APPLICATION OF CONVENTIONAL AND ADVANCED TECHNIQUES FOR THE INTERPRETATION OF LANDSAT 2 IMAGES FOR THE STUDY OF LINEARS IN THE FRIULI EARTHQUAKE AREA

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ABSTRACT

This work describes the results obtained in the study of linears derived from the analysis of Landsat 2 images recorded over Friuli during I975.
A particular attention is devoted to the comparison of several passes in different bands, scales and photographic supports.
Moreover reference is made to aerial photographic interpretation in selected sites and to the information obtained by laser techniques.

I. FOREWORD AND AIM OF THE WORK

After the dangerous May I976 earthquake (about I000 people killed) a large research effort was focused in the Friuli area in order to reach a better geological and geophysical knowledge of the whole territory.
In this framework and interdisciplinary research was enterprised in order to evaluate the range of the contribution that the space coming data (Fig.I) could bring to geotectonic studies in these specific zones.
We analyzed the Landsat 2 images in a very detailed way in order to define:

a) the best image properties, from bands and scales point of view, for the analysis of linear phenomena;
b) a quantitative comparison of the Landsat images with aerial photographic interpretation over a selected site;
c) the evaluation of the contribute of Fourier spectra laser techniques to the "objective" tracing of linear trends;
d) a standard method to recognize and classify linears.[oo]

2. GENERAL GEOLOGIC SETTING

Friuli region is located in the eastern part of Southern Calcareous Alps. The boundary with the Austrides coincides with the Gailtal line towards the North, whereas a transitional zone characterizes the boundary with the Dinarides s.s. towards the East.

[oo] As linears we intend those phenomena which in satellite images exhibit a continuous "about linear" trend.

The following structural units can be distinguished from the North to the South (Fig.2): Carnic Range, Tolmezzo and Julian Alps, Carnic and Julian Prealps, Gorizia-Trieste Karst. The outcropping formation, I5.000 meters thick, range in age from the Ordovician to the Miocene. Most of them indicate marine and/or transitional environment. The youngest units are continental such Cesclans conglomerates of uncertain (Plio-Pleistocene) age, Wurm moraines outcropping mainly in the Tagliamento morainic amphitheatre and the Holocene alluvial deposits of the plain. Ercinic orogeny involved paleozoic units with overthrusts and folds East-West directed and with South vergence (Fig.3). The main structural elements, connected with the alpidic orogeny, are overthrusts East-West directed and with South vergence in the southern area and North vergence in the northern one where there is a superposition with the ercinic structures. Units, outcropping and buried in the South East of the region, display overthrusts NW-SE directed (Dinaric system). All these structures, connected with alpidic compressive and distensive phases, are accompanied by a number of faults with N-S, NW-SE and NE-SW direction. Regional structures, created during alpidic orogeny (Lamaric phases and following ones), are presently accounted either to gravity flow, due to the uplift of the Alps, or collision between "adriatic plate" and the European continent.

3. IMAGE ANALYSIS

- Photointerpretation

The study of our images was done following these steps:

a) analysis and drawing of linears (from Landsat 2 frames)
   I - from I:I.000.000 positive film of band 7 (Fig.4)
   2 - from I:500.000 print of band 7
   3 - from I:250.000 prints (B&W) band 7 (Fig.5a) and 5 (Fig.5b)

b) rose diagrams (Fig.6) compilation for lenght distribution of linears referred to the area of the image in different scales and bands
   I - for angular grouping of $I0^{\circ}$ (Fig.6d)
   2 - for angular grouping of $22,5^{\circ}$ (Fig.6a,b,c)

c) rose diagrams compilation for lenght distribution of linears (angular grouping : $I0^{\circ}$) referred to structurally homogeneous blocks
   I - from I:I.000.000 positive film (Fig.7)
   2 - from I:500.000 print (Fig.8)

d) lineaments drawing in the area controlled by geologic map resources
   I - from I:I.000.000 band 7 positive film of 9/I0/75

e) rose diagrams compilation (angular grouping : $I0^{\circ}$) referred to the lenght of lineaments[oo] of inferred tectonic source
   I - from I:I.000.000 positive film in the whole geologically controlled area (Fig.9)
   2 - idem for each single block (Fig.I0)

- Considerations

From the analysis of these Landsat 2 images of I975(3 passes),the following considerations rise in the field of:

a) interpretation
   Band 7 exhibits a structural information content higher qualitatively than band 5; example:
   b7 Dec 75 linears n.262 total lenght km 2989
   b5 Dec 75 linears n.234 total lenght km 2II9
   (from I:250.000 print)

The b7 image recorded on I0th Sept (AZ $I4I^{\circ}$, EL 42°) shows a total number of linears higher

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[oo] As lineaments we intend those linears which upon an appropriate control show a clear geologic source of the phenomenon

than the 27th 75 one (AZ I52°, EL I5°) partly due to change in snow cover; example:
b7 Sept 75 linears n.470, total lenght km 438I
b7 Dec 75 linears n.2I8, total lenght km 2I49
(from I:I.000.000 positive film)

The information derived from positive film (scale I:I.000.000) seems to be better detectable expecially from a regional point of view in comparison with the corresponding prints also in more detailed scale.
In fact it was noted that the "long linear phenomena" have in general a lower level of comprehensive detectability in larger scales.
This is also partly due to the fact that the images recorded on positive films have more detailed countours and more accuracy in gray levels scale than the corresponding prints.
The rose diagrams of density and lenght of linears of two different periods (September and December '75) enhance in September the trends connected with NW-SE components (Dynaric system) while in December have no particular prevailing direction.

b) geology
Total field linears, which are the results of the analysis of Sept 75 I:I.000.000 positive film, were "filtered" in order to draw the lineaments of the area. It was not possible to classify the whole image, in fact the eastern portion (Jugoslavia) was lacking from the point of view of geological map resources.
Moreover due to the geologic complexity of the territory, the area interested at the highest level by May 6th 76 earthquake was divided into 4 blocks having homogeneous structural characteristics (Fig.4). The four blocks correspond to: A block-Tolmezzo Alps p.p.; B block-Julian Alps p.p.; C block-Julian Prealps; D block-Carnic Prealps p.p.
Density and lenght of linears and lineaments are computed and drawn by means of rose diagrams which gave rise to the following comparison:

I - total field of lineaments (Fig.9) towards total field of linears (band 7 of Sept I0th and Dec 27th passes-Fig.6)
This fact may be due to the E-W component of the geologic structures in the area that could be enhanced by sun azimut and elevation during the month of December

2 - Total field linears towards total field of lineaments in the four blocks: in these blocks the comparison linears-lineaments shows about equal values in C, a lower agreement in A and B, and a very different behaviour in D (Figg.7,8,I0)

4. AERIAL PHOTOGRAPHIC INTERPRETATION

Just where the different behaviour was observed (D block p.p., Fig.4) a detailed photogeologic study with special reference to structural analysis was enterprised.
This area, with cover about 2I0 sq.km is part of Eastern Carnic Prealps, it is largely covered by mountains with sharp relieves raising from 200-400 meters a.s.l. of the bottom of the valleys up to I700-I800 meters a.s.l.
A narrow belt of hills is present (300-400 meters a.s.l.) in the southern portion of the area.
Detailed geologic surveys has been performed before the earthquake over the 2/3 of this territory by one of the authors.
They were brought to end sebsequently, together with photogeologic analysis.

- Geologic setting
Most of the territory is formed, at the outcrop, by Mesozoic marine carbonatic rocks (U. Trias.U.Cretaceous).
Only in the southern portion Tertiary formations outcrop: they are represented by flysch facies (Maestrichtian p.p.-M.Eocene) and molasse (L.Oligocene-Pontian) deposits.
Quaternary continental deposits are of importance only locally.
Four overthrusts having South vergence are the largest outcropping geotectonics.
They are (moving from South to North): Arzino, Periadriatic, Tramonti and High Tagliamento overthrusts.
Moreover several faults systems are in this area; prevalently these faults have deep slopes

and the about NE-SW ones.
During the field surveys it was observed that:

a) the faults having their directions between WNW-ESE and N-S displace systematically all the other structures, enclosed there in the overthrusts.
These faults can therefore considered as the most recent.

b) The movements along these faults are, in the most of cases, of transcurrent type: there is a certain dextral shear tendency.

c) Mesoscopic features show that also the overthrusts surface give rise to strike-slip movements if they have an about WNW-ENE trend.

- Photogeology

The photogeologic study having a structural purpose was performed utilizing B&W aerial photos (I:25.000 scale) taken in September I969.
The linear features detected on the photos were drawn on topographic maps at the same scale.
Subsequently these elements were controlled by means of detailed geologic field surveys.
Therefore the lineaments reported and measured on the maps correspond in any case to movement planes, i.e., generally, to faults having different type and meaning.
On the whole I4I8 lineaments were detected, amounting to a lenght of about I369 km.
They are distributed in the following classes (Fig.II).

Cl. I^	(270°-280°)	km 39.363	% 2.9	n 64
2^	(280°-290°)	25.756	I.9	39
3^	(290°-300°)	62.935	4.6	47
4^	(300°-$3I0^{\circ}$)	II5.075	8.4	63
5^	($3I0^{\circ}$-320°)	76.237	5.6	52
6^	(320°-330°)	I84.938	I3.5	95
7^	(330°-340°)	204.570	I4.9	II4
8^	(340°-350°)	233.328	I7.0	I35
9^	(350°-360°)	I63.589	II.9	II7
I0^	(0°-$I0^{\circ}$)	72.240	5.3	96
II^	($I0^{\circ}$-20°)	33.475	2.4	86
I2^	(20°-30°)	34.800	2.5	93
I3^	(30°-40°)	2I.825	I.6	84
I4^	(40°-50°)	27.225	2.0	98
I5^	(50°-60°)	23.700	I.7	80
I6^	(60°-70°)	I6.300	I.2	57
I7^	(70°-80°)	I2.525	I.0	42
I8^	(80°-90°)	2I.325	I.6	56

- Considerations

The results of this aerial photogeologic analysis agree perfectly with field collected data but exhibit overall difference when compared with Landsat 2 image interpretations. This event appears very clearly if it is considered not only the rose diagrams of the linears and lineaments of the whole area of the image (Fig.6-7) but expecially the ones referred to the single D block (Figg.7,8,I0).
Many factors contribute to this discrepancy; among the most relevant ones we include:

a) Landsat images sun azimut and inclination.
This factor is of great influence in satellite images where lineaments corresponding in aerial photointerpretation to classes 5,6 and 7 appear very difficult or impossible to be detected

b) Difference in scales ,wavelenght and bandwidth between the two types of information .
Only the scale influence reduces passing from I:I.000.000 positive film to I:500.000 and to I:250.000 prints. In this framework the comparison between Figg.6a-8d and between all these and Figg.6b,c is quite significant.(see also Fig.II)

e) The "weight" of the new detected lineaments (air photos)

In the study of airphotos a lot of very narrow but continuous lineaments were detected (these lineaments correspond on field mainly to 4 ÷ IO classes).
These elements were partly unknown before this detailed analysis and for this reason they were not included in the geologic map resources utilized for linears-lineaments filtering.

5. OPTICAL FOURIER TRANSFORM ANALYSIS

The two-dimensional Fourier transform is well known. It starts from a coherent laser, in order to analize the spatial distribution of the "frequencies" contained in a photographic image.
A particular care in this work has been devoted to the preparation of the image which had to be examined and in the handing of the resulting optical Fourier spectra.
The investigated area was subdivided in squares IOxIO km sized: a network was laid on to the photographic derivative function image of band 7 (Dic 75).
The derivative function was obtained by superimposing a negative to the positive transparency and relatively shifting of about one scan-line in the sun azimut direction the two slides.
In this way only the significant contrasts were enfasized, while the slowly changing phenomena disappeared completely.
Each square of the network was analized at laser light.
The corresponding Fourier transform spectra were recorded on photographic plate, and, at the same time, examined over 360° with a photomultiplier employing a 10° butterfly filter.
In that way, for each square, 36 mesurements were obtained showing the $\pi/2$ rotated spatial distribution of the frequencies contained in the original information
These series of data were filtered in order to avoid both the systematic and the random errors.
A completely different approach was employed for the spectral analysis: a signal coming from a non-focused TV camera looking at the spectrum was treated with an analog slicer and displayed on a colour TV monitor.
The result of the non focusing process is that a point on the image becomes a small area, so that the distribution of points can be considered as a distribution of a photographic density that can be easily sliced.
In Fig.I2 the mosaic of the contours of an intermediate slicing level (the same for each square) is shown.

- Considerations

As it is easy understable these two non conventional analysis have to be utilized with care in the interpretation step, because the geometrical distribution is an average of information about objects having the same direction, but is not possible to say anything about the meaning of such a distribution from a geological point of view.
When in a certain area, as the one of this study, a deep relationship exhists between linears and lineaments, in this case the utilization of this methodology is useful.
In fact in this case the Fourier analysis can contribute to the definitions of "objective" regional geotectonic trends which are related to the geodynamic history of the territory.
From the comparison of the Fourier spectra and the rose diagrams of linears referred to structurally homogeneous blocks it was noted that a good agreement exhists considering the A block trends; in the other ones this is also true except for the 20°-50° W sector.
Another comparison was done between the Fourier spectra and the rose diagrams of lineaments for the same blocks, taking into account that a quite good corrispondence appears (except for D block) in the studied areas between linears and lineaments.
In this case a good agreement was found for C block, a fair one in A and B (obviously except for the 20°-50° W sector) and a marked difference in D in its Western side.
In this last block if the aerial photos are considered it is possible to observe a noticeable agreement just in Western sector between their rose diagram and the Fourier spectra (mosaic of the corresponding squares, Fig.I2).
The explanation of these data, basing on the type of analysis that was adopted, may be due to the presence of frequent, relatively short and discontinuous linears.
In fact they are not photinterpretatively emphasized in satellite images, but they appear very well detectable by Fourier spectra analysis of the same areas and clearly by aerial photogeology.

6. CONCLUSIONS

The research performed utilizing satellite images, aerial photography and field surveys in a combined approach for the study of linears in Friuli earthquake area, suggests, at this step, the following considerations:

a) For the identification and classification of linear phenomena revealed by Landsat images it is mandatory at the beginning to compare for the same territory different passes, bands and scales.
In the images of Friuli it was ascertained that the most information was recorded in b7 positive film, I:I.000.000 scale, 9.I0.75 orbit.

b) The differences verified in Landsat and aerial photographic information are mainly due to the different capability in perceiving the evidence of long and short linear phenomena at the surface.
In fact aerial photographic analysis revealed small and discontinuous elements which are very difficult to be discerned, identified, and "weighed" in the normal photointerpretative approach to Landsat images.

c) Fourier spectra analysis applied to satellite data, besides confirming "normal"linear trends detected by the photointerpretation of selected frames, appears as a powerful method in evaluating exactly the small and detailed elements (at satellite observation scales). As a matter of fact Fourier spectra analysis revealed a trend (20°-30° W about) not evident in Landsat images photointerpretative stage and that, on the other side, was very clear in aerial photographic interpretation. This is possible obviously in zones where a quite close linear-lineament interdependence exhists.

d) As a standard methodology,for the analysis of space coming data in area exhibiting a similar behaviour from a geologic and climatic point of view,this research seems to suggest the following steps:
I - choice of a proper b7 image taken in late Summer or early Autumn
2 - linears drawing from I:I.000.000 positive transparency
3 - linears-lineaments preliminary geologic filtering
4 - Fourier spectra analysis, driven for the selection of the size of the square elements by the geologic evidence of the territory on study
5 - comparison between the trends shown by Fourier spectra analysis and the ones obtained by satellite image photinterpretation
6 - aerial photointerpretation in those areas where the most discrepancy appears (see point 5) and as a spot check-up in few sites (to be selected on the basis of the geologic complexity of the territory)

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F I G U R E S

Fig. I - Friuli and surrounding areas. MSS band 7 Landsat 2 image (I2.27.75 orbit) printed from 70mm negative film

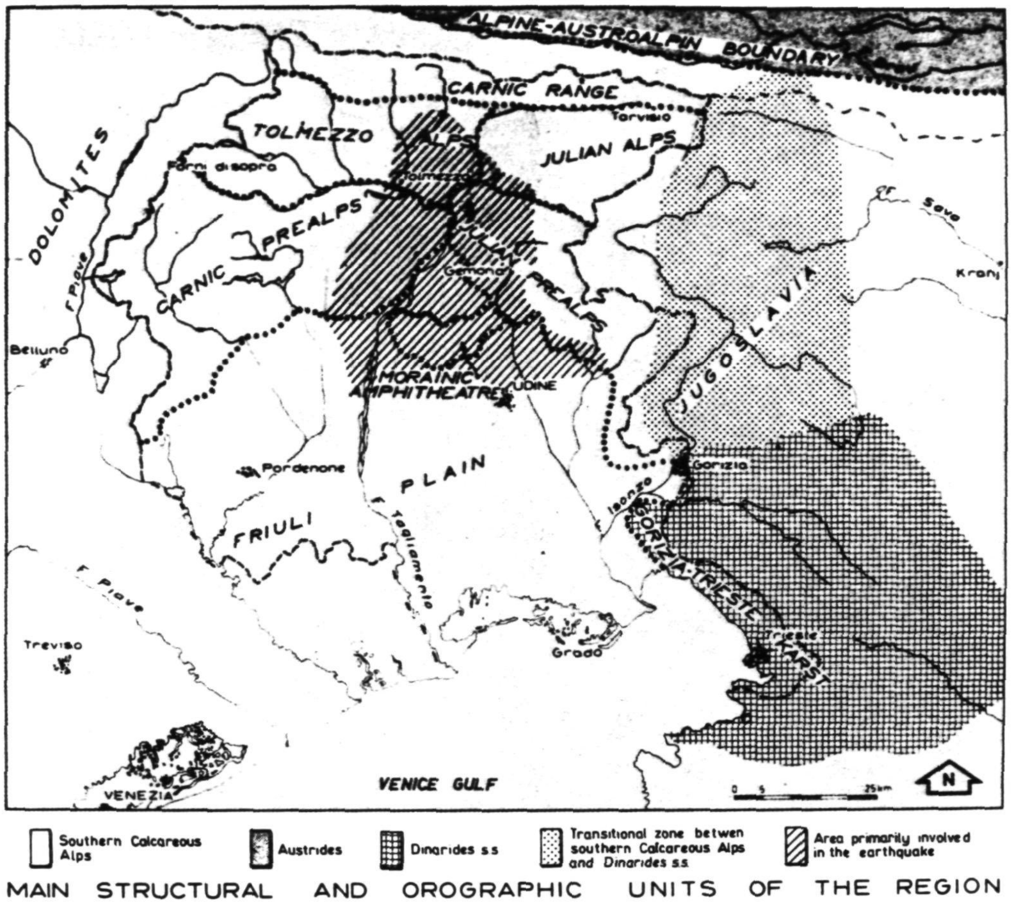

Fig. 2 - Main structural and orographic units of the region

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TECTONIC SKETCH-MAP OF FRIULI

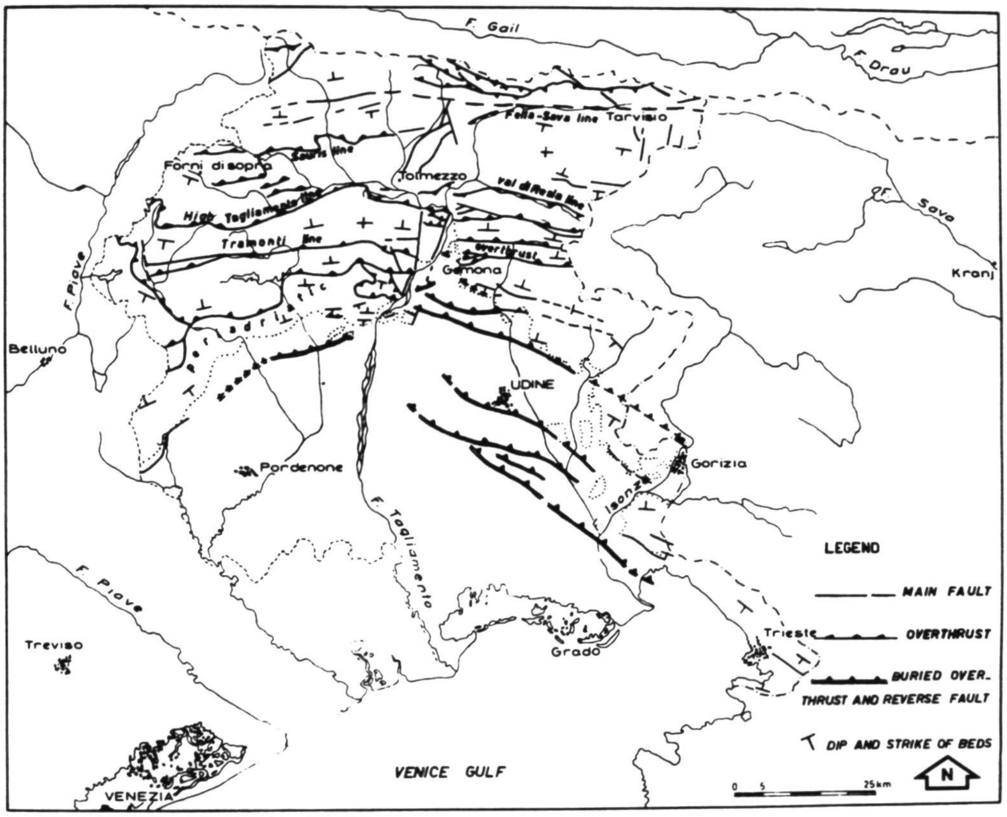

Fig. 3 - Tectonic sketch-map of Friuli

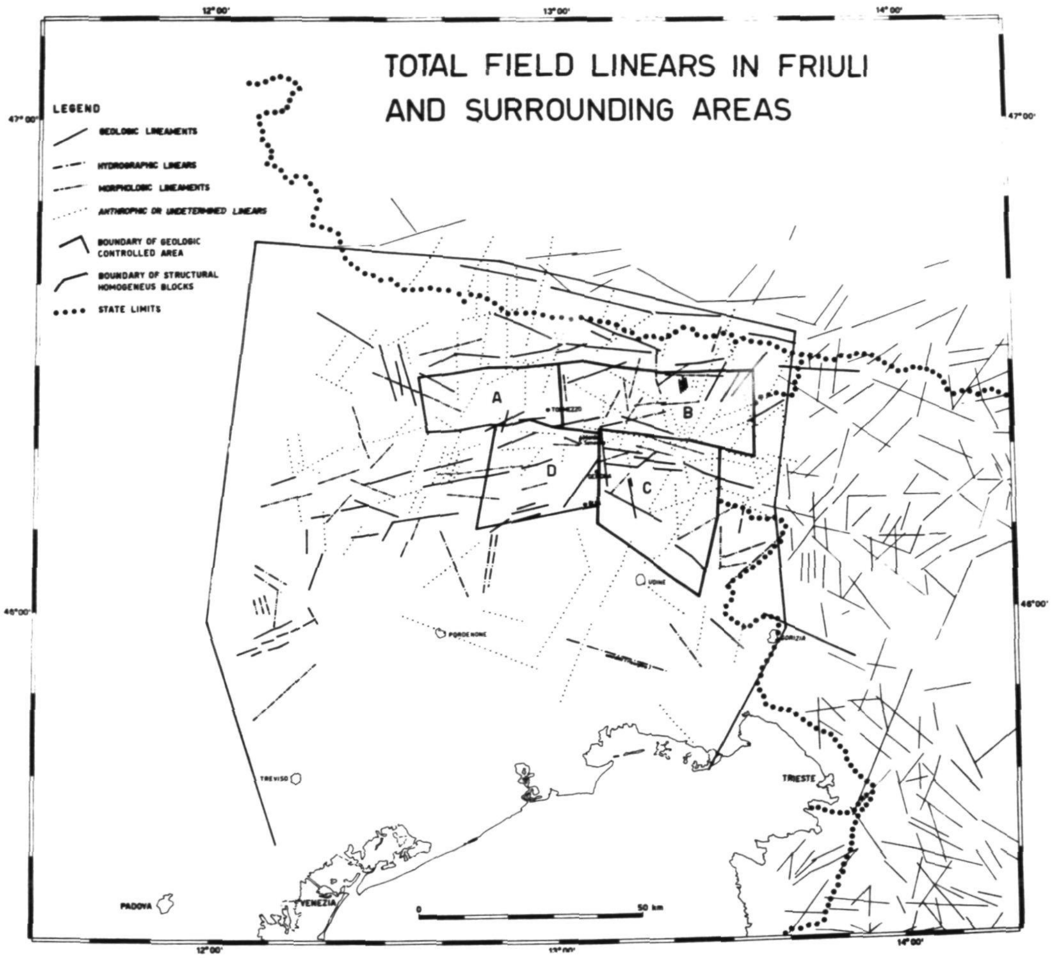

Fig. 4 - Total field linears and their classification obtained from the study of I:I.000.000 positive film of band 7 (9.I0.75 orbit)

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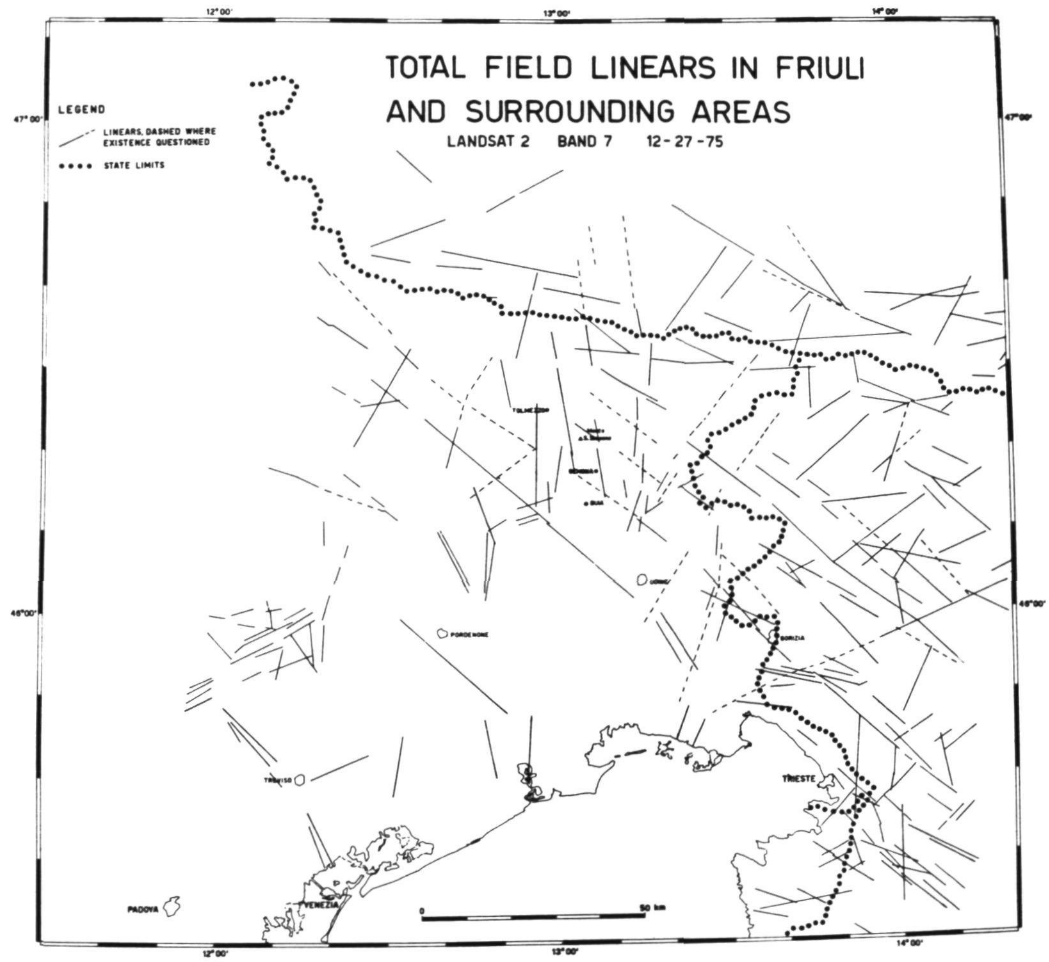

Fig. 5 a - Total field linears in Friuli and surrounding areas from b7, I:250.000 print (I2.27.75 orbit)

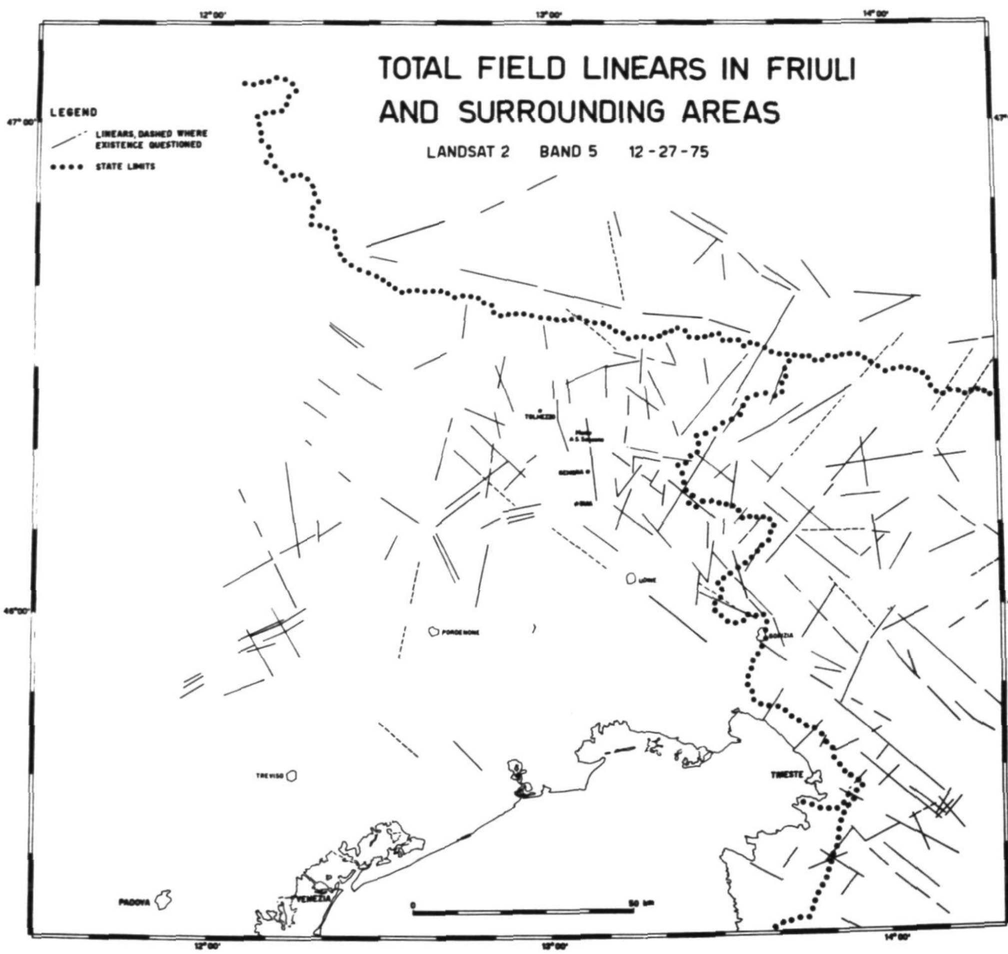

Fig. 5 b - Total field linears in Friuli and surrounding areas from b 5 I:250.000 print (I2.27.75 orbit)

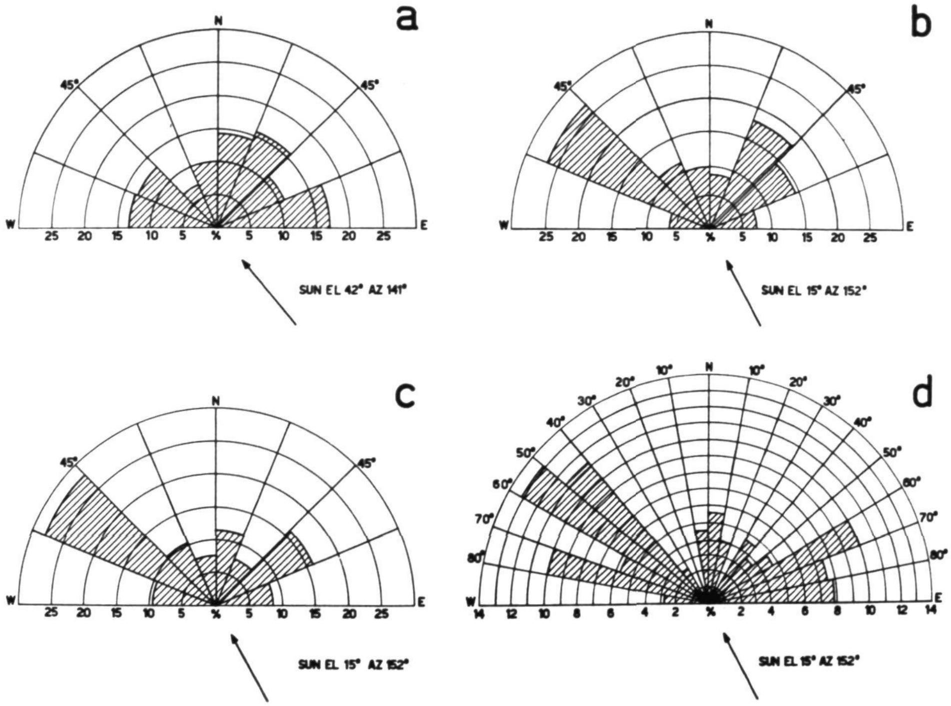

Fig. 6 - Rose diagrams (lenght distribution) of linears referred
to the whole area of the image

a) from b 7 I:I.000.000 positive film (9.I0.75)
b) from b 7 I:250.000 print (I2.27.75)
c) from b 5 I:250.000 print (I2.27.75)
d) from b 7 I:500.000 print (I2.27.75)

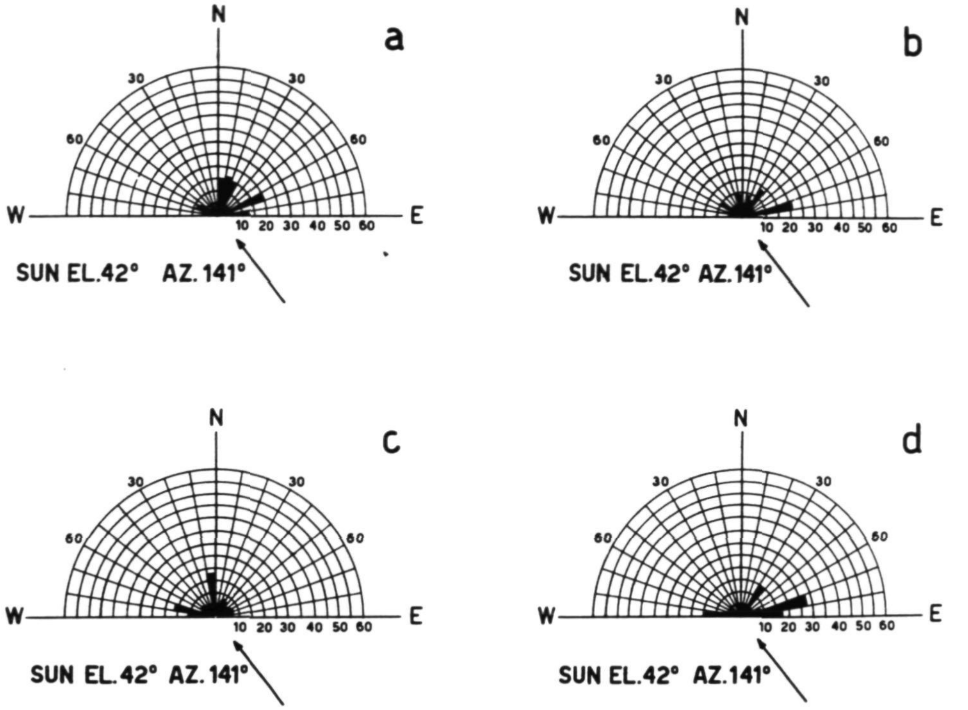

Fig. 7 - Rose diagrams of linears referred to structurally homogeneous blocks (a,b,c,d correspond to A;B,C,D blocks of 4). The diagrams are derived from b 7 I:I.000.000 positive film (9.I0.75 orbit, Fig.I)

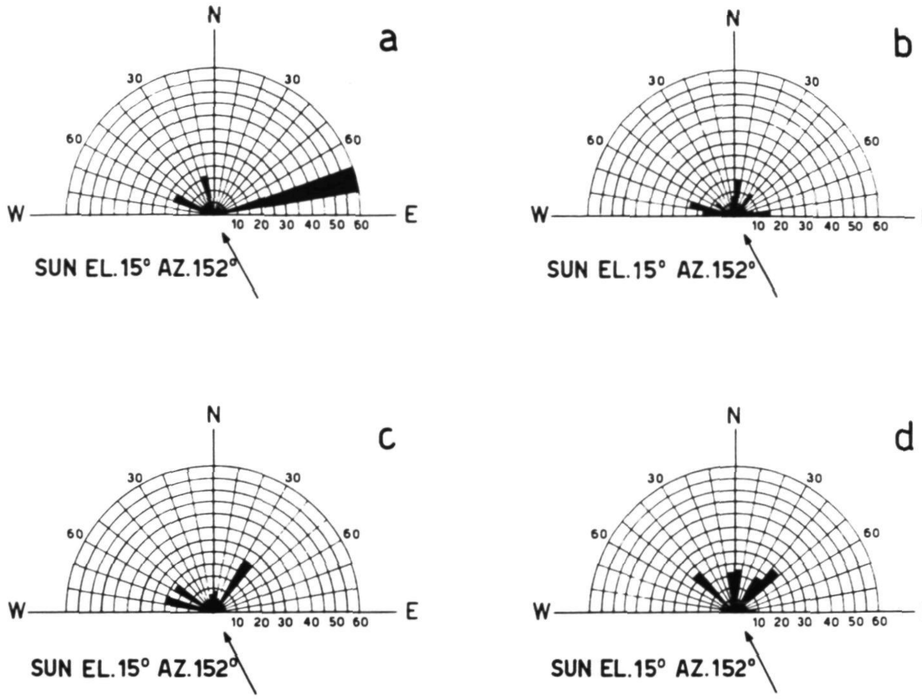

Fig.8-Rose diagrams of linears referred to structurally homogeneous blocks (a,b,c,d correspond to A,B,C,D blocks of Fig.4). The diagrams are derived from b7 I:500.000 prints (I2.27.75 orbit)

Fig.9-Rose diagrams from b7 positive film (9.I0.75 orbit) drawn from the whole geologically controlled area

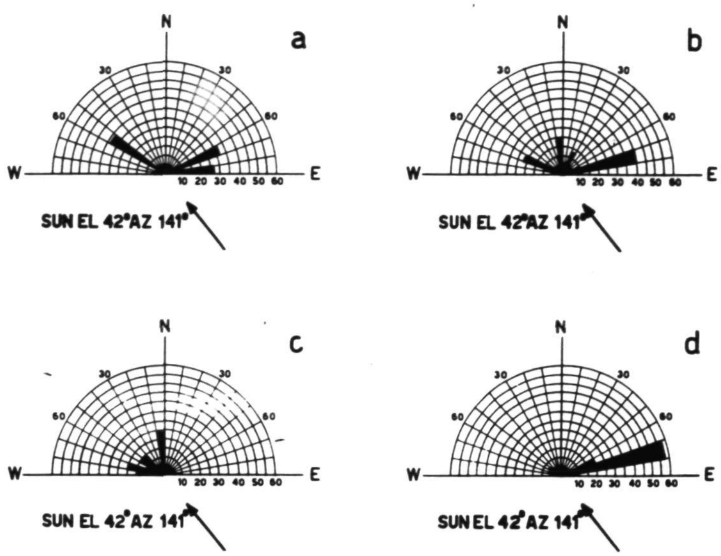

Fig. IO - Rose diagrams of lineaments from b7 positive film (9.IO.75 orbit) drawn for each single block

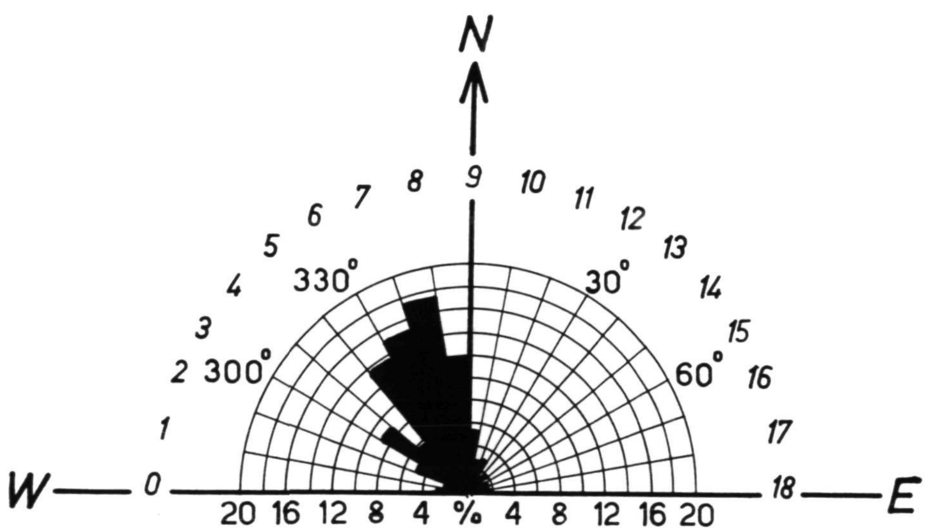

Fig. II - Rose diagrams (lenght distribution) of lineaments detected on B&W air photos of the Tolmezzo-Trasaghis-Forgaria area

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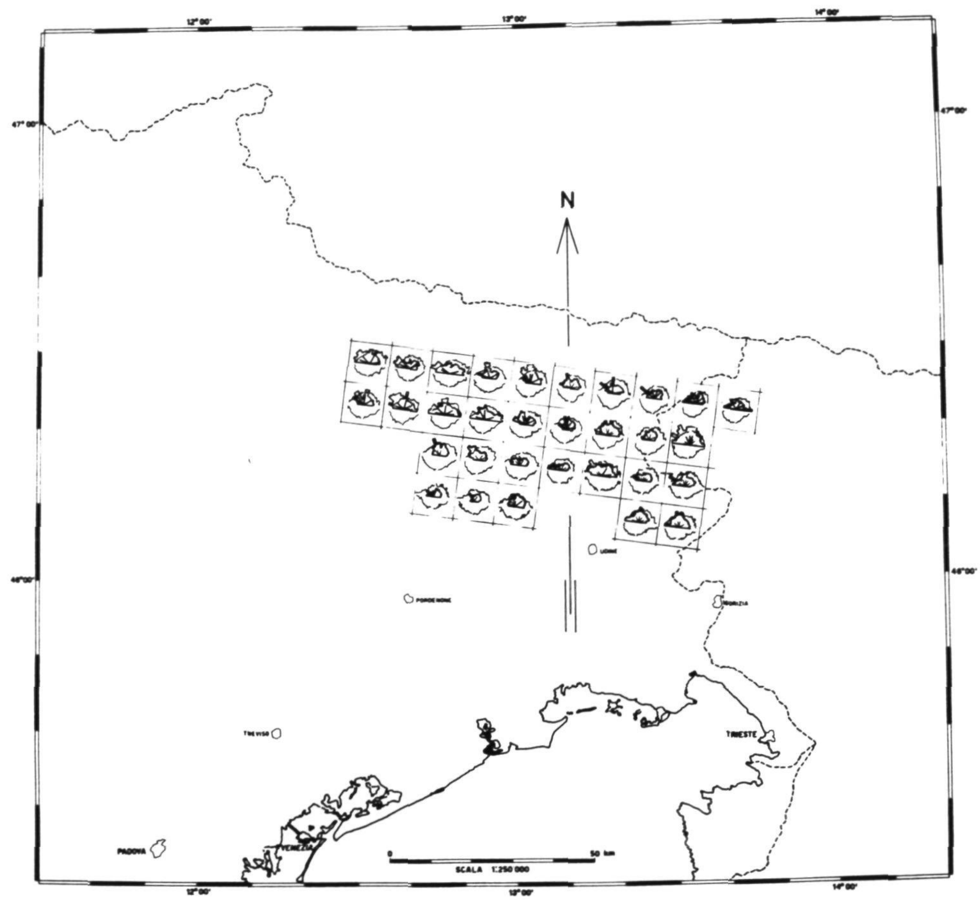

Fig. I2 - Mosaic of the results of Fourier analysis (assemblage of the whole cells):

I) the irregular contours correspond to analog representation of Fourier spectra.

2) The rose diagrams correspond to photomultiplier angular survey.

3) The arrows are, in a qualitative form, the interpreted trends.