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STUDY OF POLLUTION AT SEA

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BSTRACT

The detection with ERTS of three types of pollution are discussed in his report.

1) Industrial waste poured into the sea from a ship.
2) Complex pollution in front of industrial ports.
3) Pollution (in a broad sense) by rivers.

The difficulty to differentiate between pollutants on the surface of he sea and atmospheric haze is emphasized.

In the second part of this report, multispectral classifications btained at sea and on coastal lakes by numerical computation are discussed.

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PREFACE

The aim of this investigation was to assess the ability of ERTS imagery to detect various types of pollution at sea in the western Mediterranean.

Mediterranean is almost a closed sea therefore pollution is a serious problem. Various industrial activities are being developed along the coast and some of them are a real threat to the environment. Furthermore, the French Riviera is a very touristic place frequented by many tourists and, far away towards the west, from the Camargue region to the Spanish border, 180 kilometers of beaches are being developped and will soon be thronged by 300,000 or 400,000 tourists from all countries of Western Europe.

Shellfish, mussels, oysters are bred in the coastal lakes and such breeding often suffer from waste coming from industrial plants.

Important industrial activities are located on the coast. Marseilles ranks second among European ports, coming after Rotterdam but a head of London. A large part of its activity is with oil (67 million metric tons in 1971).

Four refineries (Shell, B.P., C.F.R., Exxon) are already installed with a total refinery capacity of 40 million tons per year.

A 400,000 tons steam cracking plant will soon begin operating along with other units manufacturing ethylene oxide, propylene, etc. and vinyl chloride (300,000 tons per year).

The new port of Fos handled 3,500,000 cubic meters of natural gas imported from North Africa in 1972, and because of its accessibility to large tankers, this location has been choosen for terminal of the two longest European pipelines.

A great many tankers cross this part of the Mediterranean to carry oil from the Middle East or North Africa to Europe.

In this investigation, the repetitivity of ERTS coverage is essential. We received at most 6 repetitive scenes of part of the studied zone since ERTS was launched. Consequently, we have been able to detect a systematic pollution such as pollution by rivers or industrial ports, ~~but it is very difficult to detect accidental spills with~~ so few images.

Band 4 is the best suited to detect patches on the sea, but the quality of this image is unfortunately often poor owing to atmospheric transmission problems.

It has been observed that a certain amount of pollution occurs systematically in (and in front of) certain ports (Genoa, Savona, Fos, etc.). It must be pointed out that it is not very easy, on a given image, to differentiate between pollutants (or sediments) on the surface of the sea and atmospheric haze.

The transport into the sea of sediments by the Var river (French Riviera) has always been observed on all the images received. This phenomenon does not happen so regularly with the Rhone River.

As far as tanker spillage is concerned, two cases can be distinguished. If the tanker is pouring oil at the time when the photo is taken, the patch appears elongated behind the ship. Such an object can be clearly detected if the patch is about 300 m wide and 2 or 3 km long. If the oil had been poured several hours previously, the patch may be more or less scattered by the wind on the surface of the sea. It is then difficult to be sure whether such a patch corresponds to an oil spill or to atmospheric haze.

During this investigation we have been lucky enough to detect a patch of industrial waste 25 km long and about 200 or 300 m wide poured at sea off Corsica by an Italian ship. This spill contains residua of titanium, sulfuric acid and ferrous oxides.

This examples proves that satellite monitoring of pollution at sea is possible if the patch is sufficiently large. The main problem is to obtain a frequent coverage of the studied zone.

In order to determine what volume of oil can be detected with ERTS, various experiments, related to ERTS passes, were previously scheduled at sea. The program included the pouring of various products under three different ERTS tracks and then the sensing of these products with ERTS and airborne imagery at the same time. Detection with ERTS failed because of bad atmospheric transmission. Airborne imagery (visible and IR) was satisfactory.

The second part of this report deals with multispectral classifications obtained from CCT, at sea and on coastal lakes.

This subject was not previously included in the aim of this project. However, classification computer programs were written and tested for the MMC 009-04 project and it was then found that it would be interesting to apply these multispectral classification methods to the differentiation of various water qualities in the investigated zone.

These computer programs were just available in April 1974.

I - INTRODUCTION

In the first part of this report several cases of pollution at sea are discussed.

ERTS images frequently show patches on the sea, but it is often difficult or hazardous to relate them to pollutants. Therefore three aspects of unquestionable pollution will be discussed here.

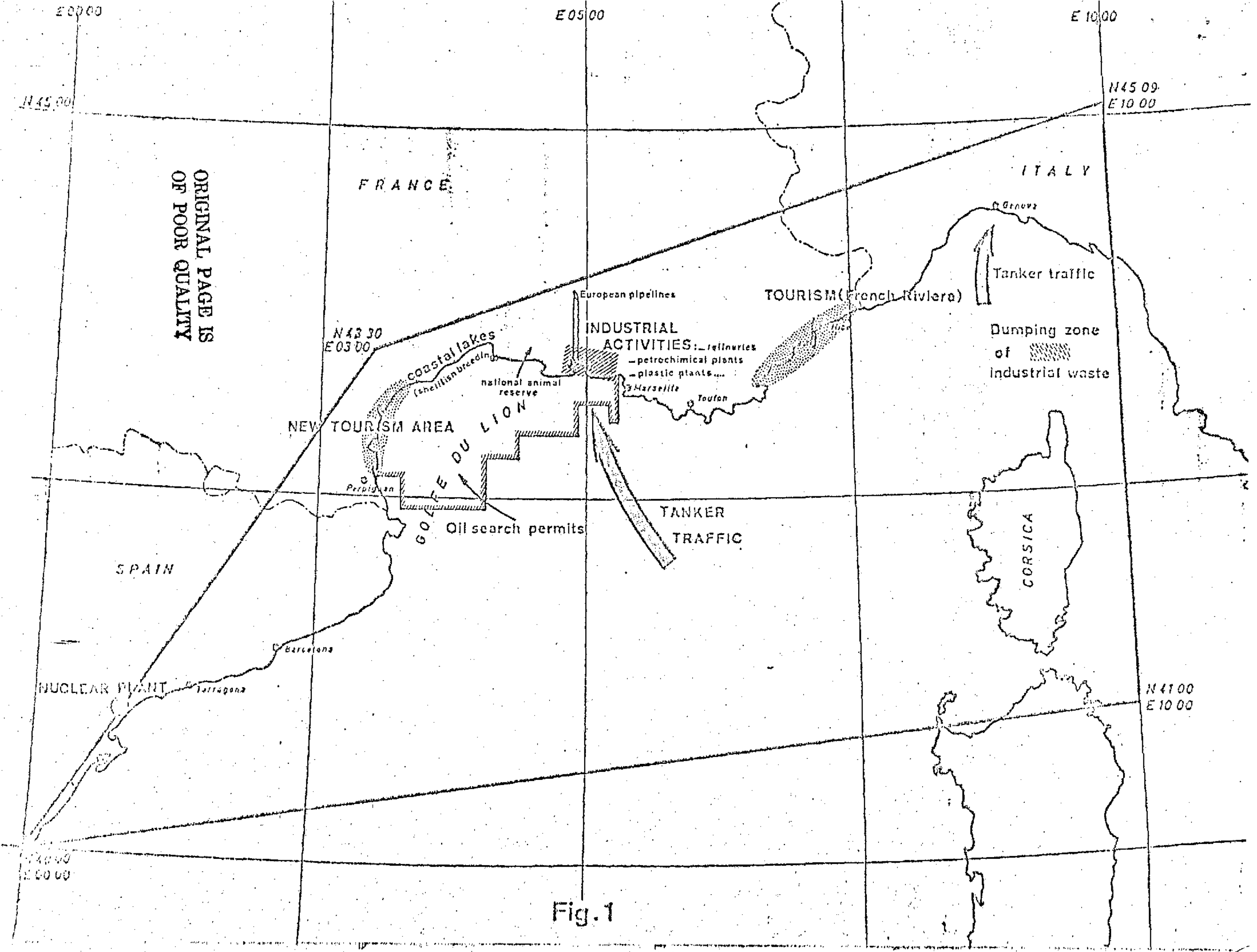
1. - Dumping of industrial waste by an Italian ship (ERTS 1075-9393)
2. - Pollution (in a broad sense) by industrial ports.
3. - Pollution (in a broad sense) by rivers.

In the chosen area (Fig. 1) the atmosphere is often clear, and we could have expected a good repetitive coverage. Meanwhile we received at most 6 images corresponding to part of the studied area.

The second part of this report deals with multispectral classification obtained on coastal lakes and at sea off the Mediterranean coast of France. The studied area includes the Rhone Delta with the swampy Camargue region. Farther towards the SW lie the coastal lakes of the Languedoc-Roussillon region. Shellfish, mussels and oysters are bred in these lakes and such breeding grounds often suffer from waste coming from industrial plants.

From the Camargue region to the Spanish border, 180 kilometers of beaches are being developed. New shorefront areas appear and will soon be thronged by 300,000 or 400,000 tourists from all countries in Western Europe.

From another point of view, the Rhone River plays an important role in the sedimentation processes in the Gulf of Lions.



E 00 00
E 05 00
E 10 00
N 45 00
N 45 09
E 10 00
FRANCE
ITALY
Genova
Tanker traffic
TOURISM (French Riviera)
European pipelines
INDUSTRIAL ACTIVITIES: – refineries
– petrochimical plants
– plastic plants....
Dumping zone of industrial waste
N 43 30
E 03 00
coastal lakes
(shellfish breeding)
national animal reserve
Marseille
Toulon
NEW TOURISM AREA
GOLFE DU LION
Perpignan
Oil search permits
TANKER TRAFFIC
CORSICA
SPAIN
Barcelona
NUCLEAR PLANT
Tarragona
N 41 00
E 10 00
N 40 00
E 00 00

Fig. 1

FIRST PART

II - POLLUTION AT SEA

II.1 - Industrial Waste (ERTS 1075-9393)

The elongated patch detected on this image (A, Fig. 2) corresponds to a spill of 3,000 tons of industrial waste from a ship coming from an Italian plant manufacturing titanium. This waste contains 80% of liquids and 20% of solid residuum. The liquid part is made of solutions of ferrous and ferric oxides, etc., and of 330 tons of sulfuric acid. The solid part contains mainly residum of titanium ore (illmenite), vanadium (710 kg) and cadmium (30 kg).

This waste was dumped on the surface of the sea with a flexible hose. Fields surveys and ground truth corresponding to this waste were conducted by Co-I organization "Centre National pour l'Exploitation des Océans".

This aspect of the patch on the ERTS image is certainly due to the solid content of the waste. It is about 25 km long and 200 or 300 m wide. The best detection is with band 4.

A similar patch can be seen 35 km to the NE of the patch previously described. It possibly corresponds to another dumping. If this is the case, the very large white zone lying between this last patch and the Italian coast could possibly correspond to its progressive scattering towards the NE and N. The main currents in this part of the Mediterranean are shown on Fig. 3.

Many other "patches" can be seen on the surface of the sea on this ERTS image, but we cannot say if they correspond or not to polluted areas. These patches may be due to either a transport of sediments or to a blurring by atmospheric haze.

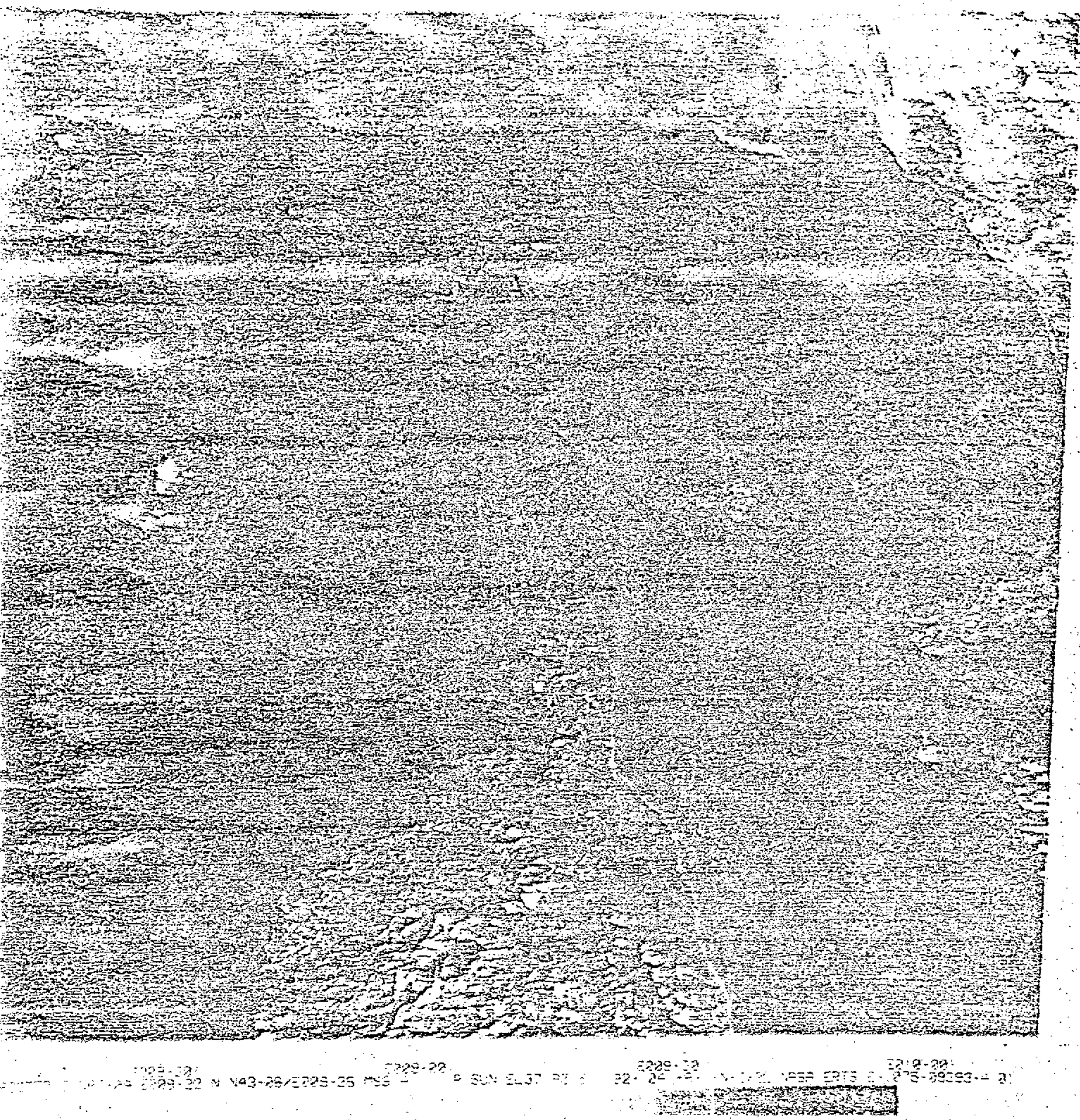


Fig. 2

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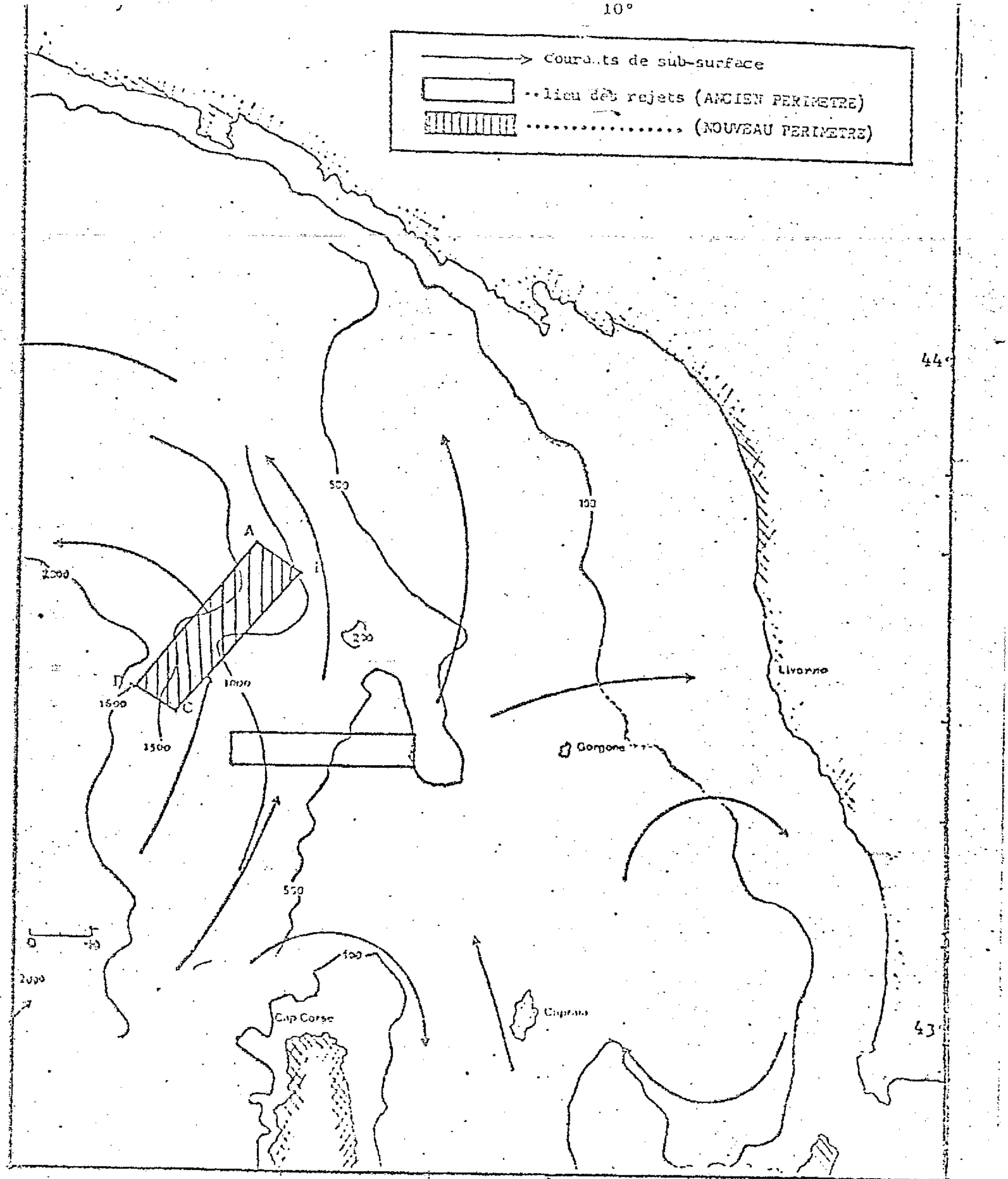

MAIN CURRENTS IN THE DUMPING ZONE

Fig. 3

II.2 - Patches observed in front of industrial ports

Fig. 4 shows a sketch of the various patches observed in the Italian Gulf between Livorno and Savona. It summarizes the observations made on 7 different ERTS images.

13 August 72	-	1021 - 9385
6 October 72	-	1075 - 9390
		1075 - 9393
7 October 72	-	1076 - 9445
		1076 - 9451
18 December 72	-	1148 - 9453
10 May 73	-	1291 - 9395

The industrial waste described in paragraph II.1 is indicated in Fig. 4 (patch A).

The large patches indicated in Fig. 4 and runing along the coast appear nearly at the same location whatever the season may be from 13 August 72 until 10 May 73. They are certainly not related to atmospheric effects since they always disappear on the coast itself. Some patches never reach the coast.

Meanwhile it is difficult just from studying these images to assess the presence of pollution. These patches may be due to either effluents coming from the industrial ports (La Spezia, Genoa, Savona, etc.) or to terrigenous outflows coming from river basins.

The elongated patch south of Savona was observed only on the 12-18-72 frame . It seems to be smoke from a power plant.

No field check was made on this zone.

Pollution often appears in Fos, an industrial port W of Marseilles (France) but its study is difficult with ERTS because it does not extend far enough offshore. It is more easily detected with Skylab imagery.

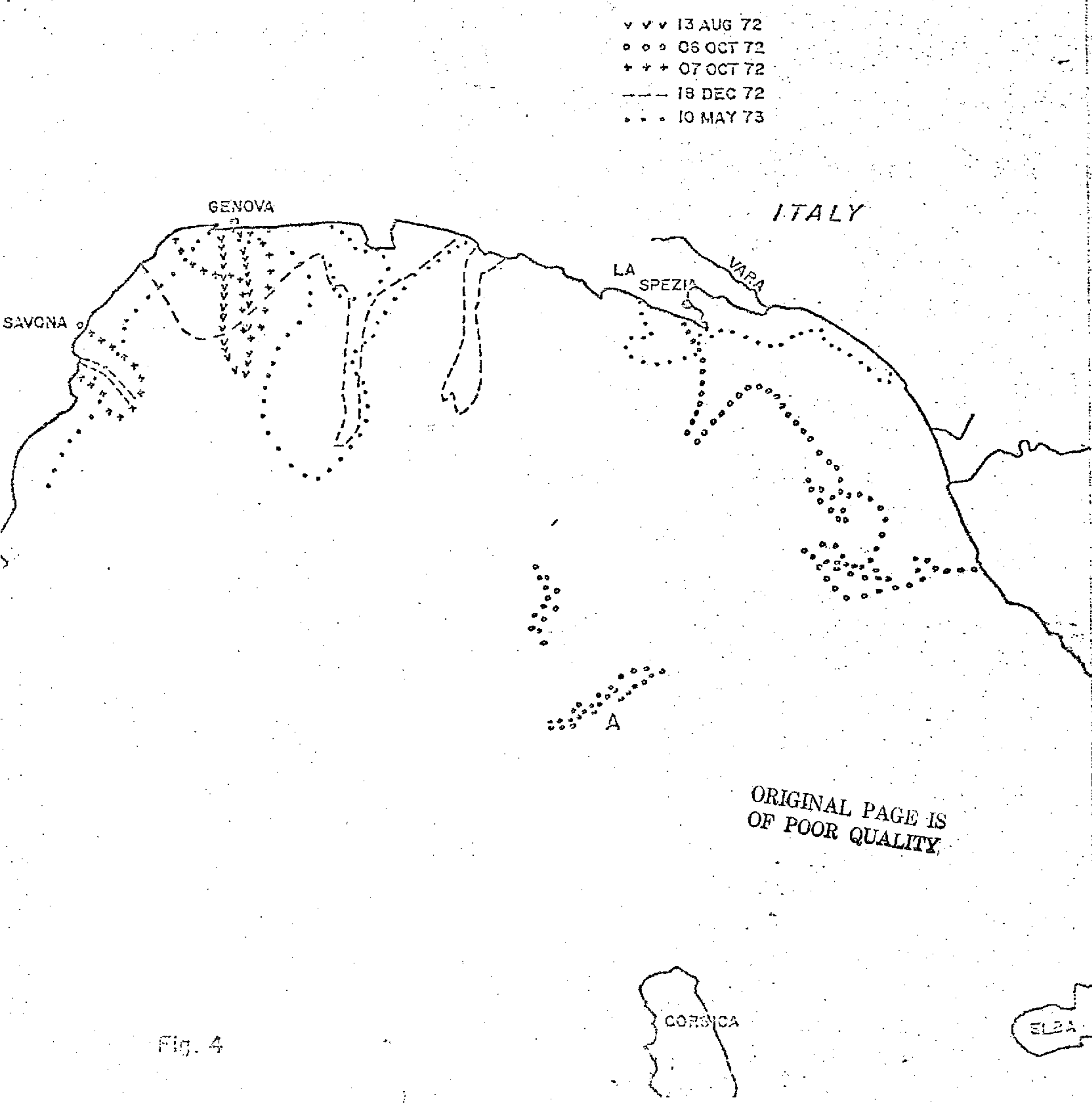
v v v 13 AUG 72
o o o 06 OCT 72
+ + + 07 OCT 72
— — — 18 DEC 72
. . . 10 MAY 73
GENOVA
SAVONA
ITALY
LA
SPEZIA
VARA
A
CORSICA
ELBA

Fig. 4

Rainfalls and meteorological conditions should be studied in detail on the zone, but unfortunately commercially available meteorological maps are compiled on too general a basis to be useful for solving this problem.

Figures 5 and 6 show these meteorological maps for October 5 and 6, 1972.

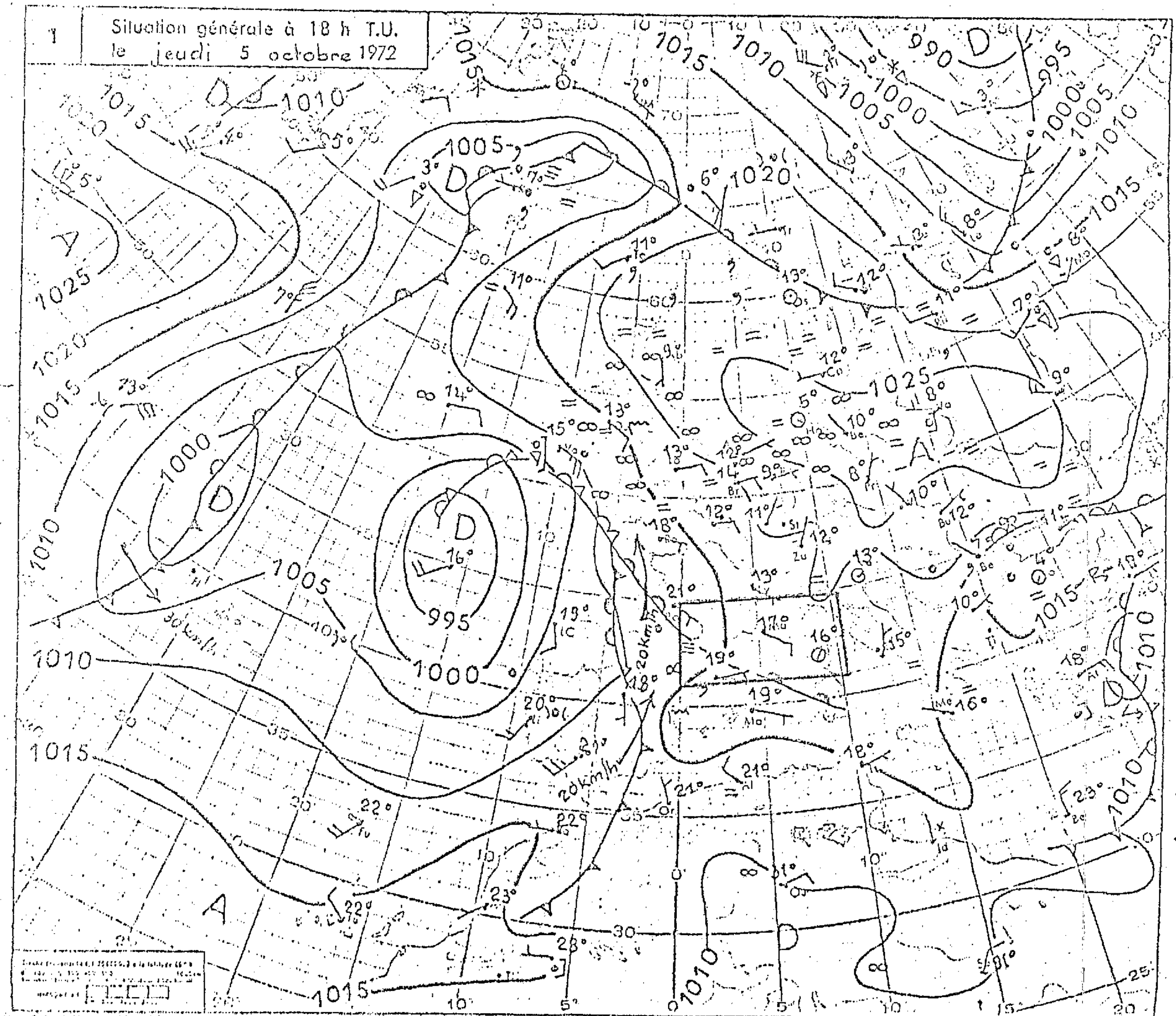

Fig. 5

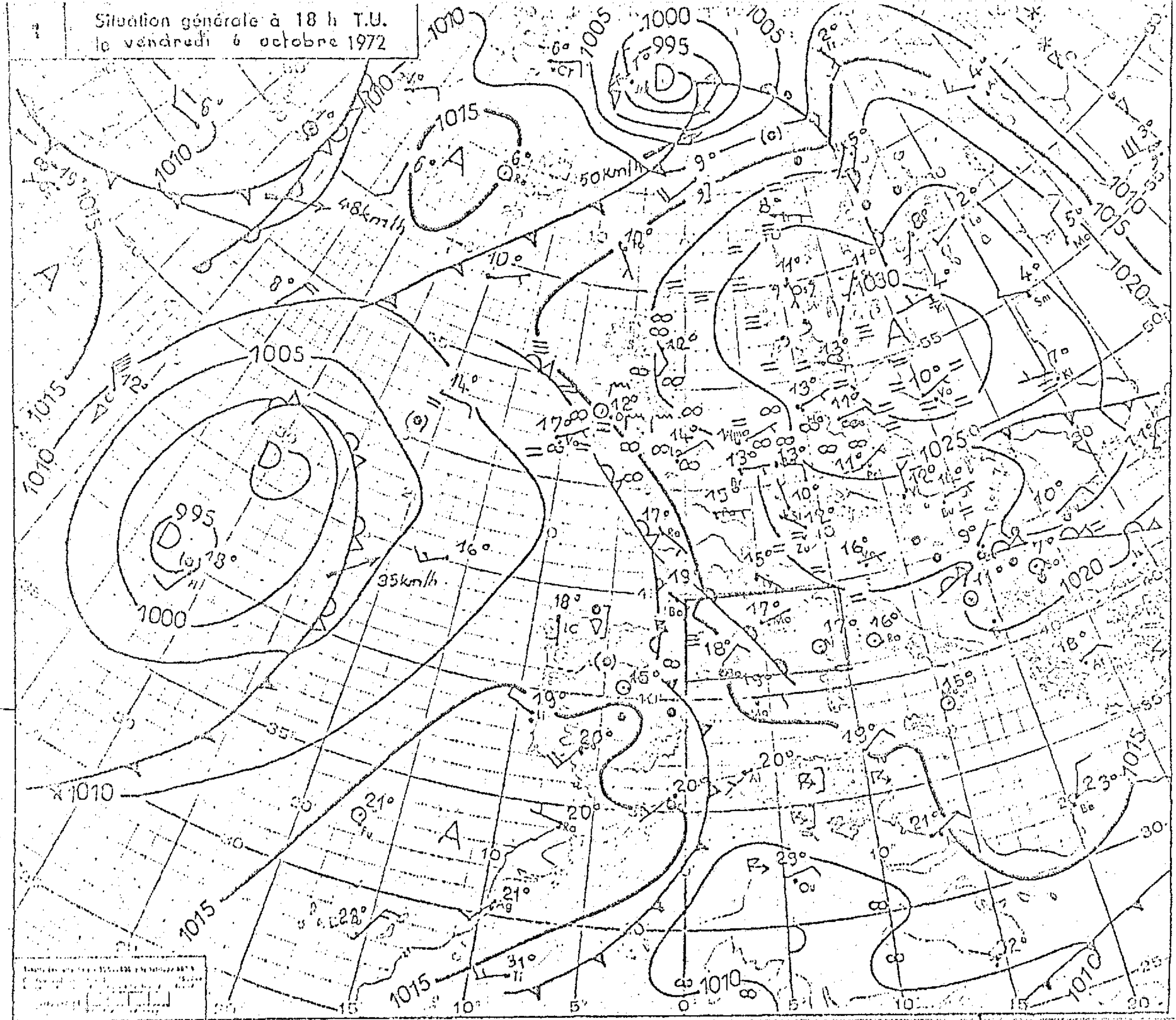
Situation générale à 18 h T.U.
le vendredi 6 octobre 1972
50km/h
48km/h
35km/h

Fig. 6

II.3 - Example of "Pollution" (in a Broad Sense) by the Var River

The studied zone is shown in Fig. 7 at a 1:200,000th scale. It is located on the French Riviera which has been very popular with and frequented by tourists for a long time. The Var River reaches the sea near the Nice Airport, 2 kilometers west of the city.

Fig. 8 is a sketch compiled from 4 ERTS images:

19 Sept. 72 - 1058 - 9450
7 Oct. 72 - 1076 - 9451
6 Jan. 73 - 1167 - 9512
1 March 73 - 1221 - 9515

MSS band 4 clearly shows that the area located on the sea between Nice and Cap d'Antibes in all cases is covered by sediments coming from the Var River.

Fig. 9 is a chart where directions and speeds of winds are plotted at some dates corresponding approximately to the time during which the ERTS images mentioned above were taken. These data were recorded at Toulon, about 110 kilometers West of Nice. This chart shows that rainfalls were almost inexistant between Sept. 72 and March 73. Winds blew alternately from the NW and ENE, sometimes from the West and East. The studied ERTS images show that in each case the sediments of the Var River always spread on the sea West of Nice, between Nice and Cap d'Antibes, 12 kilometers towards the SW.

It is thought that this example is good proof of the usefulness of ERTS periodic coverage for pollution and sedimentary studies.

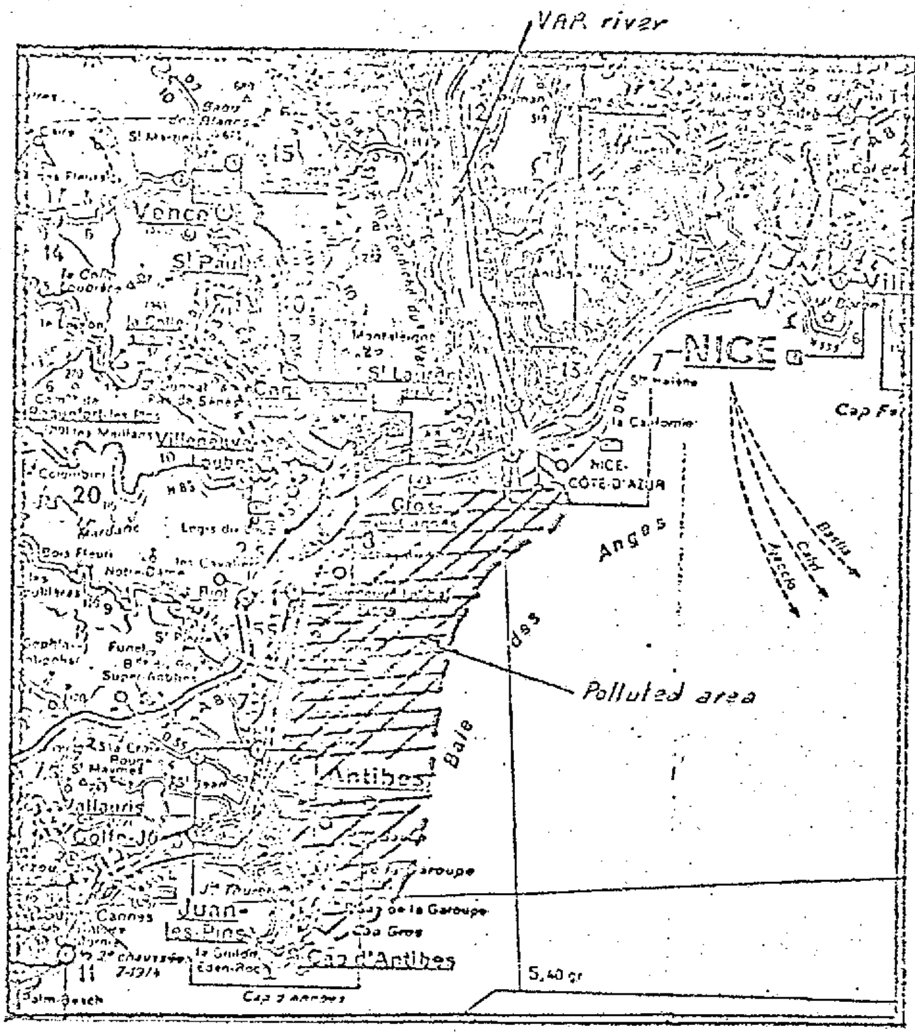

Fig. 7

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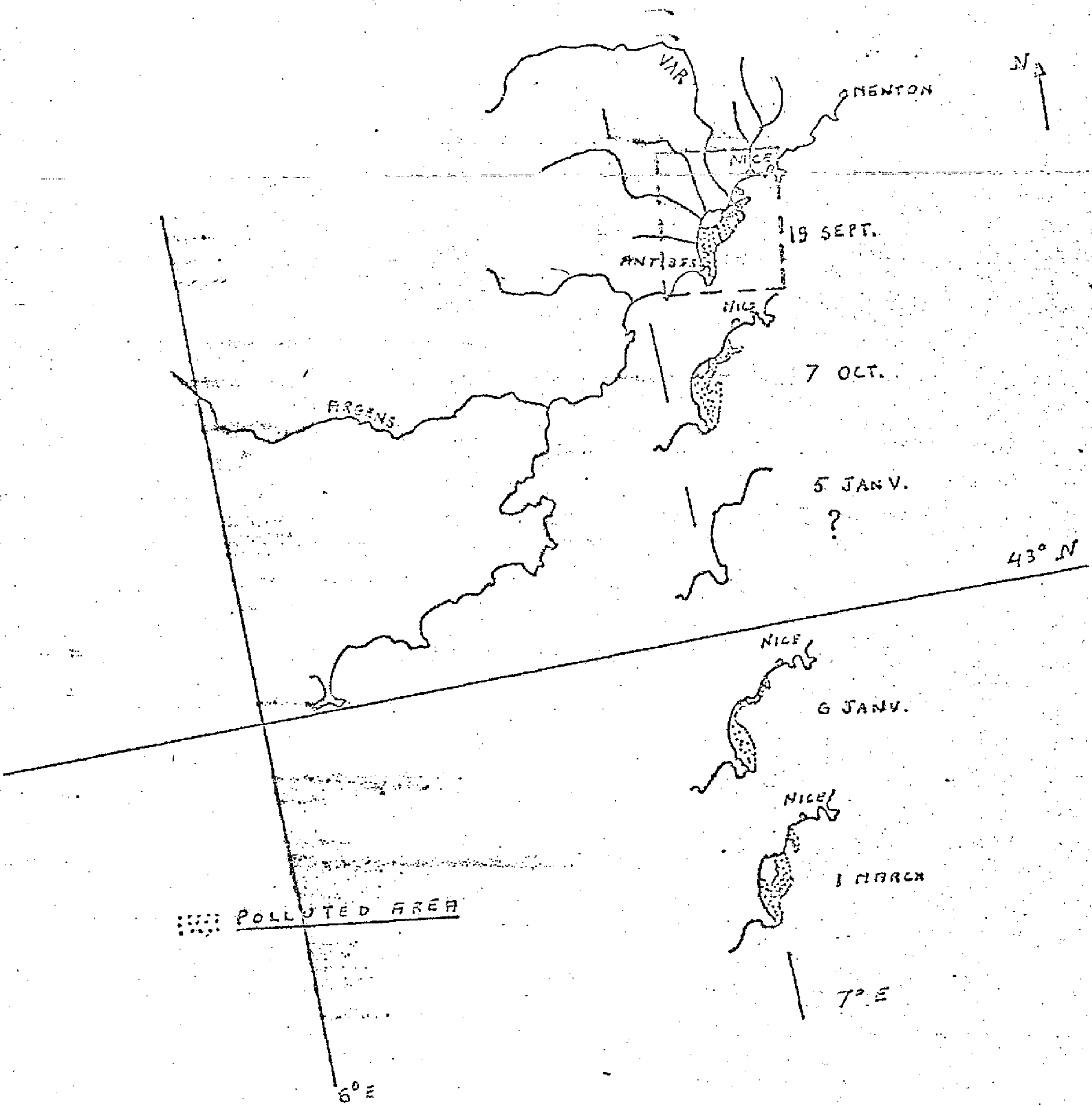

Fig. 8

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TOULON	CLOUDS					WINDS						Rainfall			SUN.	TEMP MIN	TEMP MAX
21-9-1972	7	7	5	–	–	E	8	E	14	ENE	9	–	–	néant	3.7	16.3	23.1
22-9-72	6	6	4	–	–	E	8	E	14	E	6	–	–	"	8.3	17.3	24.6
8-10-72	0	1	0	–	–	WNW	3	S	4	W	2	–	–	"	9.5	11.8	24.4
9-10-72	3	0	0	–	–	calme		calme		W	6	–	–	"	9.9	9.6	23.6
13-11-72	8	3	3	–	–	WNW	3	W	10	W	8	–	–	"	8.5	11.2	17.5
14-11-72	-	3	5	–	–	WNW	8	W	6	W	5	–	0.1	0.1	8.7	13.4	17.7
15-11-72	-	1	2	–	–	W	7	W	11	W	10	–	–	néant	9.2	10.8	17.3
19-12-72	1	2	2	–	–	calme		E	7	ENE	5	–	–	"	8.0	2.9	13.9
20-12-72	0	2	7	–	–	NNE	4	E	10	ENE	4	–	–	"	7.8	7.5	13.1
25-1-1973	4	3	6	–	–	calme		ESE	2	NE	2	–	–	"	5.8	4.2	14.7
26-1-73	1	0	3	–	–	WNW	2	W	8	W	8	–	–	"	8.5	4.6	12.0
11-2-73	7	3	1	–	–	W	7	WNW	12	NNW	13	–	–	"	9.0	5.0	11.1
12-2-73	0	4	4	–	–	NW	2	WNW	7	WNW	9	–	0.7	0.7	8.9	4.7	13.0
20-3-73	0	2	0	–	–	ENE	4	ESE	13	E	6	–	–	néant	10.4	8.8	15.6
21-3-73	0	0	0	–	–	E	4	SE	4	E	5	–	–	"	10.8	6.8	19.2

none

none

Fig. 9

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SECOND PART

III - MULTISPECTRAL CLASSIFICATION OF WATER

Part of an ERTS image (1187-10025) has been selected for multispectral classifications. The studied zone is located in the northeastern part of this image and includes the Western part of the Rhone Delta, the swampy Camargue region and the main coastal lakes on the Languedoc-Roussillon Mediterranean Coast.

Two different numerical classification techniques have been used.

a) a so-called "adaptative method" which makes use of statistical analysis.

b) a classification method using principal component analysis (unsupervised method).

III.1 - Adaptative method

This method makes use of statistical analysis. It consists in classifying samples according to various distribution laws that are taken from the image itself. There is no need to define computer training areas as is the case with other methods. As a point of departure, the computer is given solely the coordinate of several points located in the areas to be classified (a priori classes). Around each initial pixel and on a total number of pixels (400 for example) that may be set at will, the computer searches for the neighboring pixels that may be taken together to make up a homogeneous zone, i.e. pixels that obey the same law of distribution. For a given class this law is often a Gaussian law. The computer may possibly select a certain number of adjacent points, or else it may skip some of them if they do not have the same statistical properties. A given class is retained only if its structure obeys a certain law. For example a class is retained

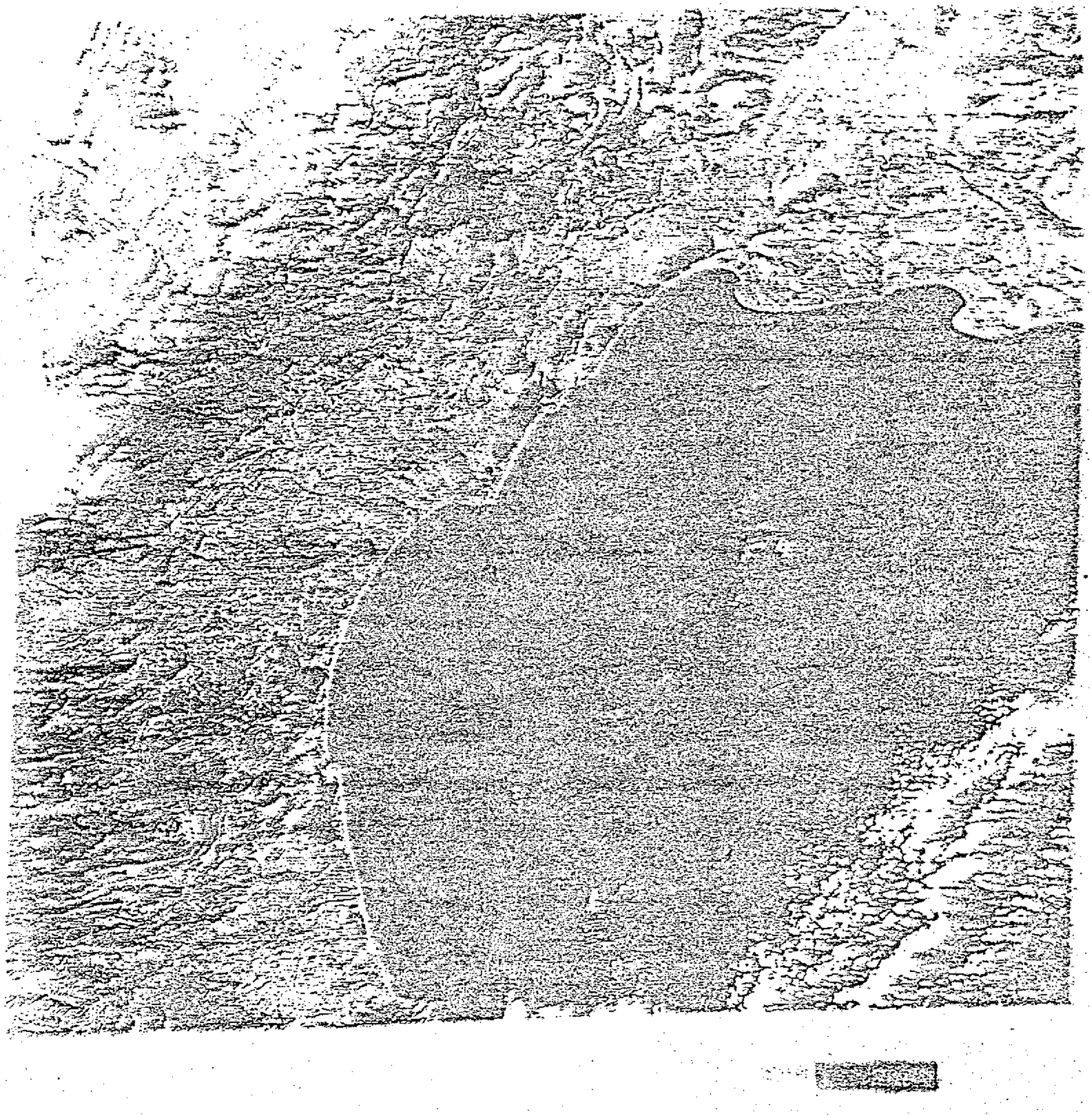

Fig. 10

only if each point in this class statistically has 3 neighbors belonging to the same class among the 9 nearest neighbors. The computer program makes several iterations (3 for example). The aim of each new iteration is to classify the blanks remaining after the previous iteration.

For each homogeneous class retained, the probability density function d(x) is obtained by the following formula:

$$d(x) = \frac{\sqrt{\text{Det } V^{-1}}}{(2\pi)^{k/2}} e^{-1/2\, X^t\, V^{-1}\, X}$$

where k = 4 for an MSS image.

$$X = \begin{matrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{matrix}$$ vector corresponding to the amplitudes of a given point.

X^t = transposed vectof of X.

V = covariance matrix of the class.

V^{-1} = inverse matrix of V.

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In Fig. 11, six a priori test zones were selected by hand in the first iteration.

First zone : in the center of the Vaccares lake.

Second zone : on littoral barrier beaches corresponding to a former Rhone delta.

Third zone : in a swamp to the east of Vaccares lake.

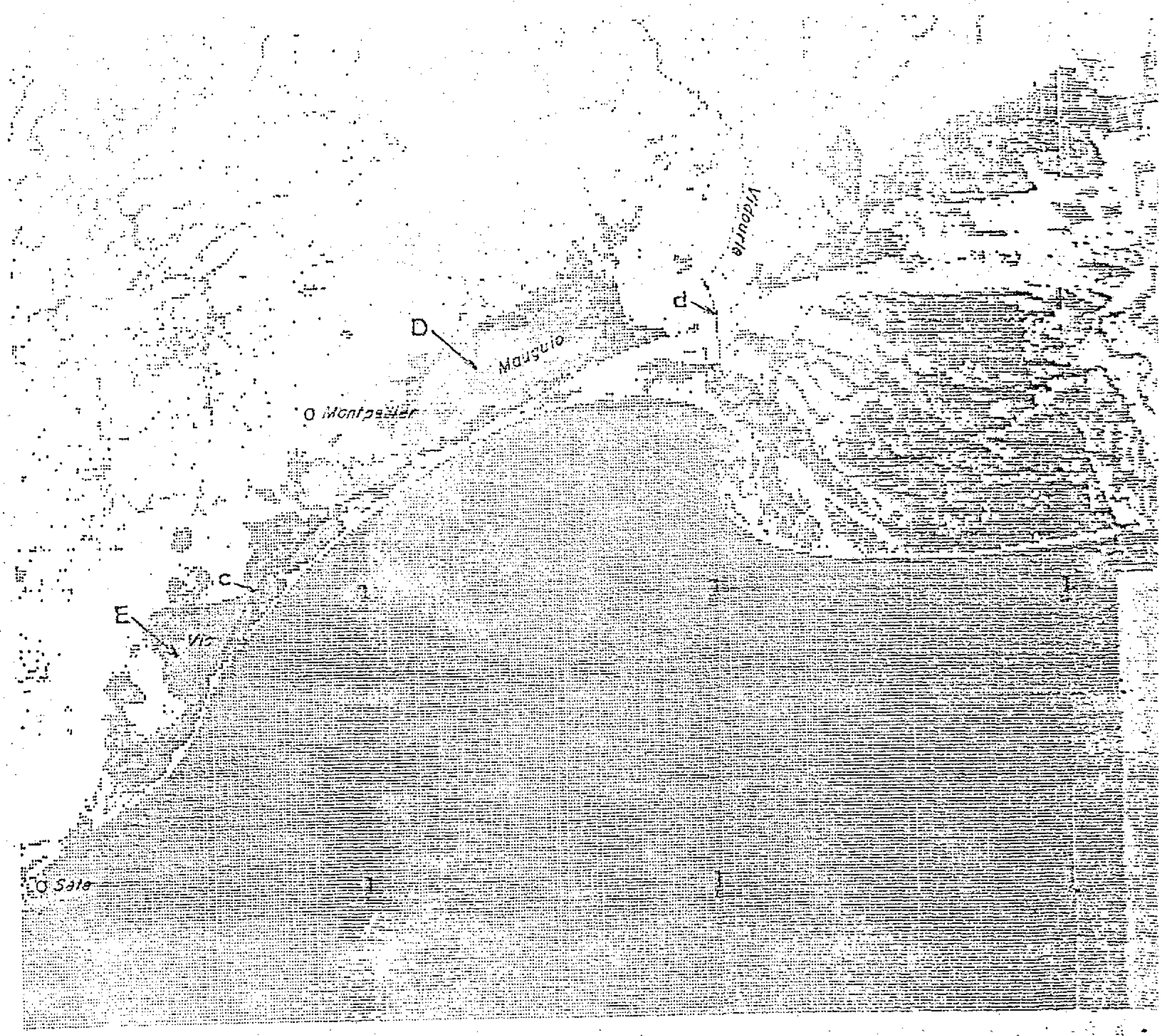
Fourth zone : in a swamp to the west of Vaccares lake.

Fifth zone : in a cultivated area.

Sixth zone : on sea.

After the first iteration, the 6 classes selected were mapped but large areas were still unclassified (blank zones).

After a set of 3 iterations 7 other classes were automatically selected by the computer, and finally 11 different classes are mapped on the final result (Fig. 11).



MULTISPECTRAL CLASSIFICATION OF II CI

Fig. 11

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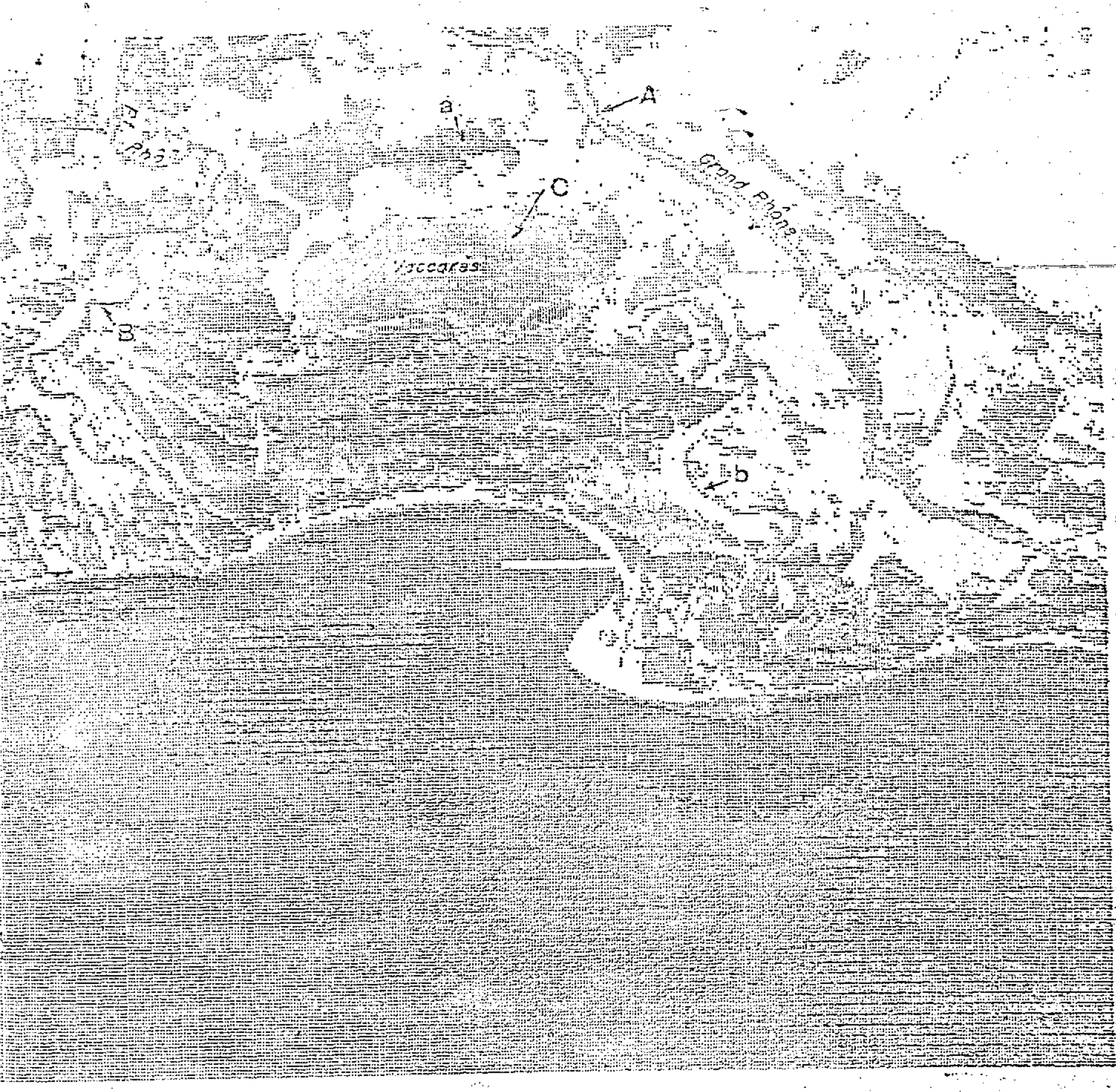


II CLASSES OF WATER (adpiative method)

II

It must be pointed out that in the case of water multispectral classifications, the statistical laws for each class are very precise ; this is not generally observed in terrain classification.

III.2 - Principal components analysis

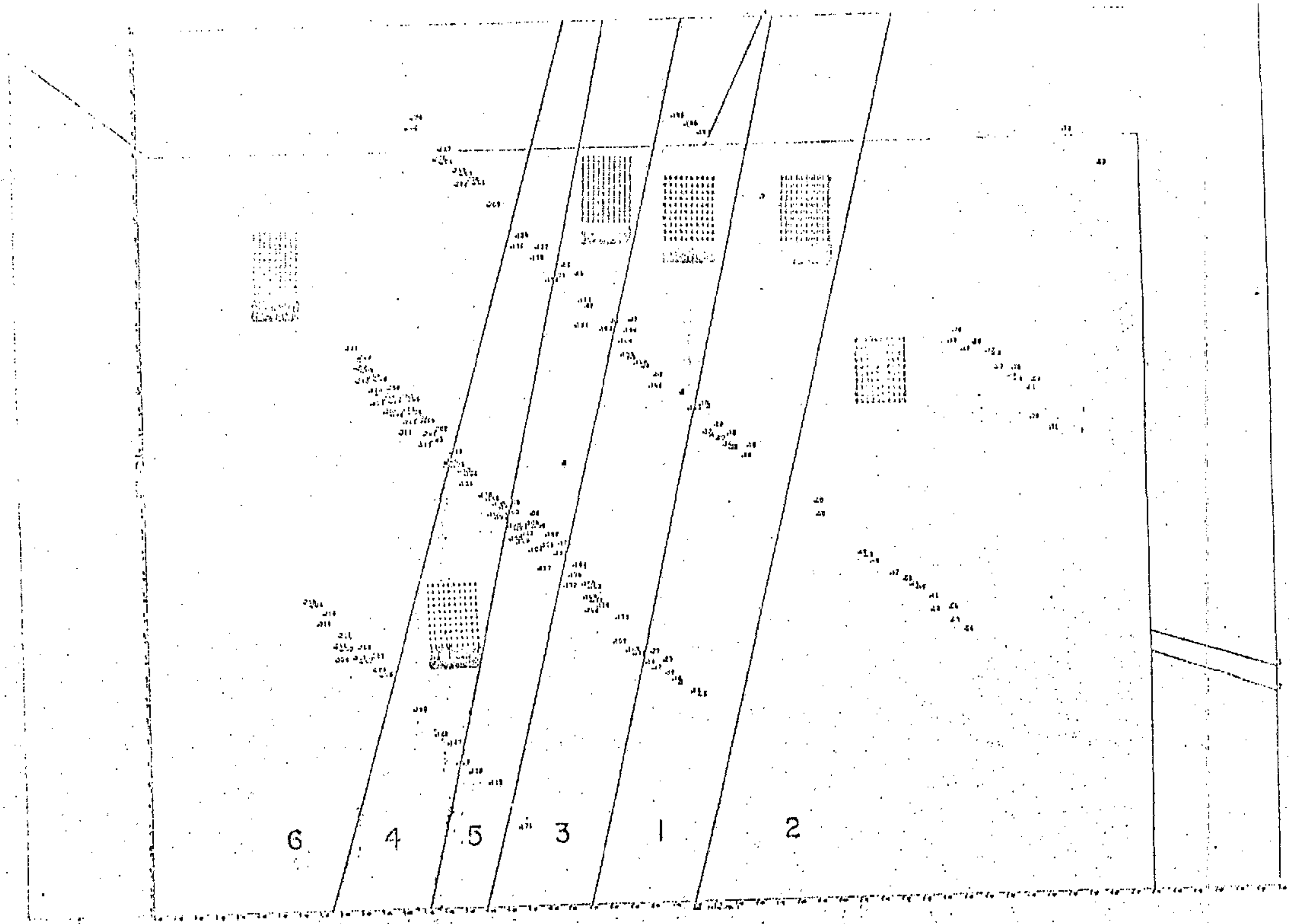
Fig. 14 shows the classification obtained on the same zone by principal component analysis.

With this method there is no need to select test sites. In the four-dimensional space corresponding to the four wave lengths, the computer itself defines the "volumes" characterizing the different classes of objects present on the image. In our examples we found that about 97% of the total information on the four ERTS spectral bands could be represented on a plane, that is to say with only two principal components. The different "volumes" of the 4-dimensional space mentioned above are projected onto this plane (Fig. 12). It then becomes relatively easy to separate the different classes of objects in this plane, either by hand or automatically. Six different classes of water are indicated in Fig. 12. The different computer training areas were taken as follows (Fig. 13):

Class 1 : in the center of Vaccares lake.
Class 2 : in the Southern part of Vaccares lake.
Class 3 : on sea, off the mouth of "Vieux" Rhone River.
Class 4 : on sea, west of "Pointe du Sablon".
Class 5 : on sea, off Grau d'Orgon.
Class 6 : at sea, in the southwestern part of the image.

The location of these different test sites (no:1 to 6) is indicated on Fig. 13.

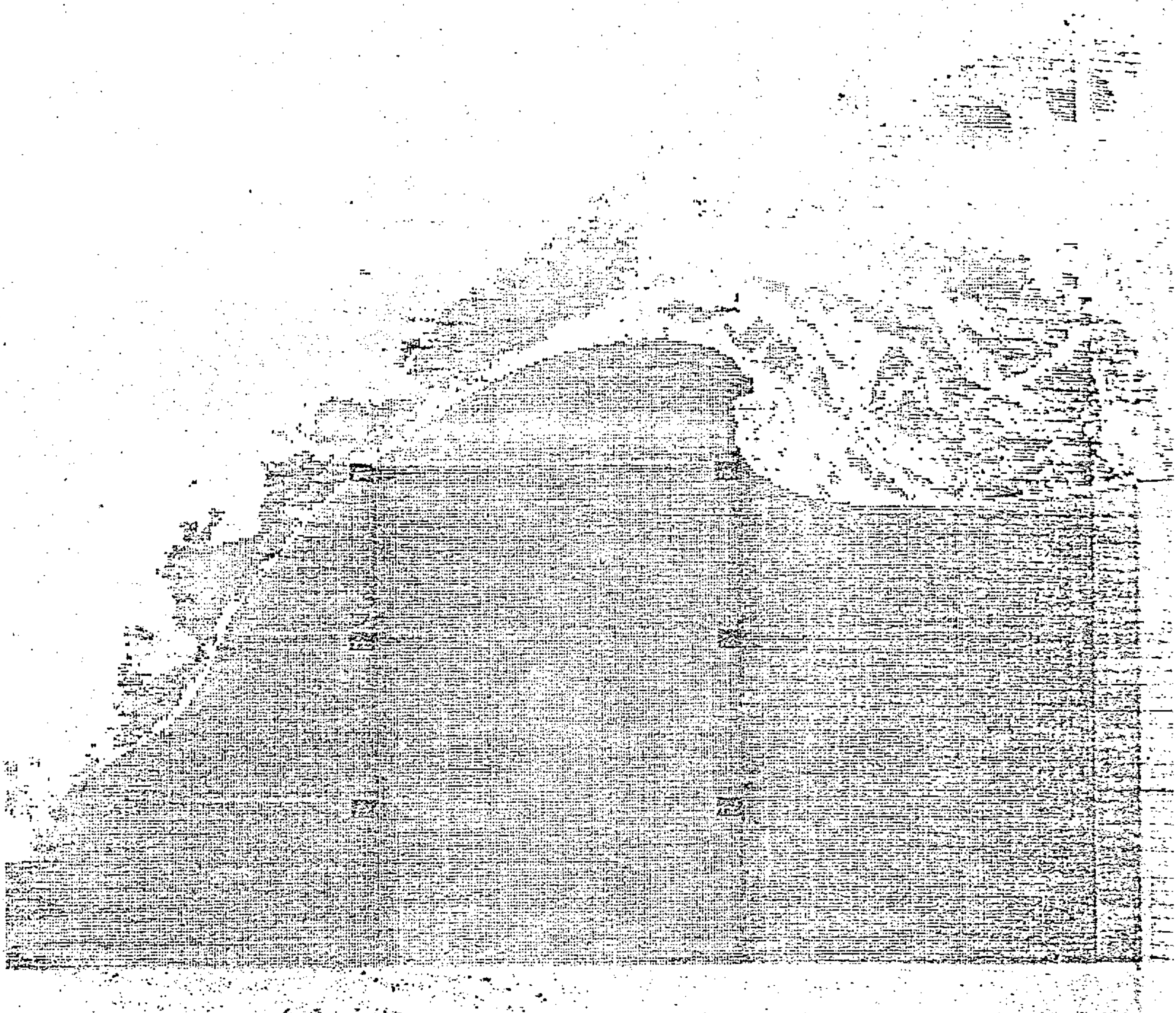
300 pixels were used for the definition of these 6 different classes. The projection of these samples can be seen on the projection plane Fig. 12. It clearly appears that the 6 classes are distinct.



MULTISPECTRAL SEPARATION OF 6 DIFFERENT CLASSES OF WATER

(projection plane in the principal components classification method).

Fig. 12



MULTISPECTRAL CLASSIFICATION

(principal componen

Fig. 13

ATION OF 6 CLASSES OF WATER

components analysis)

Fig. 13

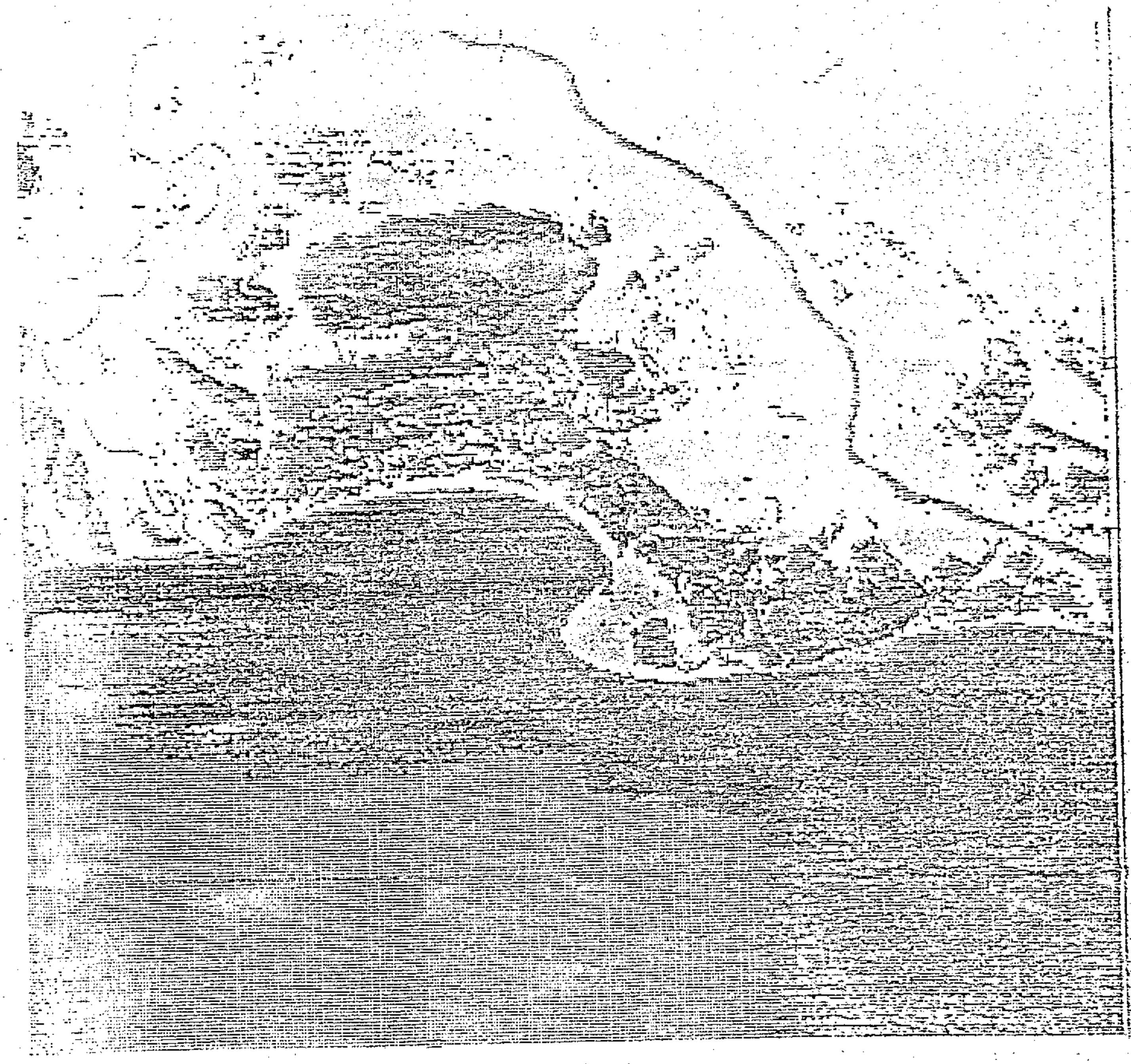


Fig. 14

On the sea, both methods give similar results. For example, the Rhone River outflow is clearly detected along the coast in the two Fig. 11 and 13.

Field surveys are planned in order to interpret these different results but it may already be thought that the different water classes detected in the coastal lakes often correspond to different algae concentrations.

IV - CONCLUSION

Three types of pollution are discussed in the first part of this report.

1) Industrial waste poured into the sea from a ship.
2) Complex pollution (in a broad sense) off industrial harbors.
3) Pollution (in a broad sense) by rivers.

From these examples it can be concluded that ERTS is a useful remote sensor for detecting such types of pollution if their extent is large enough.

In the first case, the location and time of dumping are not known. Therefore only large patches, about 3 or 4 km long and 400 or 500 m wide, can be sensed. The pouring ship itself has never been detected.

The two other cases correspond to a systematic pollution at a well known location. Smaller patches can be detected and studied.

In all cases repetitivity of the imagery is essential for the study of pollution.

The ability of ERTS has now been tested. In the future, it will be necessary for an operational pollution surveillance to an image be taken at each pass of the satellite / over the studied zones.

Some examples of water multispectral classifications by computer processing are discussed in the second part of this report. The computer programs precedently tested for terrain mapping (project MMC 009-04), seem well adapted to water classification.

A complete interpretation of the maps obtained on coastal lakes and at sea is still in process but it seems already obvious that ERTS imagery owing to its periodic coverage, is an irreplaceable tool for this kind of study.