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SATELLITE IMAGES AND THEIR TREATMENTS APPLIED TO THE IDENTIFICATION OF THE "ROMAN RETICULUM" IN THE VENETIAN PLAIN

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1.0 Introduction

Since the first appearance of images taken by artificial satellites (ERTS - I, SKYLAB), the "lineations" may be considered among the most striking and significant information obtained in the field of geology.

The term "lineations" is used to describe linear, and prevalently straight - line, discontinuities which are generally given a tectonic applanation. From a cenceptual standpoint, it may be assumed a priori that these lineations probably will not be homogeneous along their entire extension. Or more precisely stated: they do not seem homogeneous, judging from the nature of the indicators which show their existence (bibliography, 2).

However, linear systems were noted not only in mountainous zones, where their morphologic - tectonic nature was almost certain, but also in plains areas where it was more difficult to offer a precise structural meaning (faults, fractures).

In order to more closely examine the importance of such linear alignments in more or less flat areas, we decided to focus particular attention on a dense system of lineations in the entire Venetian Plain. This system was identified through suitable treatments of SKYLAB images.

Following appropriate research, it was possible to attribute a hydrogeological - anthropological meaning to these lineations. They correspond, in fact, to lengthy stretches of buried "Roman Centuriations" which had only been partially noted up to now.

They may only be recognized as roads and canals in certain zones of the Plain, particularly to the north-east of Padua ("Centuriazione dell' Agro Patavino").

The area under consideration extends from the Lessini Mountains in the west to the Karst in the east including about 8.000 km^2 (Fig. 1). From a hydrological viewpoint, numerous rivers (Brenta, Piave, Tagliamento, Isonzo, etc.) cut through this zone. It is further characterized by a belt of rising underground waters referred to as the "spring line" showing an arched development approximately parallel to the coastline and indicating the passage from the upper-middle to the lower plain in the strict sense. Moreover important hydrogeological structures (paleoconoids, ground-water flow lines, areas of accumulated groundwater) have been identified which present interesting correlations with the lineations appearing in this study (bibliography, 8, 9). In fact, as will be discussed in greater detail in the following paragraphs, the territorial subdivision based upon "Roman Centuriation", with its dense network of canalization having an orthogonal innerrelationship, served the function - among others - of reclamation in marshlands and drainage of both rain and spring water.

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2.0 Historical Notes

The Venetian Plain is one of the zones in which traces of the "Roman Centuriation" still remain evident. This is a system of territorial subdivision along boundary lines[1] which were orthogonally placed at precise distances and repeated in space[2]. These boundaries physically corresponded to canals, roads or true registered property subdivisions.

In the zones where dating was possible, the age of the "Centuriations" was established in the II-I century B.C., whereas their orientation (direction of the "Kardines") varies from NW to NE.

As a result of subsequent human modifications, most of these "Centuriations" were cancelled or buried. Nevertheless, certain traces of a hydrogeological and structural nature do remain regarding the superficial layer of the alluvial deposits in the Venetian Plain.

It was deemed useful to synthesize in a "Sketch of the areas in the Venetian Plain with known Roman Centuriations" (Fig. 2), which also includes the name and the directions of the "Kardines" in these areas, the present knowledge concerning the diffusion of such a pattern of field subdivision.

The preparation of this composite drawing was possible thanks to the detailed bibliographical research of Prof. L. Bosio and carried out in part by Dr. G. Rosada, both of whom are staff members of the Archaeology Institute of Padua University.

3.0 Material Employed

The basic images used for analogue treatments are photographs taken during the second manned mission aboard the SKYLAB in September, 1973. The SKYLAB[3] space station contained numerous scientific instruments including a "Multispectral Camera - S 190 A-" with coverage capability ranging from 0.4 to 0.9 μ on the electromagnetic spectrum. More precisely, the area in question is included on four different bands explored on the basis of the chosen film and the corresponding filter. Table 1 presents a graphic synthesis giving the conventional denomination of each band, its range and color.

These photographs, characterized by a particularly fine grain, may easily be enlarged to the scale of 1:100.000 without sacrificing the clearness and precision of the details, thus providing a linear resolution of about 10 meters on the ground.

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1) The boundary lines were subdivided into "Decumani" and "Kardines", the former generally running E-W and the latter running N-S.

2) The most common subdivision repeated in the majority of the "agri centuriati" is the squared "centuria" of 200 "iugeri", having 20 "actus" on each side; that is: about 710 meters.

3) Launched by NASA on 14 May 1973, in a 55^{0} orbit with respect to the equatorial plane at an average distance of 435 km from the earth.

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TABLE 1

Conventional denomination	band	film used	filter	corresponding color
42	0,5-0,6	PAN-X B&W SO-22	AA	green-yellow
41	0,6-0,7	PAN-X B&W SO-22	BB	orange
38	0,7-0,8	IR B&W EK-2424	CC	dark red
37	0,8-0,9	IR B&W EK-2424	DD	near infrared

4.0 Methodology

The methodology developed in this study forms two procedures. One deals with the analogue processing of the images; the other concerns the treatment and presentation of the data obtained by the interpretation of the images themselves.

Both of these directions were investigated during research, because the subject matter of our work has both interpretative and historical - environmental implications. It is felt, in fact, that the analysis of linear elements, present in plain areas, may offer many possibilities in the description of both human and natural structures when buried. This description, in turn, is useful to accomplish more accurate territorial planning.

4.1 Analogue Treatments of the Images

As already mentioned, the boundaries, or "limits", of the "Roman Centuriations" coincide with communication lines and artificial waterways, the majority of which are now either buried or filled with earth. Therefore, an eventual identification of these structures is facilitated by using appropriate image treatments to accentuate the hydrogeological and structural indicators which underline their presence in the photographs.

Among these indicators the most important should be noted:

1. The different humidity conditions in the unsaturated zone of the subsoil; that is, in the stratum lying between the topographic surface and the phreatic aquifer.

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2. The geometrical distribution of the iso-orientated agrarian parcels. In fact, the infilled canals are almost always characterized by a different amount of humidity with respect to the circumjacent zones and they, just as the buried communication links, often determine the geometric - structural distribution of the agricultural parcels.

Previous studies, developed by one of the authors, which deal particularly with the analogue processing of SKYLAB images for hydrogeological purposes (bibliography, 9) have shown that the choice of the most suitable treatment method may be reduced to the "ratio method", applied specifically to bands 42 and 38 (green-yellow and red).

The presence of belts containing anomalous amounts of humidity in the unsaturated layer of the subsoil causes marked reduction of reflection in photographic infrared (band 37 and, subordinately, band 38), together with normal green - orange reflection (bands 42 and 41).

Establishing the ratio between these bands, one can clearly display the zones characterized by the hydrogeological situation mentioned above. As a result, the canalizations and buried roads of the "Roman Reticulum" may be identified, given their bi-unique relationship. Furthermore, the application of this ratio permits an improved description of the geometric distribution of the agrarian parcels.

The analysis of the ratios between bands 42-38, including the entire plain, was carried out on (diapositive) slides using the DURST LABORATOR -SM 183- enlarger and rectifier. This instrument was useful not only to enlarge the multi-spectral images to the desired scale, but also to correct their slight, but not negligible, geometric deformations. These slight deformations arose from a less than perfect horizontal position of the satellite sensors and from the curve of the earth.

The basic maps upon which the "lineations"("limits") have been placed are the 1:100.000 topographic plates ("foglio") of the I.G.M. (Istituto Geografico Militare).

4.2 Elaboration of Data Obtained

The interpretation of the ratios between bands 42 and 38, covering the entire zone in question, and studied both from a photographic[4] and optical - projective viewpoint, provided the information necessary to draw up the map: "Systems of 'Roman Centuriation' in the Venetian Plain, deduced from analogue treatments of satellite images (SKYLAB)" (Fig. 3).

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4) The authors are grateful to Mr. F. Fermon, C.N.R. laboratory technician in Padua, for his photographic treatments of original material.

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During the interpretative phase of research, I.G.M. 1:100.000 maps were utilized, as previously stated. Thus it was possible to acreen the tracts of "lineations" corresponding to existing communication lines, to waterways and canals and to previously unknown structures probably buried near the surface. Therefore, in zones of a plain as well as in mountainous areas (bibliography, 2) the initial hypothesis was verified, that often an alignment is not homogeneous along its entire length, or at least it is not marked by indicators which are homogeneous to one another[5].

The alignments were then statistically treated by grouping them in appropriate classes to which the following were associated: "total development" (l_i), "number" (n_i), "density" ($\frac{\Sigma i}{A}$), "frequency" ($\frac{ni}{A}$).

The size of the classes was selected as 15^o (sexages.) in order to permit a full description of all the "lineations" systems; in other words, all the "Centuriations" in the area. This proved an appropriate choice both to describe and to synthesize the phenomenon itself. In order to achieve a certain homogeneity, the area was divided into two parts, one to the west of the present course of the Piave river, the other to the east.

Based upon the data included in the tables attached (Tables 1-5), five polar diagrams (circular histograms) were constructed, describing the following, respectively:

1. Total field of the "lineations" west of the Piave (Fig. 4)
2. Total field of the "lineations" east of the Piave (Fig. 4)
3. Relationship of the "lineations" to the west and east of the Piave
4. Relationships of the buried "lineations" and "lineations" corresponding to roads and canals west of the Piave (Fig. 5)
5. Relationships of the buried "lineations" and "lineations" corresponding to roads and canals east of the Piave (Fig. 5)

All of the rose diagrams are composed of two semicircles with a common diameter. The upper semicircle presents the distribution of the "Kardines", whereas the lower one relates to the "Decumani".

This type of synthetic representation which we propose seems effective to point out the percentual differences in extent of the two types of "limits" within the same "Centuriation". It is clear that with this type of representation, the classes of "Decumani" to be associated with the relative classes of "Kardines" have an orthogonal inner relationship.

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5) In order to more clearly illustrate the causes of the true distribution of the "lineations" identified, the map also includes both recently reclaimed zones in which intense human activity has probably destroyed any trace of pre-existent structures and zones covered by clouds when the photographs were taken.

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As far as diagrams 4 and 5 are concerned, the percentages of unknown lineations as compared to those of known features (canals and roads) became quite distinct within the same class. As a result, one may quickly gain a visual synthesis of the degree of a conservation or destruction of a certain network, both along its meridian and parallel "limits".

The methodological development of the treatment and presentation of the data provides the elements of synthesis necessary for a further correlation. This exists between the areas of diffusion of the networks and their mutual spatial relationships to the hydrogeological and geologic - environmental conditions of the zone in question.

5.0 Conclusions

From the comparative analysis of the tables and polar diagrams, which synthesize all of the information obtained by our treatments of SKYLAB images, the following considerations may be made:

1. The zone to the west of the Piave presents three clearly distinct "lineation" systems attributable to the same number of "Centuriations", whereas the eastern zone is characterized by one single system. A comparison also indicates that there is a general counter-clockwise increase in the percentage of "lineations" of the Kardines and a decrease of the percentages in the same direction of the Decumani. This means, in other words, that a progressive movement of the "Kardines" from NE to NW corresponds to an increase in the data visible on the treatments (buried traces) and to an increase in the evidence remaining in the zone (canals; roads); where the "Decumani" are concerned, a directional variation from SW to SE shows a progressive decrease in statistical information.

This paper is not the most appropriate seat in which to formulate hypotheses of a historical nature about this phenomenon. Nevertheless, it seems interesting to note that the direction of the majority of the "Kardines" identified coincides with both the structural and topographical direction of the average slope of the Venetian Plain as well as with the flow of the principal water ways. An analogous observation is valid for the "Decumani"; the most numerous classes (S 76° - 90° W and S 61° - 75° W) are precisely those which are iso-oriented according to the extension of certain fundamental hydrogeological aspects of the plain (i.e. the "spring line", etc.).

2. The data, as provided by interpretation of analogue treatments, is far greater in the case of the buried "lineations" than where roads and canals, visible on conventional maps, are concerned. This concept is also rendered, in approximate terms, by a comparison between the sketch in Fig. 2 and the map in Fig. 3. This is particularly true for a zone to the east of the Piave River where a surprising 88 % ca. of the recognized "Kardines" and "Decumani" were previously unknown. In the western zone, the relationship between buried lineations and those recognizable on I.G.M. 1:100.000 sheets lies at about 65 % for the "Kardines" and 74 % for the "Decumani".

Moving on to a synthetic description of the map of the identified systems of the "Roman Reticulum", one notes that there are areas in which two or even three systems of "lineations" are superimposed, probably pertaining to "Centuriations" of different epochs. Among these, one should notice an area to the left of the Brenta River between Cittadella and Padua; a zone east of Padua toward the Venetian Lagoon; a band between Castelfranco and Istrana, and finally a zone north of Treviso toward Spresiano.

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Considerations based upon morphology, structure and area of extension could lead to the supposition that the underlying, and therefore older, system is that characterized by the N 0°-15° W "Kardines" (S 76°-90° W "Decumani") as compared to the more recent one having N 0°-15° E and S 76°-90° E "limits".

It is more problematic, however, to attribute a relative age to the system lying to the south of the "Montello", especially, considering its relatively limited dimensions and its episodic presence in the zone west of the Piave.

At this point, it seems significant to compare the map of "lineations" with knowledge, of a paleo-hydrogeographic nature, already acquired in the zone (bibliography, 8). In particular, a map dealing with the principal hydrogeological aspects of the Venetian Plain, as prepared by one of the authors in a previous study (bibliography, 9), is referred to here.

The correlations between the actual distribution of the various "Centuriations" and the paleo-hydrography are immediately evident. For example, the zone to the right of the Brenta River, which has always been characterized by numerous movements of the water course, shows a "Centuriation" with low density and frequency of the "limits". This is particularly accentuated along a line of flooding, still active in Roman times, which arches to the S-SW from the area near Ponte della Friula. In addition, the meandering stretch of the river between Curtarolo and Padua clearly shows a discordant relationship to the "limits", wherever they were found, thus indicating that it is more recent than the "Centuriation". This dating had already been established on the basis of a photo-interpretation dealing with the morphological-structural conditions of the agrarian parcels in the same zone (bibliography, 8).

As far as the zone to the left of the Brenta is concerned, one notices that, for example to the south of Cittadella and coinciding with the "spring line", traces of "Centuriations" are absent. The "Centuriation" of the farm land probably served the fundamental purpose, among others, of land reclamation and control of surface waters. Thus, the "Reticulum" developed south of the "spring line" where the waters emerging farther north (runoff water, numerous springs and resurgent sources gathered) could be utilized.

This consideration seems to be sufficiently verified along the entire extent of the "spring line", even east of the Piave and particularly to the left of the Tagliamento River.

Summary

This study presents the methodology developed and the results obtained in the identification of the "lineations" in the Venetian Plain using appropriate treatments of SKYLAB images.

These linear elements are recognized as tracts of "Roman Centuriation", a "Reticulum" which extends across the entire area examined. In particular among the possible analogue treatments, the importance of the "ratio method" is evident, specifically the ratio between bands 42 (green-yellow) and 38 (orange-red). Finally, the relationship is brought to light between the pattern of distribution of the "lineations" and the hydrogeological and geological-environmental situations of the Plain.

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classes of lineations	Σl_i	n_i	%	$\frac{\Sigma l_i}{A}$	$\frac{n_i}{A}$
KARDINES					
N 0°-15° E	682.00	325	45	0.142	0.067
N 0°-15° W	777.90	349	51	0.162	0.072
N 31°-45° W	57.50	24	4	0.012	0.005
Total	1.517.40	698	100	0.316	0.144
DECUMANI					
S 76°-90° E	678.50	270	44	0.141	0.056
S 61°-75° W	65.80	20	4	0.014	0.004
S 76°-90° W	808.80	322	52	0.168	0.067
Total	1.553.10	612	100	0.323	0.127

Tab. 1

classes of lineations	Σl_i	n_i	%	$\frac{\Sigma l_i}{A}$	$\frac{n_i}{A}$
KARDINES					
N 16°-30° W	1.018.300	464	100	0.339	0.155
DECUMANI					
S 61°-75° W	738.200	324	100	0.246	0.108

Tab. 2

classes of lineations	Σl_i	n_i	%	$\frac{\Sigma l_i}{A}$	$\frac{n_i}{A}$
KARDINES					
N 0°-15° E	682.00	325	27	0.087	0.042
N 0°-15° W	777.90	349	31	0.099	0.045
N 16°-30° W	1.018.30	464	40	0.130	0.059
N 31°-45° W	57.50	24	2	0.007	0.003
Total	2.535.70	1162	100	0.323	0.149
DECUMANI					
S 76°-90° E	678.50	270	30	0.086	0.035
S 46°-60° W	65.80	20	3	0.008	0.003
S 61°-75° W	738.28	324	32	0.094	0.041
S 76°-90° W	808.80	322	35	0.103	0.041
Total	2.291.38	936	100	0.291	0.120

Tab. 3

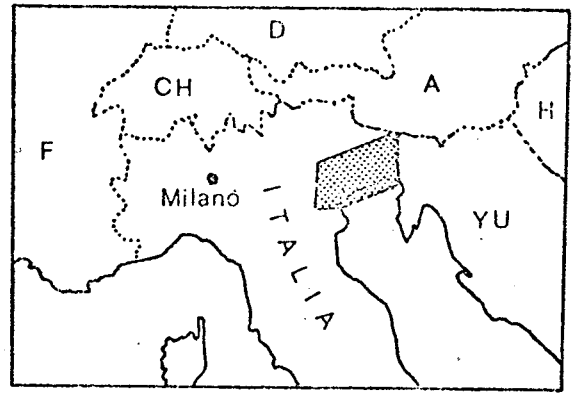
classes of lineations	Σl_i	n_i	%	$\frac{\Sigma l_i}{A}$	$\frac{n_i}{A}$
KARDINES					
N 0°-15° E	387.20	176	57	0.080	0.037
	246.50	100	36	0.051	0.020
	48.30	49	7	0.010	0.010
Total	682.00	325	100	0.141	0.067
N 0°-15° W	617.20	249	79	0.128	0.052
	124.80	67	16	0.026	0.017
	35.90	33	5	0.007	0.007
Total	777.90	349	100	0.161	0.073
N 31°-45° W	33.60	13	58	0.007	0.003
	21.70	9	38	0.005	0.002
	2.20	2	4	0.001	0.001
Total	57.50	24	100	0.013	0.006
DECUMANI					
S 76°-90° E	579.40	201	72	0.120	0.041
	209.60	95	26	0.044	0.020
	19.80	26	2	0.004	0.005
Total	808.80	322	100	0.168	0.067
S 76°-90° W	399.70	144	59	0.083	0.030
	207.30	76	30	0.043	0.016
	71.50	50	11	0.015	0.010
Total	678.50	270	100	0.141	0.056
S 46°-60° W	58.90	15	90	0.012	0.003
	6.10	4	9	0.001	0.001
	0.80	1	1	0.001	0.001
Total	65.80	20	100	0.014	0.005

Tab. 4

Tab. 5

classes of lineations	Σl_i	n_i	%	$\frac{\Sigma l_i}{A}$	$\frac{n_i}{A}$
KARDINES					
N 16°-30° W	892.80	337	87	0.298	0.112
	91.30	90	10	0.030	0.030
	34.20	37	3	0.011	0.012
Total	1.018.30	464	100	0.339	0.154
DECUMANI					
S 46°-60° W	649.90	258	88	0.217	0.086
	77.40	56	10	0.026	0.019
	10.90	10	2	0.004	0.003
Total	738.28	324	100	0.247	0.108

Fig. 1
AREA INCLUDED IN THE STUDY



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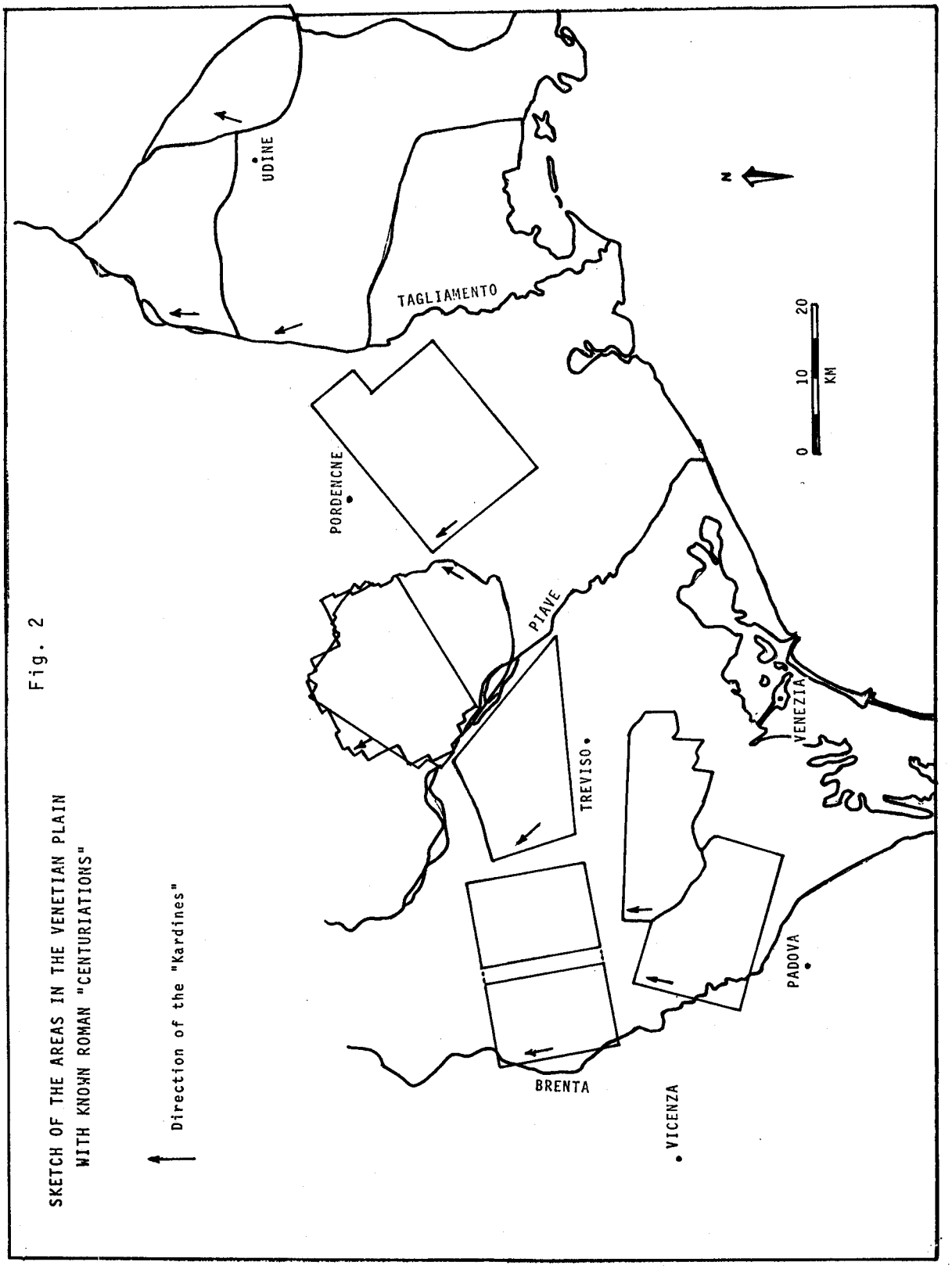

Fig. 2

SKETCH OF THE AREAS IN THE VENETIAN PLAIN
WITH KNOWN ROMAN "CENTURIATIONS"

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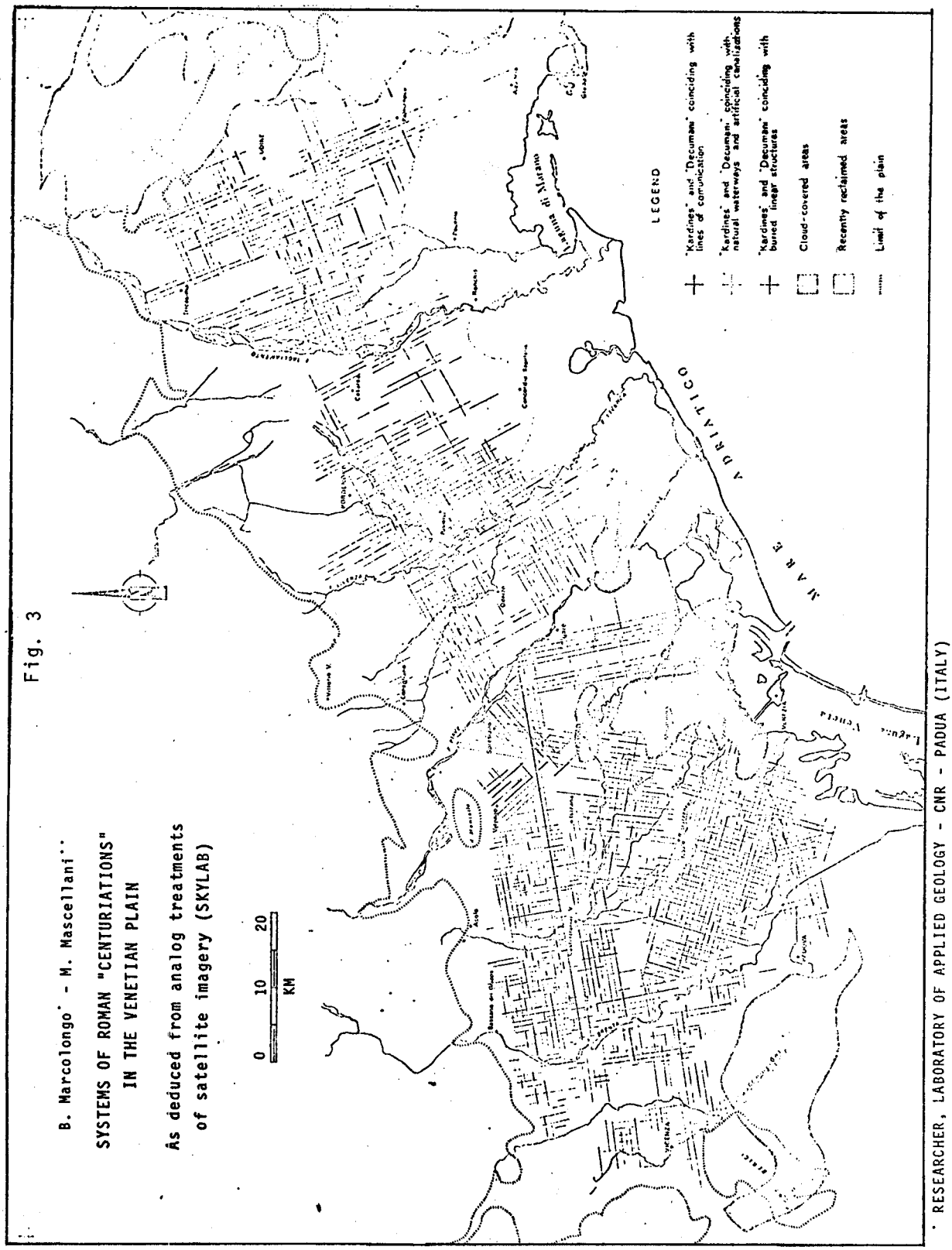

Fig. 3

B. Marcolongo* - M. Mascellani**

SYSTEMS OF ROMAN "CENTURIATIONS" IN THE VENETIAN PLAIN

As deduced from analog treatments of satellite imagery (SKYLAB)

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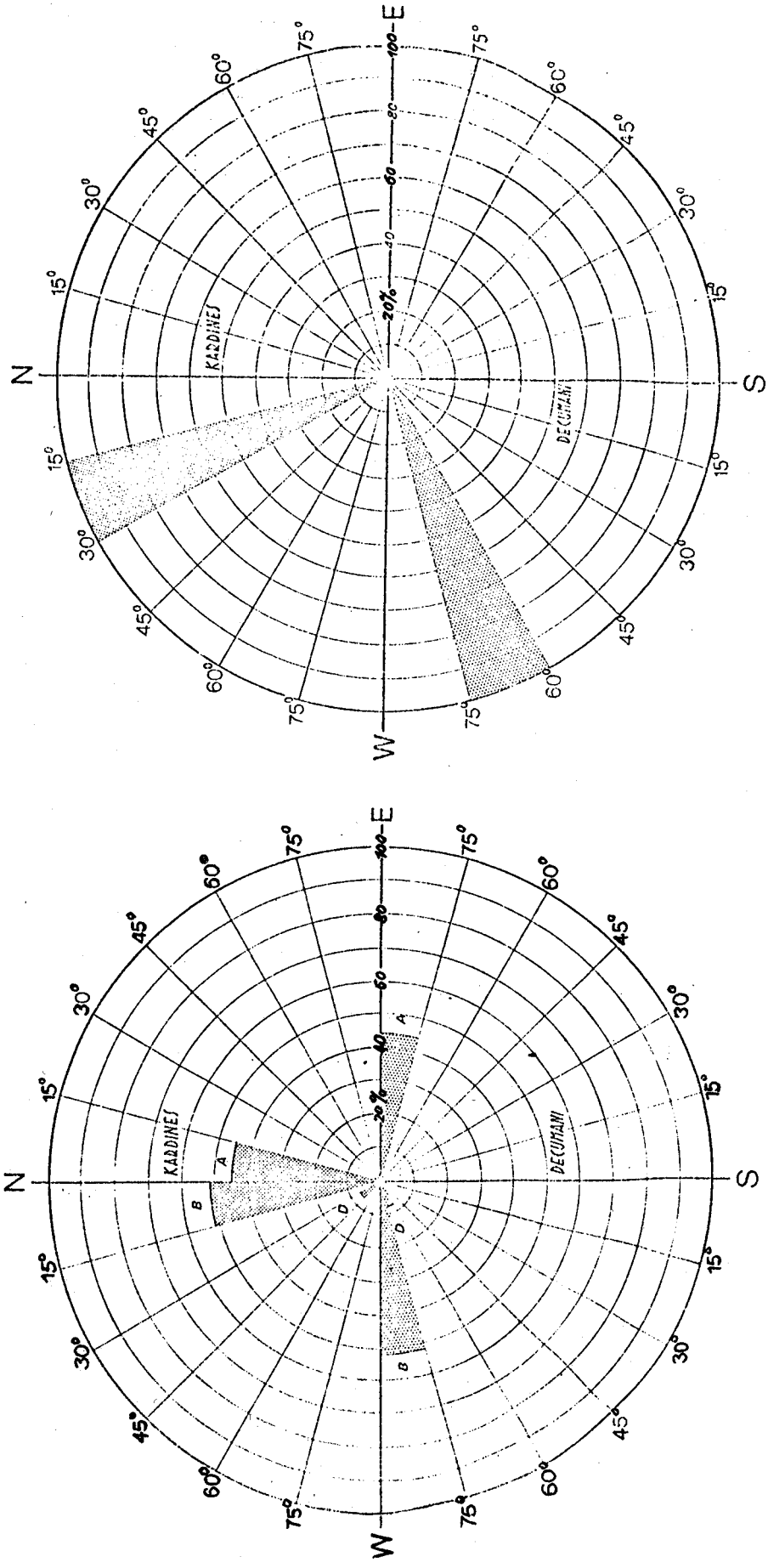

Fig. 4

TOTAL FIELDS OF "LINEATIONS" TO THE WEST
AND EAST OF THE PIAVE RIVER

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