Remote sensing analysis of lineaments on a single landsat image: the role of the «human factor» and its relevance in tectonic studies and mineral exploration

Análisis de lineamientos detectados por sensores remotos sobre imágenes landsat: la influencia del factor humano y su relevancia en estudios tectónicos o de investigación minera

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In the present work we deal with the influence of the so-called «human component» on lineament photointerpretation and LANDSAT images. The statistical study of the lineaments drawn by three different analysts on the same LANDSTAT image is performed, being the tested a geologically well-known portion of the Iberian Hercynian Massif: the Badajoz-Córdoba Shear Zone. The results obtained let us consider attentively the role played by the analyst subjectivity on the final lineament networks. As a result, the consequence of the studies of this type on mineral exploration and tectonics are discussed, being undeniable the validity of this technique.

Key words: remote sensing, lineaments, subjectivity, tectonics, mineral exploration, Badajoz-Córdoba Shear Zone.

En este trabajo se estudia la influencia del que se ha dado en denominar «componente humano» en la fotointerpretación de lineamentos estructurales sobre imágenes LANDSAT. Se realiza un estudio estadístico de las fotolíneas dibujadas sobre un mismo soporte fotográfico por tres analistas diferentes. El área utilizada para la realización de la prueba es el Corredor Blastomilonítico de Badajoz-Córdoba, una región relativamente bien conocida del Macizo Ibérico. Los resultados y conclusiones alcanzados permiten efectuar una estimación semicuantitativa del papel jugado por la subjetividad del analista sobre las redes de fotolíneas

obtenidas. Las principales consecuencias que se derivan de este estudio son discutidas desde la perspectiva de la tectónica y de la exploración mineral, resaltando la validez de la técnica de teledetección utilizada.

Palabras clave: teledetección, lineamientos, subjetividad, tectónica, exploración mineral, Corredor Blastomilonítico de Badajoz-Córdoba.

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REMOTELY-SENSED LINEAMENTS: APPLICATIONS AND CONSTRAINTS

A very important section of remote sensing consists of the surveying, analysis and interpretation of lineaments (here considered as linear features observed on both satellite images or aerial photographs), which are frequently related to geologic structures. In this sense, photolites are some of the morphological features better reflected in the different techniques of remote sensing (i. e. photointerpretation and satellite-image analyses on the basis of a large number of lines). Nevertheless, the recognition of these linear features is not devoid of problems. According to STEFOULI & OSMASTON (1986), some methodological aspects should be considered in order to facilitate the study of photoline networks and consensuate the quality and number of lines observed by different analysts.

So far, the uses of remote sensing techniques (WEBER, 1985) in the areas of geologic surveying, such as geological mapping, seismology, metallogeny and mineral exploration, and the search of potential sites of petroleum and gas deposits, have known large advances. From the different techniques, the recognition and analysis of linear features on satellite images has provided very useful devices for mineral exploration, mainly when combined with geochemical, geophysical and field data (ANTON-PACHECO & SANDERSON, 1989; MARTINEZ-ALONSO et al., 1989; TSOMBOS & KALOGEROPOULOS, 1989; WIDDOWSON, 1989) and ground-water exploration (SANDE DE GALDEANO et al., 1985). In the same way, lineament analyses are often related to tectonic studies at all scales, from the microtectonic (MEKARINIA et al., 1989). through the fold-belt and plate-boundary geodynamics (POSCOLIERI & SALVI, 1985; WISE & GRADY, 1985). Thus, the evolution of lineament tectonics as an independent branch of geotectonics rises from all these advances, in which consideration is given to the lineament tectonics of ancient and modern mountain belts, platforms, sedimentary basins, as well as to the lineament genesis and its relationships to the characteristics and anomalies known in the crust and the upper mantle (KATS et al., 1986).

The procedure of lineament analysis on remotely sensed images involves the computer-aided processing of large amounts of data sets (KORONOVSKII et al., 1986) as well as the performance of areal density distributions by means of contour line maps (which may lead to the identification of regional structural trends), the consideration of subparallel lineaments swarms rather than individual lines, and the rejection of some linear elements while others are combined into lineament zones or lineament frameworks. The interpreta-

tion of lineaments is based on the spatian correlation of remotely sensed images of geological objects as well as on the density of the available geological-geophysical data. This interpretation involves successive approximation to the objected, generating the remote-sensing image from the better known to the less studied ares (TROFI-MOV, 1985).

The detection of lineaments holds a series of scarcity sources, a group of image features (suchs as spectral range of wavelength, illumination angle or restitution) as well as environmental (point of observation, quality of lighting) or psicological (optical illusions, knowledge of the studied area, prejudgments) should be considered as a cause of scattering in the studies of this type (FARROW, 1975). KORONOVSKII *et al.* (1986) have set to work a computer-aided technique to remove the influence of effects as the forementioned. Nevertheless, even in this case, which largely lacks the human subjectivity, some of the linear elements identified were disregarded, while most of them were found to coincide with those identified by visual interpretation. From a different point of view, lineament maps drawn from a set of satellite images of the same area may display considerable variations in the number of lineaments identified (in this case the maps with fewer lineaments not being subsets of those with many lineaments) although despite the differents the same preferred orientations of lines may be found, as PARSONS and YARDLEY (1986) report. Moreover, every analyst holds its own way of photointerpretation, and this constitutes an additional source of scatter.

As a consequence of all this, a question rises on the role played in the final result by the analyst subjectivity and animic state during photointerpretation. The aim of this work is to test the influence of the «human component» on LANDSAT imagery pho-

tointerpretation and to check both some of its constraints and their role on the results obtained. With this porpouse, three different analysts have performed a statistical study of photolines on a geologically well known area of the Iberian Variscan Massif: the Badajoz-Córdoba Shear Zone, which is located in the boundary between the so-called Ossa-Morena (ZOM) and Central-Iberian (ZCI) Zones. This area occupies most of the central part of the picture 25DEC81 2-218-33 7 01 1143-1800 A 06MAY 85 processed by TELESPAZIO for ESA-EARTHNET.

GEOLOGICAL FEATURES OF THE TESTED AREA

As it was pointed above, the study area constitues a part of the Badajoz-Córdoba Shear Belt, which is located to the SW of the Iberian Peninsula within the Hercynian Iberian Massif. This major structure of both the Iberian Massif and the European Variscan Belt separates two terranes, the Central-Iberian to the N and the Ossa-Morena to the S (APALATEGUI & HIGUERAS, 1983; APALATEGUI & QUESADA, 1987). This belt has undergone a long tectonometamorphic history since Upper Proterozoic up to Lower Carboniferous (A 300 m. y. time span). The different episodes involve initial eclogitic metamorphism and large scale thrusting followed by an extensional tectonic regime during Lower Paleozoic times, and then a major transpressive sinistral evolution from ductile through brittle conditions. The latter masks all the previous structures and imprints the characteristics of a sinistral intracontinental shear zone to the whole area (ARTHAUD & MATTE, 1977), shown in the Upper Paleozoic fault distribution map in Fig. 1.
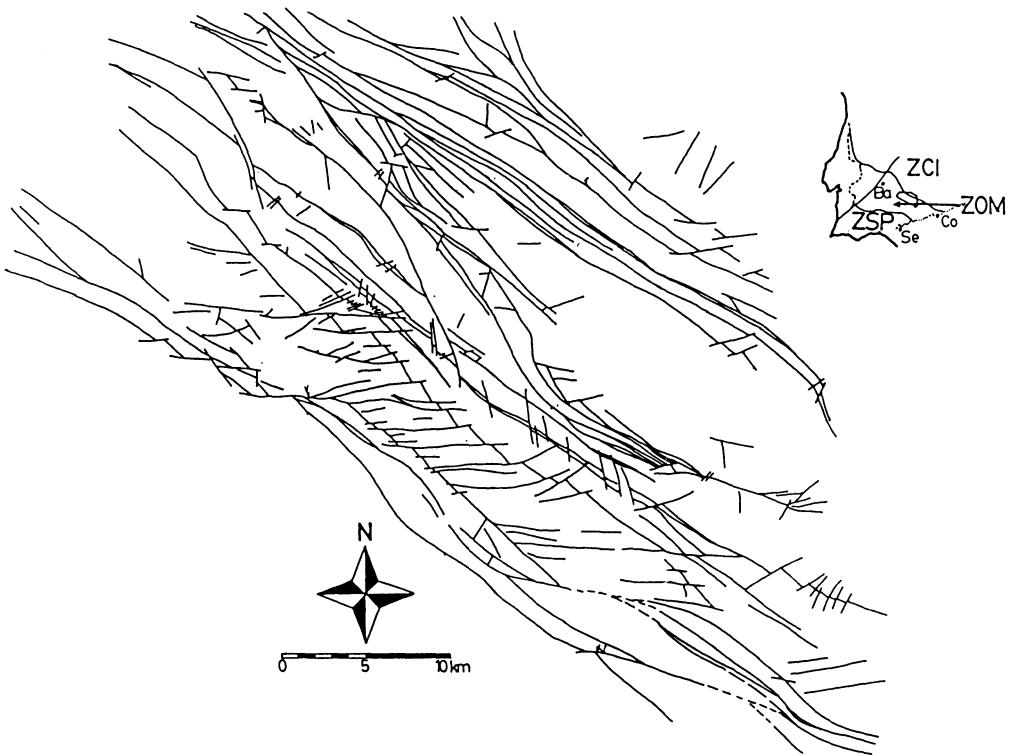
Fig. 1.   Hercynian and late-hercynian fault distribution map for the central part of the Badajoz-Córdoba Shear Zone. Most of the NW-SE-trending faults are Lower Paleozoic thrust structures carrying high grade metamorphic rocks. ZCI, Central-Iberian Zone; ZOM, Ossa-Morena Zone; ZSP, South-Portuguese Zone; Ba, Badajoz; Co, Córdoba; Se, Sevilla.

THE LINEAMENT ANALYSIS

Conditions previous to the photointerpretation

Each of the three own distinctive predispositions in photointerpretation. They three had performed before photointerpretation studies on both aerial photographs and satellite images at least during two years, thus holding a ripen style of drawing lineaments. In the three cases photointerpretation was carried out with sunlight of varied intensities and different sidelightened orientations of the satellite pictures. Nevertheless, the number of days employed by each analyst to construct the final linea-

ment network was quite diverse: analyst B (B. A.) employed only one day, while it took three days to analysts C (. M. M.-T.) and analysts A (R. R. L.) employed some weeks, this surveying the image under a varied set of lightning, image orientations and animic states.

The knowledge of the study area and the subsequent prejudgments rose as a very important matter of discussion. In this respect, analyst B was unable to avoid checking his knowledge of the area during lineament drawing, and as a result, much of the NW-SE trending photolines were considered despite most of them might correspond to lithological variations. Long lineaments were drawn only if they were well-defined,

and the connection of minor lines into lon- ger ones was disregarded unless their rela- tion was suspect to be undoubtful. On the contrary, analyst A rejected all informations on the area and constructed a line network constituted only by the lineaments obser- ved, not those inferred. Individual lines we- re shorter than in the previous case, being avoided their connection into larger lines as well. Prejudgments on the meaning of the NW-SE trending lines made observer A unable to draw much of them, as its non- tectonic origin was suspected. Finally, analyst C provided a very compact frame of photolines, as much of them were connec- ted through larger and no linear feature of the image was disregarded by meaningless.

During the drawing of the lines it was prevented any discussion on the matter of

collaboration in order to guarantee that no interferences or influences of one analysts upon the others might occur. Once each analyst finished its lineament framework, they three were joined and its statistical analysis begun.

General discussion of the results obtained

The lineament frameworks of the three analyst (labelled A, B. and C in Fig. 2) were used in three manners: firstly, to check through them the way each analyst cons- tructs the lineament net; secondly, to be compared between them; and thirdly, to as- certain some results of geologic relevance. The networks A, B and C are compared in order to establish the number of and distri-
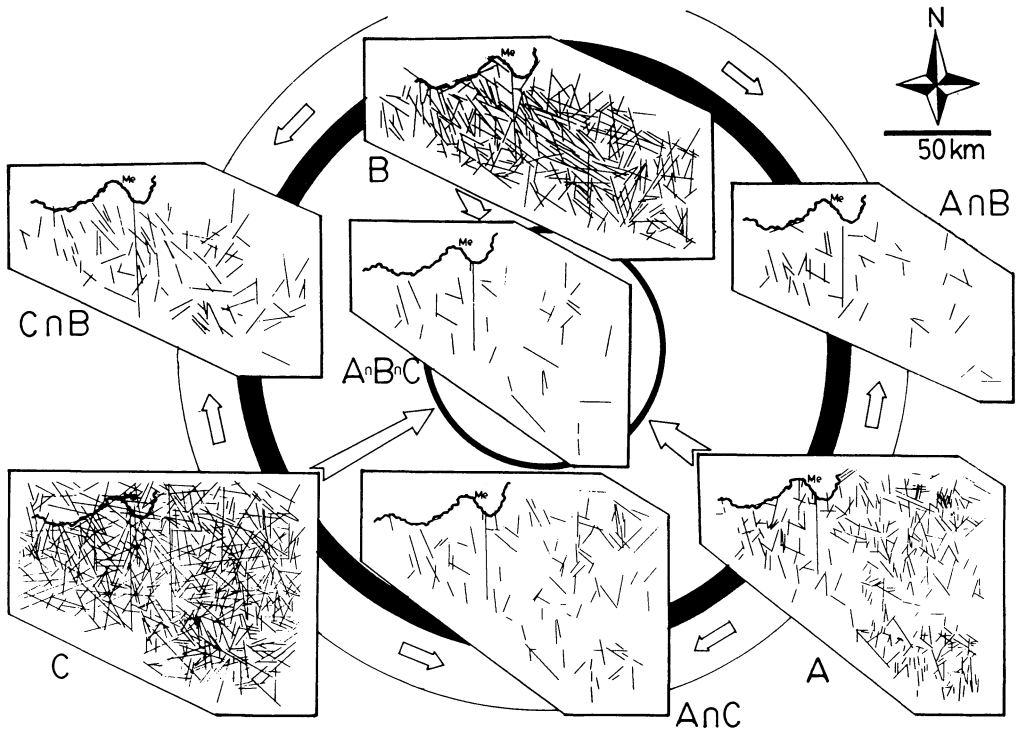

Fig. 2.　Lineament frameworks relative to the study area (references are the Guadiana River and the town Mérida, here labelled Me). A, B and C are, respectively, the lineament frameworks interpreted by analysts A, B and C. The frameworks A∩B, B∩C and A∩C contain the lineaments deduced by the two analysts involved by the labels, while the one situated at the center of the figure contains the li- neaments observed by the three.

bution of the lineaments observed by two the analysts and then by the three. In this sense, it is found that the nets containing fewer lineaments constitute subsets of those with much more lines or, on the contrary, that the latter contain a high proportion of the lineaments interpreted by the less optimistic analysts. Notwithstanding, each network contains, a varied proportion of lineaments which are unique to it.

Table I resumes the main features of the photointerpretation performed by each analyst. It may be observed that each one owns a particular way of photointerpretation, as reflected in the number, strike and length of the lines constituting the three photoline frameworks. It is clearly observed that each of them tends to draw lineaments

longer or shorter (reflected by their average length) and more or less numerous (pointed out by the ratio lineament length/area) over a slightly different area. These first results, referred to the quality of the whole lineament framework of every analyst, might be referred to as general and proper characteristics. On the contrary, the distribution of the photointerpreted lineaments in 10.° orientation intervals (Table I) should be ascribed to the influence of the image on the analyst and the response of the latter. The absolute magnitudes number and length of lineaments are closely related (see Fig. 3), remarked by high correlation coefficients in Table I, although they are sometimes far from a linear relation (the case of observer C).

TABLE I. Statistical analysis of some of the measurable features of the lineament frameworks of Fig. 2 ascribable to both special characteristics of the study area and the way in which they are perceived by each analyst.

| Analyst	A	B	C
Number of lineaments	332	333	558
Area studied (Km^2)	8984.40	8593.70	10937.50
Lineament total length (Km)	4329.70	7626.20	13121.60
Lineament average length (Km)	13.04	22.90	23.52
Lineaments/area (Km^{-2})	27.06	25.80	19.60
Lineament length/area (Km^{-1})	0.482	0.887	1.200
Linear regression; 10.° orientation intervals			
Number of lines versus total length			
r (corr. coeff.)	0.972	0.971	0.726
N.° lineaments/10.°	18(14)	18(9)	31(6)
Average length/10.° (Km)	240(181)	423(247)	729(153)
Lineament percent versus average length			
r (corr. coeff)	0.092	0.08	− 0.47
Mean average length (Km)	14(3)	9(3)	24(3)
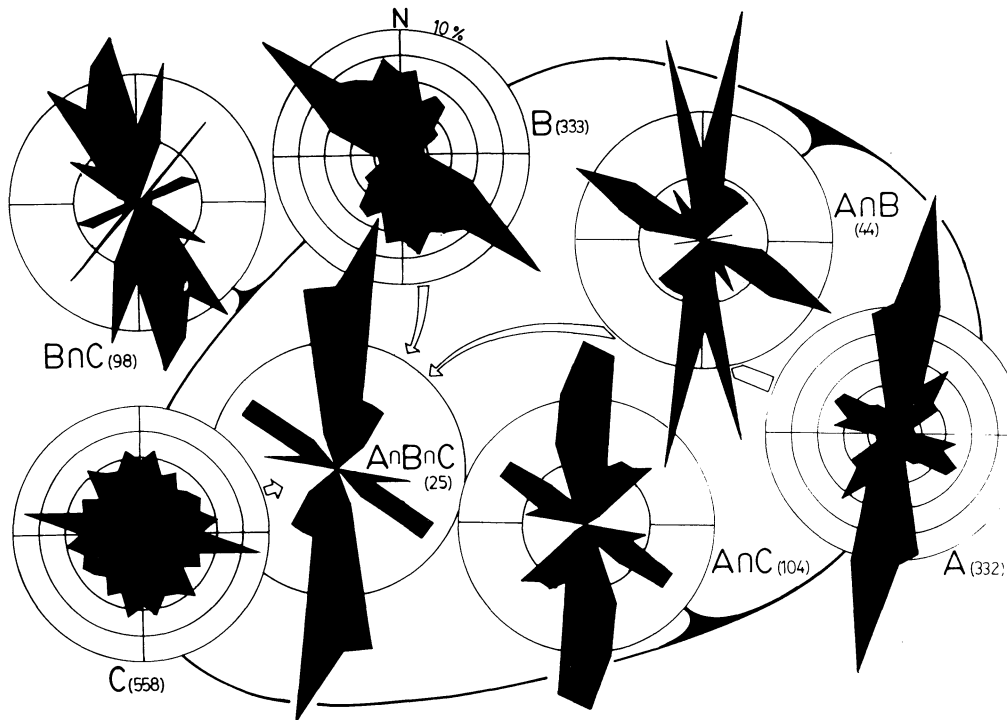
Fig. 3. Orientation distribution diagrams for the lineament frameworks of Fig. 2. The numbers between
brackets indicate the number of lineaments used to construct each diagram. The outer circles in every
rosa sign 10% frequency.

This should mean that, disregarding the fact that the larger the number of lineaments, the larger the whole length, for instante, a particular observer may found a large number of lines within a 10.º orientation interval and assign them a mean length shorter than the assigned to the others, thus reflecting special features of fracture pattern in the study area, special features of the image or, as could be our case, a special response of the analyst to the image. These features are remarked when a comparison is made between the average percent of lines in a 10.º orientation interval versus their respective medium length (Fig. 3). From the values obtained for the «r» coefficient, it may be inferred that no relation exists between the average of the lines within such orientation intervals, and the proportion of such lineament conjunct respect their whole

number. In fact, it is to be expected that photointerpretation of a particular area should reflect the presence of a varied set of lineament systems each of them characterized by a proper average length. Neverthless, if on a particular area analyzed by more than one observer such relations varies, it cannot be totally ascribed to the characteristics inherent to the area, but to the quality of their perception by the analyst and the influence of the latter on the eventual lineament scheme drawn.

It may be state from Fig. 3 that each analyst holds a particular perception of the different lineament orientation systems present in the study area. The shapes of the roses, A, B and C are very different from each other, probably due to the fact that A enchanced the N-S system disregarding the meaningless NW-SE one, while B did it on

the contrary and C performed a photointerpretation which unable a clear differentation of systems because of its relatively homogeneous distribution.

Despite these differences, some common features underlie the lineament frameworks drawn by A, B and C. Table II results from the comparison of the characteristics shared by A, B, C, A and B, B and C, C and A, and A, B and C. The small correlation coefficients may indicate that the relationships between each of them are meaningless when referred to the number, percent,

length or average length of the lines considered in 10.° orientation intervals. Nevertheless, at least 30 % of the lines drawn by A or B (the less optimistic analysts) were also seen by C, although only 13 % of them are common to A and B. The orientation distribution diagrams (Fig. 3) resulting from these intersections enhance the sharpness of the main lineament systems which may be deduced mainly from A and B: the N40E, N130E and N180E. Thus, this scattering might be ascribed to the relative importance of a reduced group of given photoline sy-

TABLE II. Statistical analysis of the measurable features of the lineament networks obtained from the intersections between frameworks A and B, B and C, C and A, and A, B and C in Fig. 2.

Analysts compared	A-C	A-B	B-C	A-B-C
Correlation coeffs.				
% lineaments/10.°	0.411	0.378	0.306	
N.° lineaments/10.°	0.468	0.436	0.301	
Average length/10.°	−0.424	−0.139	0.309	
Total length/10.°	0.202	0.440	−0.001	
Common characteristics				
N.° lineaments	104	44	98	35
Total length (Km)	1960.9	835.5	2062.2	735.5
Lineaments average length (Km)	18.85	18.98	21.04	21.55

Number and percent of photolines resulting from lineament networks intersections:

Analyst	1st intersection with:	2nd intersection with:
A (332 lin. = 100 %)	B (44 lin. = 13.25 %)	C (35 lin. = 10.54 % of A's lineaments)
	C (104 lin. = 31.32 %)	B (35 lin. = 10.54 % of A's lineaments)
B (333 lin. = 100 %)	A (44 lin. = 13.21 %)	C (35 lin. = 10.51 % of B's lineaments)
	C (98 lin. = 29.43 %)	A (35 lin. = 10.51 % of B's lineaments)
C (558 lin. = 100 %)	B (98 lin. = 17.56 %)	A (35 lin. = 6.27 % of C's lineaments)
	A (104 lin. = 33.65 %)	B (35 lin. = 6.27 % of C's lineaments)

stems which become progressively evident when the orientation distribution diagrams resulting from the intersections between two or the three lineament frameworks are considered.

The intersections of these line frameworks result in a number of clear and undeniable lineaments (only 6-10 % of the lineaments observed by each analyst). This reduced group of lines represents high percent values of the lineaments common to A and B (80 %), B and C (35 %) and A and C (33 %). This could mean that the final result of considering the lines drawn by two analysts common to a third one is to enhance a reduced but very significative group of lineaments of real significance. The orienta-

tion distribution of this latter groups yields a rather precise and true scheme for the lineament systems involved in a particular area.

From the previous discussion it may be concluded that he way in which every analyst performs a photoline interpretation may be delineated on the basis of the number and length of the lines drawn. As it may be observed in Fig. 4, each researcher tends to point a more or less large number of lines for every 10.° orientation interval, this being clearly ascribable to prejudgments upon the type of lines to be drawn of forgotten (Fig. 4 I) mainly due to the knowledge of the study area. Disregarding these prejudgments, each researcher draws, as a
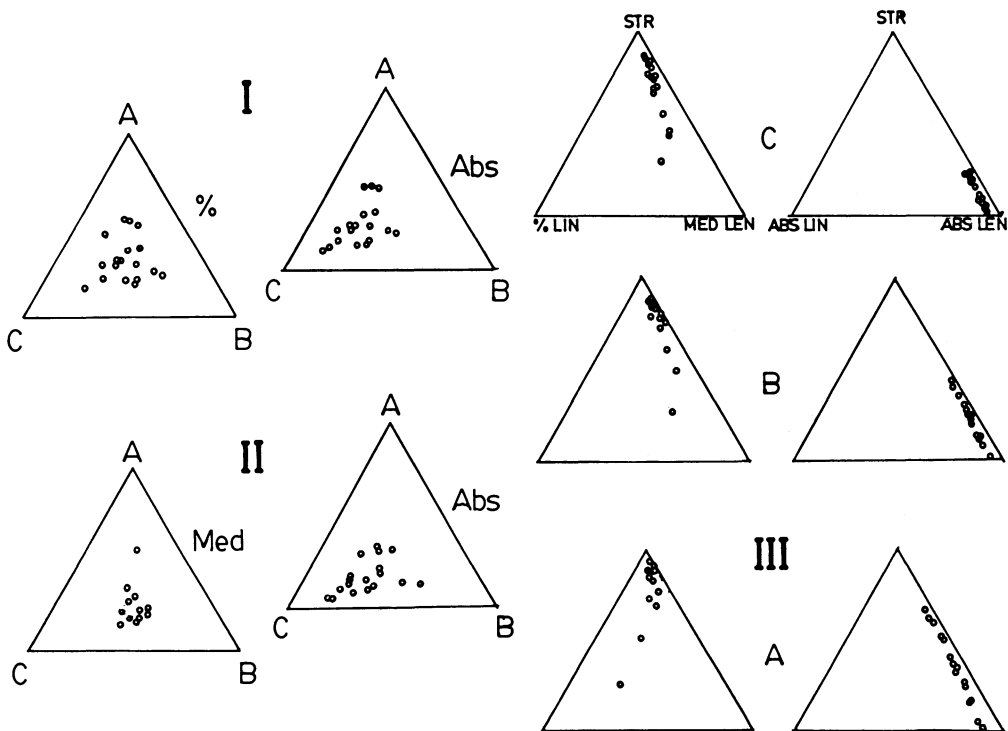

Fig. 4. Triangular diagrams where a comparison is made between: I) the percent (%) and number (ABS) of lines drawn by analysts A, B and C; II) the average (MED) ant total (ABS) length of such lines; and III) the strike (STR, with values ranging 0-180° stepped 10°), percent of lines (%LIN) and their average length (MED LEN) in left triangles, and the strike, number of lines (ABS LIN) and their total length (ABS LEN) in triangles on the right. These parameters are referred to the lineaments drawn by A (bottom), B (middle) and C (top).

general rule, lines longer or shorter than the others with a not too great dependency of the 10.° interval considered (Figs. 5 II and 5 III). From all these statements, some of the questions issued in the foregoing might be answered. Firstly, a group of attitudes inherent to the analyst play a significative role in the final results of photointerpretation. This «human component» rather differs from one analysts to another, and even makes the results very significantly. For this reason, only a relative worth should be given to single-analyst satellite-image interpretation. Secondly, some of the results obtained by an unique analysts are meaningful, and are expected to be found by the others despite the conditions of photointerpretation. In the following section we deal with the relevance and applications of the observations performed by each of the three analysts, which will be discussed in order to state the validity of the technique of lineament analysis in a practical case.

CHECKUP OF THE RESULTS WITH FIELD GEOLOGY DATA. DISCUSSION

It may be learn from the preceding section that the lineament framework obtai-

ned by a single analyst, and the subsequence orientation distribution pattern, is often quite different from those obtained by other analysts. A lineament study may yield very important results, a great deal of which are expected to issue valuable information. Due to fact that many of such informations should be real, it may be stated that the performance of a second of third lineament framework will always supply additional valuable information, as well as it will enhance some features at first unclear or even unsuspected.

For example, Fig. 5 represents orientation distribution maxime at the SW (A) and NE (B) parts of the central Badajoz-Córdoba Shear Zone, considered as a whole in rose C. A and B are ascribable to two neighboring areas separated by the Hornachos Fault, one of the proposed boundaries between the Ossa-Morena and the Central-Iberian Zones of the Iberian Hercynian Massif. This figure, referred to the orientation distribution maxima of the faults and tectonic boundaries shown in Fig. 1, is used here not only to ascertain the main fault systems (rose C), but also the differences between the patterns corresponding to the N (rose B) and S (rose A) of the fault separating the Ossa-Morena and Central-Iberian Terranes.
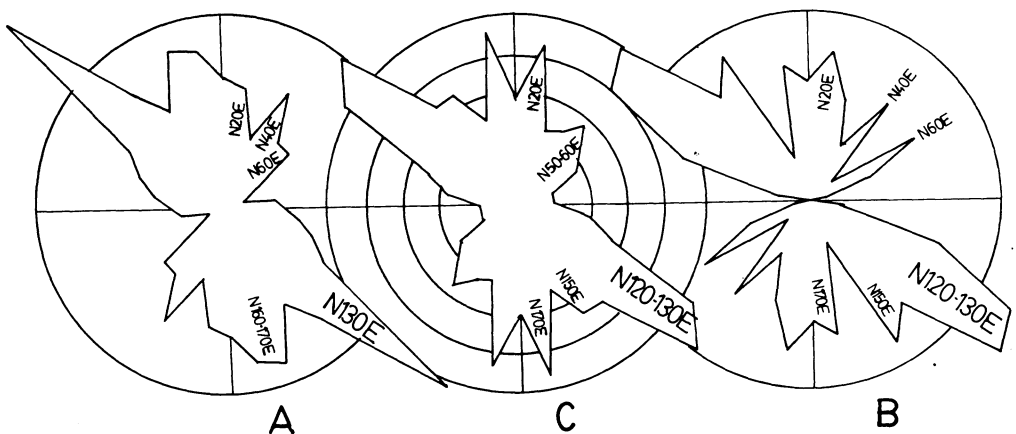

Fig. 5.   Orientation distribution diagrams of faults and tectonic boundaries in the whole study area (rose C; referred to Fig. 1), and to the areas to the N (rose B) and S (rose A) of the fault separating the Central Iberian and Ossa-Morena terranes. The main fault systems are signaled.

This orientation distribution patterns based on field geology may be compared with the orientation diagrams of Fig. 3. The rose labelled B closely fits the field example in shape, but the others do not so closely. Then, does it mean that diagrams A, C, etc., should be very carefully considered? In our opinion this is not the case, as many of the lineament systems inferred from the consideration of many of the patterns as well as from their intersections own real geological counterparts. Nevertheless, the qualitative importance of each system should be very carefully holded in regard.

The latter fact is not only of methodological interest, but also of economic and strategical relevance. Many mineral and oil exploration campaigns are supported, mainly in partly known areas, by lineament density distributions in contour line maps. From our results here presented, the contour line maps interpreted by a given analyst (which may provide the location of areas of suspected interest for drilling, sampling, exploration, etc.) are not expected to fit, even roughly, with those deduced by another one.

For example, Fig. 6 shows the lineament density contour map provided by lineament framework B in Fig. 2. This map, drawn on the basis of the areal distribution of the intersections among different photolines would be rather different if line patterns of corresponding to analysts A or C had been considered. As a matter of fact, the line contour map for framework A should enhance N-S-trending density areas, as the intersections fo the prominent N-S system with lines of other systems would be the most ubiquitous feature of such lineament density contour map. On the contrary, framework C should furnish an isotropic line contour map due to its higher average number of lineaments for area and to their al-
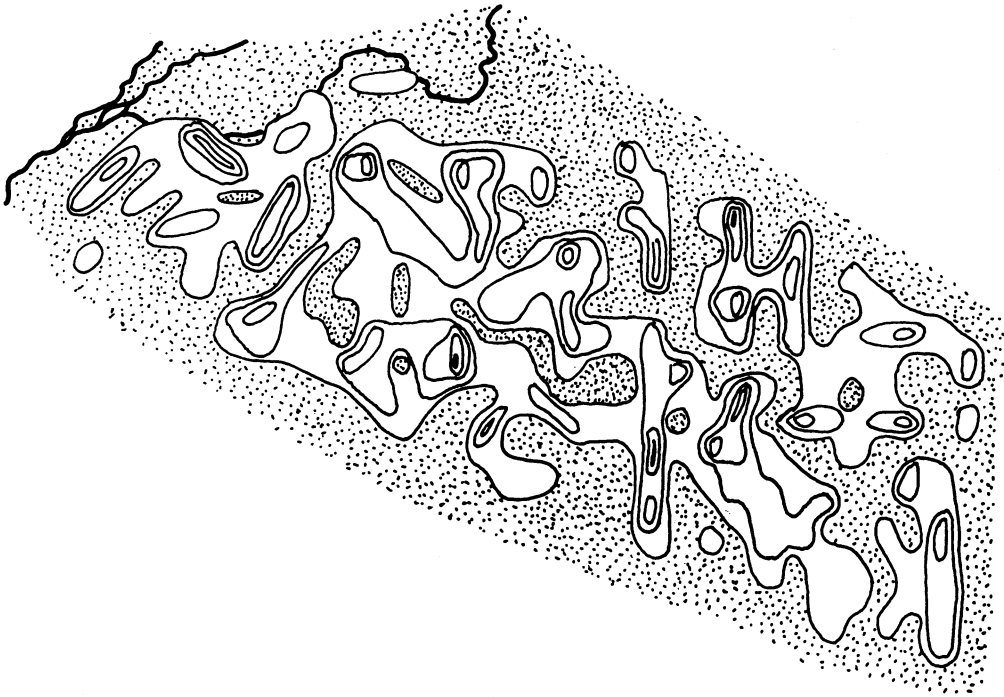

Fig. 6.   Lineament density contour map based upon lineament network labelled B in Fig. 2. Isoline intervals are 1, 2, 3 and 4%.

most isotropic orientation distribution. From a tectonic point of a view, the relevance and meaning of this contour maps is not so stressed as in the case in which an underlying economic interest exists. In tectonic studies, the kinematic inferences supported by remotely-sensed lineaments are often matter of discussion, and a successful hypothesis may be always found as a result of the source data.

In this respect, in our case the information yielded by the lineament density contour map of Fig. 6 may be easily interpreted in terms of the presence of a N130E trending sheared area close to the boundary Ossa-Morena-Central-Iberian and subsidiary N-S corridors of lineaments high density, which could thus represent the presence of a sinistral transpressive deformation regime for the area. In fact, the field geology may support these interferences, as large N130E sinistral faults and smaller coeval dextral faults are widespread. Bearing in mind this kinematic hypothesis, some lineament combinations may be searched for in networks A, B and C of Fig. 2 to fit this model. The more succesful combinations involve lineaments of the systems N130E, N-S and N40E. The latter, together with those of the N-S system, define a conjugate array from which an approximately NNE-SSW compressional stress component may be deduced. Lineaments of the two firsts systems not only define lozenge-shaped areas or domains, they are arranged in subparallel lineaments swarms as follows: the N130E swarms are bounded by N-S lineaments and occupy areas devoid of lineaments which strike is close to N-S (see B1, B2 and A2 networks in Fig. 7). On the contrary, the N-S lineaments display N130E —trending arrangements and are cross— cut by N130E lineaments. These facts, together with the presence of lozenge-shaped domains lacking lineaments, which boundaries closely fit the bands containing a great deal of N130E-trending lineaments, let us establish the presence of a central sheared domain

(dotted area in the central squared graph of Fig. 7) separating a northern area coinciding with the Central-Iberian Zone and a southern one which corresponds to the Ossa-Morena Zone. This conclusion, which is not evident from the field geology (but is supported by the fault distribution map of Fig. 1) is strengthened by the additional fact that a N130E Bouguer gravity annomaly (GAIBAR, 1976) fits such band, and separates a northern domain of negative gravity annomalies from a southern one with positive values of the referred parameter. The N-S trending lineaments fit with local N-S arrangements of the boundary between the positive and negative areas as well.

CONCLUSIONS. EVALUATION OF THE GEOLOGICAL RELEVANCE OF THIS STUDY AND ITS IMPLICATIONS

Photoline analyses are supposed to be performed with a large number of lines. Individual photolines, which may be likely or truth geologic structures or tectonically-induced geomorphic features or relieves, are more significative when considered as constituting lineaments swarms. In this sense, the interpretation of individual photolines is not of geological relevance due to the variable probability they have of being or not considered by different observers. On the contrary, the orientation distribution maxima are often in agreement among them and are of geological significance, as it may be stated from their close relation with the orientation of geological brittle structures. The shape of the lineament orientation distribution roses enhances the consequence of some lineament systems while neglects others. This has been found to be due to, firstly, prejudgments of the analyst on the meaning and relevance of a group of given lineaments, and secondly, the tendency of the analysts to connect or not aligned minor photolines onto inferred larger ones, thus
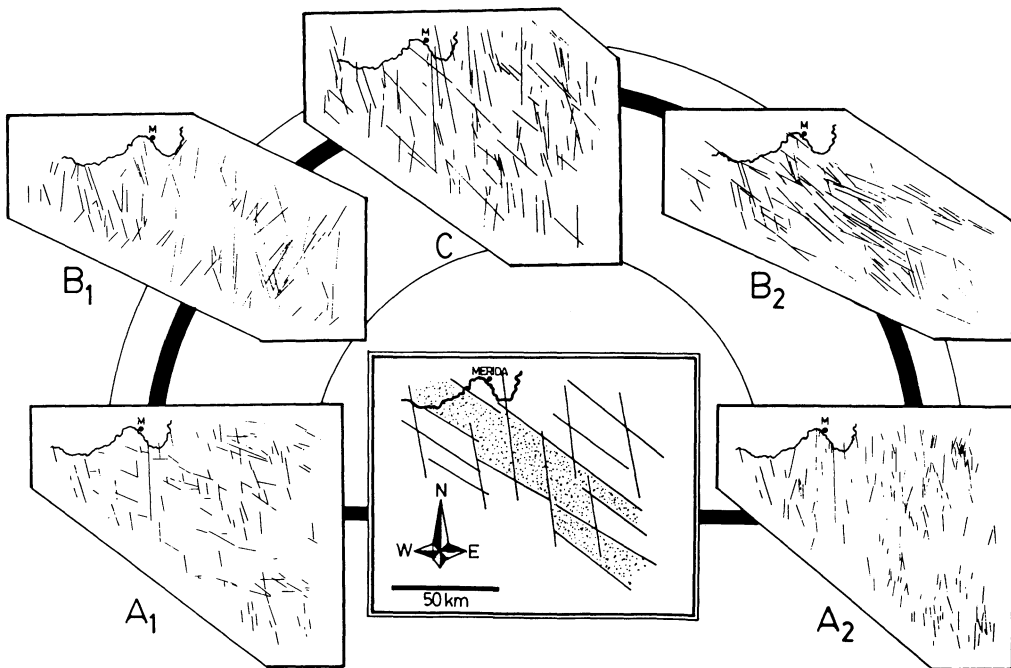
Fig. 7. Lineament arrangements based upon frameworks A (A1 and A2), B (B1 and B2) and C (C) from Fig. 2 enhancing the presence of domains separated by en area (central dotted area in the squared graph) occupied by dominantly N130E-trending lineaments.

lessening the relative frequency of the systems involved. Despite these differences induced mainly by the subjectivity of the analyst, a part of the lineament networks remains unaltered from one of them to another, this being reflected as well in the presence of orientation distribution roses with maxima in common.

From a methodological point of view, the main consequence of this study is that the consideration of the lineament networks drawn by two or more analysts lets the enhancement of the more obvious lineament systems (holding an undeniable geological meaning). The characteristics of the networks due to the subjectivity (prejudgments) of the analysts may thus be filtered and even disregarded if they are found to be unreliable.

From an applied point of view, the constitution of a lineament network and the constraints of its drawing appoint the distribution of the areas containing a high density of lineaments (by means of real or inferred lineament intersections). The resulting density contour maps are powerful devices in the plannification of, for example, mineral exploration campaigns (geochemical sampling, geophysical surveying,...) or in the location of the most adequate places for drilling. Thus, the economic relevance of the consideration of the undeniable role played by the analyst on the final results should be borne in mind in the studies of this type.

In tectonic studies the consideration of lineament frameworks drawn by different analysts usually provides additional and valuable structural the relevance, kinematic consequence and validity of which is undeniable even if the density of the field data available is not too great.

AKNOWLEDGEMENTS

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