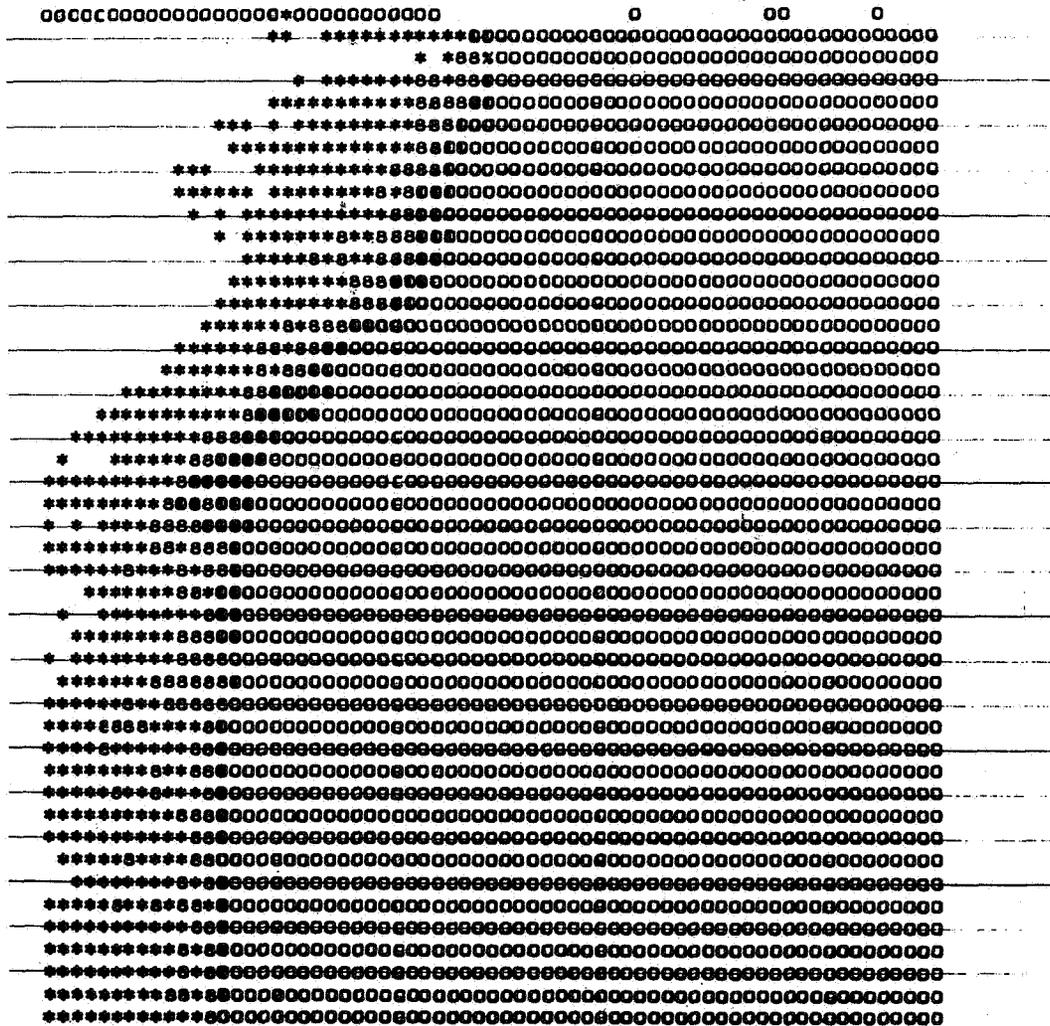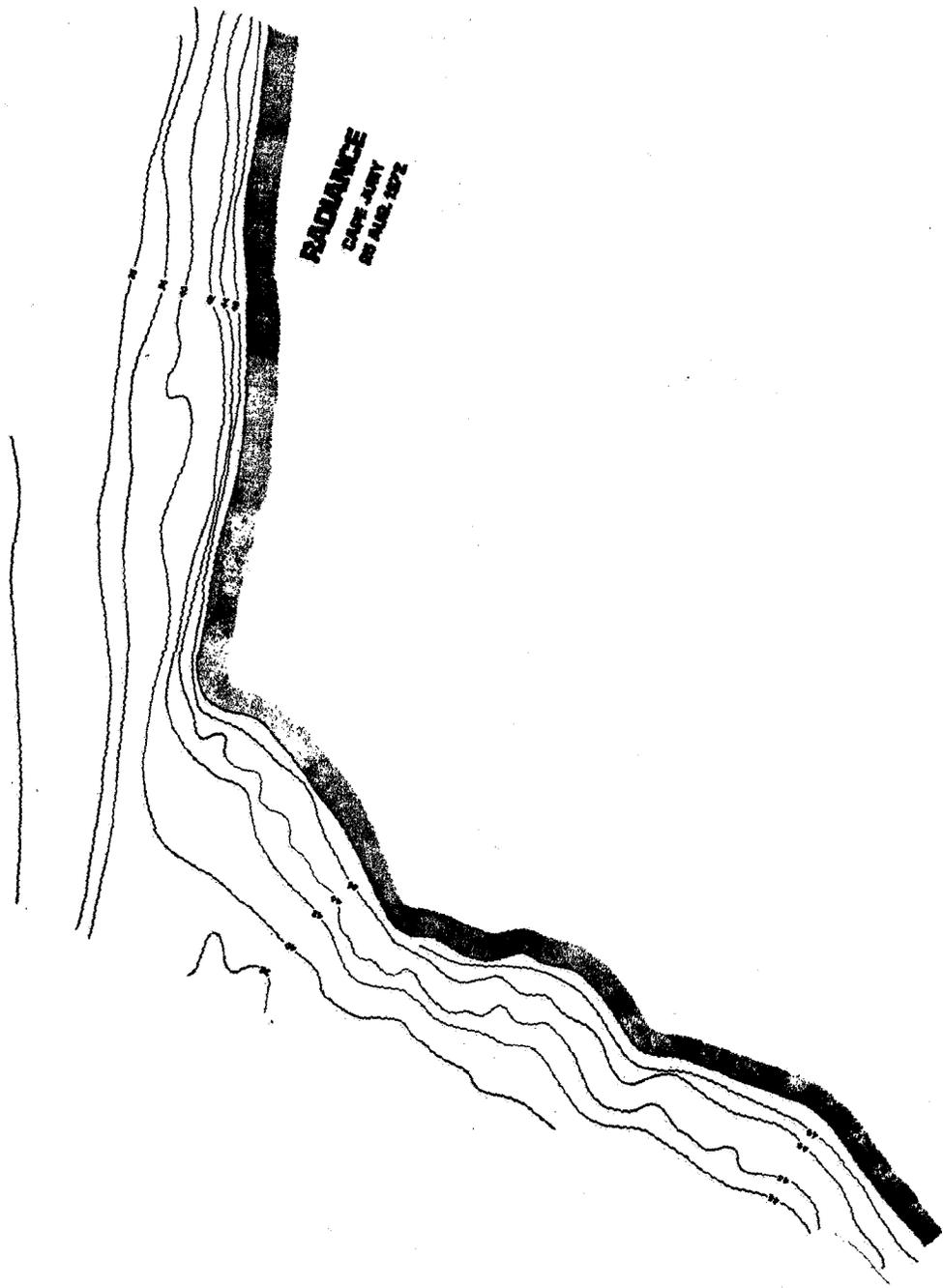Figure 9

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Figure 10