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ANALYSIS OF LANDSAT LINEAMENTS: AN EXAMPLE APPLIED TO THE STRUCTURAL CONTROL OF MINERALIZATION AT LA CODOSERA, EXTREMADURA, SPAIN

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ABSTRACT

Methods of extracting and analysing lineaments from Landsat imagery are discussed and applied to a región of mineral exploration around La Codosera, Extremadura, W Spain. The spatial and directional features of the data are compared with ground fractures and air photograph interpretation to provide a clear picture of the fracture system. Three major sets of lineaments, trending 045°, 135° and N-S, correlate with fractures and faults at known mineral prospects.

U-P mineralization is largely confined to large 045° fractures in the Alburquerque granite and Sn, W and Li mineralization mainly occurs along both 135° and 045° fractures in its aureole. Many of the gold prospects are located in N-S to NE-SW quartz veins developed at the termination, offset or intersections of a set of NW-SE right - lateral faults which form a "dominó" system linking to the Badajoz Shear Zone. The Landsat lineament pattern provides a basis from which to identify new target areas for exploration.

Key words: Landsat TM, lineament, fracture, mineralization, Extremadura

RESUMEN

Se exponen los métodos para extraer y analizar lineamientos a partir de Imágenes Landsat, aplicándose a la investigación minera de una región, en los alrededores de La Codosera, Extremadura, España occidental. Los rasgos espaciales y direccionales de los datos se comparan con las fracturas medidas en el campo y con la interpretación de fotos aéreas con el fin de obtener un esquema del sistema de fracturación. Tres direcciones mayores de lineamientos, 045°, 135° y N-S se correlacionan con fracturas y fallas a las que se asocian indicios mineros conocidos.

Las mineralizaciones de U-P se localizan en su mayor parte en grandes fracturas de dirección 045°, en el granito de Alburquerque, mientras que las mineralizaciones de Sn, W y Li se sitúan principalmente en fracturas de direcciones 135° y 045°, en la aureola de este cuerpo intrusivo. Muchos de los indicios de Au se ubican en venas de cuarzo de direcciones N-S a NE-SO desarrolladas en las terminaciones, relevos o intersecciones de un sistema de fallas de desplazamiento dextro NO-SE que forman un sistema en "dominó", relacionado con la Zona de Cizalla de Badajoz. La distribución de los lineamientos Landsat proporciona una base para identificar nuevas áreas de interés en la exploración minera de la región.

Palabras clave: Landsat TM, lineamiento, fractura, mineralización, Extremadura

1. INTRODUCTION

Satellite remote sensing systems, such as Landsat and Spot have provided much useful data for the mapping of tectonic structures and application to mineral exploration. The purpose of this paper is to discuss a structural approach to lineament analysis and to demonstrate some applications of its use in mineral exploration in the La Codosera area, Extremadura.

The advent of multi - spectral scanners and radar systems producing digital imagery has led to an explosion of new methods of analysis. Two main features of remote sensing systems have become widely used in geological and mineral exploration:

a) Multispectral measurement of surface reflectance aims to detect anomalous spectral response from surface rock, soil or vegetacion, which can in turn be related to the underlying geology, including orebodies.Thus it is limited to the detection of near - surface targets and has proved most successful in areas with little or no vegetation or where orebodies and the underlying geology produce significant 'alteration'of surface soils and/or vegetation. The mapping of soils derived from contact metamorphic rocks around the granites of Extremadura (Rowan, et al., 1987, Anton - Pacheco, et al., 1988, this volume) provides a good example of the careful analysis necessary in areas such as Spain.

2) Gradients and discontinuities in surface reflectance define lineaments. The mapping of lineaments has traditionally utilized stereo - images derived from overlapping images; Spot offers simultaneous stereo - imaging, but Landsat and most other remote sensing systems produce limited overlap of imagery. However, the multispectral nature and digital form of much remotely sensed imagery allow computer enhancement, combination and filtering of the data offering new and challenging opportunities to those engaged in geological exploration.

2. IMAGERY AND DIGITAL PROCESSING

2.1. IMAGERY

Landsat TM imagery was selected for use in this study, because it combines a moderate spatial resolution (30 m) with geologically useful spectral characteristics. The La Codosera area is contained within a single quadrant of Landsat TM data (path 203, row 33, quadrant 2). CCTs of two cloud free images acquired on 3 August 1985 and 26 January 1986 were used, the low sun angle of the latter being useful in enhancing topographically controlled lineaments.

2.2. SPECTRAL IMAGE PROCESSING

The data were processed on GEMS image processing systems at the Ordnance Survey Remote Sensing Centre in Belfast and the National Remote Sensing Centre, Farnborough. Later work was carried out using Erdas software on a Sun/4 computer at Southampton University.

The digital data were subject to various image processing techniques (contrast stretching and band combination, principal components, rationg and spatial filtering), principally using bands 3, 4, 5 & 7. The resulting images were used to map major lineaments; interpretations of individual image extracts being combined using a band 7 base at a scale of 1:50,000.

2.3. SPATIAL FILTERING

Spatial filtering may be used to transform images and enhance directional features. However, great care is needed in the interpretation of such images, particularly in areas with "cultural" features. These tend to have high amplitude, high frequency characteristics which swamp the subtle gradients and changes in texture which characterise major structural features, and which often change along their length.

Directional or gradient filters are easily applied to digital images by convolution using n x n operators, such as the Roberts or Sobel operators. In their simplest form these operators can be used to detect gradientes in an E - W, N - S, NE - SW or NW - SE direction, but larger operators are easily rotated to other directions as required. The choice of filter size (n) can be adjusted to sample gradients of various wavelengths. Application of a single operator gives a measure of the gradient in one direction; two orthogonal filters can be used to estimate the magnitude and direction of the gradient.

Another way of combining two (or more) operators is to simultaneously display different filtered images using different colour guns of the VDU, thus combining aspects of the direction and mangitude of the images (see Sanderson 1988). The resulting image effectively colour - codes the gradients according to their direction.

Other filters may be used to detect discrete lines; these are essentially types of high - pass filters set to detect lines of predetermined orientation and width which have a linear arrangement of pixels contrasting with adjacent ones.Whilst roads, railway lines, etc. may have these properties, few geologically significant lineaments have such simple form.

3. LINEAMENT EXTRACTION AND LINEAMENT MAPS

The drawing of lineaments on images is a traditional skill of the photogeologist, but is inevitably subjective. Various attempts have been made to utilize the digital nature of satellite images in the automatic detection of such linear features. Line and gradient images provide a simple basis for the automatic extraction of lineaments, the data usually being converted to binary form by setting a threshold value and the resulting image interrogated to extract directional information (eg. Haralick 1983, Conradsen, et al. 1988). More complex linear features (circular or elliptical arcs, etc.) can be extracted using more sophisticated filtering algorithms such as the Hough transform (Cross 1988).

Although the automatic extraction of lineaments provides objective data which can be produced rapidly and cheaply, great care is needed in the interpretation of such "images". Areas containing "cultural" features such as roads, fields, etc. produce a high amplitude response to the initial directional or line enhancement and often swamp the resulting interpretation. Most geological lineaments, on the other hand, are produced by very subtle gradients and changes in texture, which may be suppressed rather than enhanced by such filters. Larger geological faults are often more obvious as lineaments across which higher - frequency variations, produced by smaller fractures, bedding, etc. and even changes in field pattern and landuse, are discontinuous. The detection of such features would require very complex filtering, probably combined with artificial intelligence algorithms.

In this study image processing was used to generate a variety of images for interpretation but all lineaments were extracted visually by geologists. The separation of structural features from other geological and cultural lineaments is probably best tackled by the analyst on a subjective basis during image interpretation.

3.1. LINEAMENT MAPS

Lineament maps were digitized on a TDS digitizing table linked to an IBM PS/2, using software developed by Sanderson at Queen's University, Belfast and the University of Southampton. The data are stored on disk ready for input into plotting and processing programs. In this study all data were transformed into UTM coordinates by matching control points on the imagery and maps.

Maps of lineaments often appear as a confused (and confusing?) array of lines. To use such maps for structural analysis we must first ask the question - is the lineament map a reasonable representation of the underlying fracture system? There are several possible ways to investigate this question and these are discussed more fully in later.

4. STRUCTURALLY CONTROLLED PROCESSING

Lineament data have scalar (length), directional and spatial information, and these features require different, but interdependent, forms of analysis. Structurally Controlled Processing was developed by Sanderson & Dolan (1986) as part of EEC funded research into the use of remote sensing in the raw materials programme. Basically it consists of a package of computer programmes, written for IBM PS/2 microcomputers, to facilitate, the manipulation and display of the directional and spatial attributes of lineament data. The programs allow plotting, georeferencing, directional filtering, etc. of lineaments and the generation of maps of the following measures:

Rose-diagrams for areas or sub - areas give an effective display of the main sets of lineaments.

Frequency & Density maps calculate the total number (frequency) or lenght (density) of lineaments in a grid cell. Many authors (eg. Wheeler & Dixon 1980) have recognised an increase in fracture density in fault zones, but occasional studies claim the inverse relationship. With remotley sensed lineaments, density is not simply related to degree of fracturing and much variation can be attributed to changes in the nature of the land surface (eg. overburden thickness, forestation, etc.).

Directional Filtering involves the separation of lineaments on the basis of their orientation and may involve the inclusion or exclusion of one or more ranges of directions.The display of filtered data and/or the colour of various directions can be used to simplify the lineament data and search for patterns of individual directional modes.

Directional Frequency and Density refer to the number or length of lineaments within a pre - defined range of orientations. This measure can be used to filter out certain ranges of lineament orientations and to examine their spatial abundance.

Directional Dominance measures the proportion (porcentage) of lineaments within pre-defined orientation limits in relation to the total in a sample cell. Directional dominance maps are useful in delimiting zones of differing fracture pattern. An interesting variant of dominance is **Angular Atipicality** (Pretorius & Partridge 1974) where the anomalous areas with a high proportion of lineaments not belonging to prominent regional trends often correspond to geological targets.

Randomness can be expressed by various measures (eg. Relative Entropy and χ^2/n), which are generally very sensitive to the number of directional classes used. Changes in randomness can be related to the development of fracture patterns associated with faults, etc.

Mean Orientation of lineament sets can be calculated by vector addition and anomalous regions found. Rotation in the proximity of major wrench faults and shear zones has been recognised in many studies (eg. Carter & Moore 1978). Where many sets of lineaments exist mean orientations of individual sets (Group Means) can be obtained after directional filtering.

A common problem with many of these measures is that the small grid cells (1-5 km square) used to detect high-frequency anomalies often contain too few lineaments to yield statistically significant results. Various smoothing and filtering techniques may be applied to reduce this problem. 3 x 3 low - pass filters have been found particularly useful in increasing the effective sample size whilst maintaining a reasonable spatial resolution. Filtering methods must combine the data from adjoining grid cells and not simply operate on derived parameters, since the adjoining cells generally contain differing amounts of data.

The ability of Structurally Controlled Processing to reduce complex lineament patterns to scalar measures of a wide range of attributes can greatly facilitate structural interpretation. The resulting maps allow recognition of structural patterns and domains, can be used to test geological hypotheses and allow detection of faults, shear zones and their terminations, offsets and bends. Zones previously known from ground structural work can be mapped into poorly exposed areas and their margins and terminations delineated more accurately.

5. LINEAMENT ANALYSIS OF TM IMAGERY FROM LA CODOSERA

The distribution and angular relationships of lineaments mapped from various enhancements of TM data in the La Codosera area is shown in Fig. 1. The data can be divided into three clearly defined sets trending 045°, 135° and N-S (Table 1), with most lineaments being easily assigned to one of these three sets, which contain similar numbers of lineaments.

TABLE 1

Summary of TM lineaments, La Codosera area, W. Spain

Set	Mode	Range	%
1	045°	025 - 065	31.5
2	135°	115 - 165	26.6
3	005°	165 - 025	28.4

The pattern of lineaments is fairly constant throughout the area, but with some local variation in the proportions within each of the three sets. This is fairly clear from the rose diagrams constructed for 5 x 5 square blocks (Fig. 2). This spatial distribution of lineaments will be discussed later.

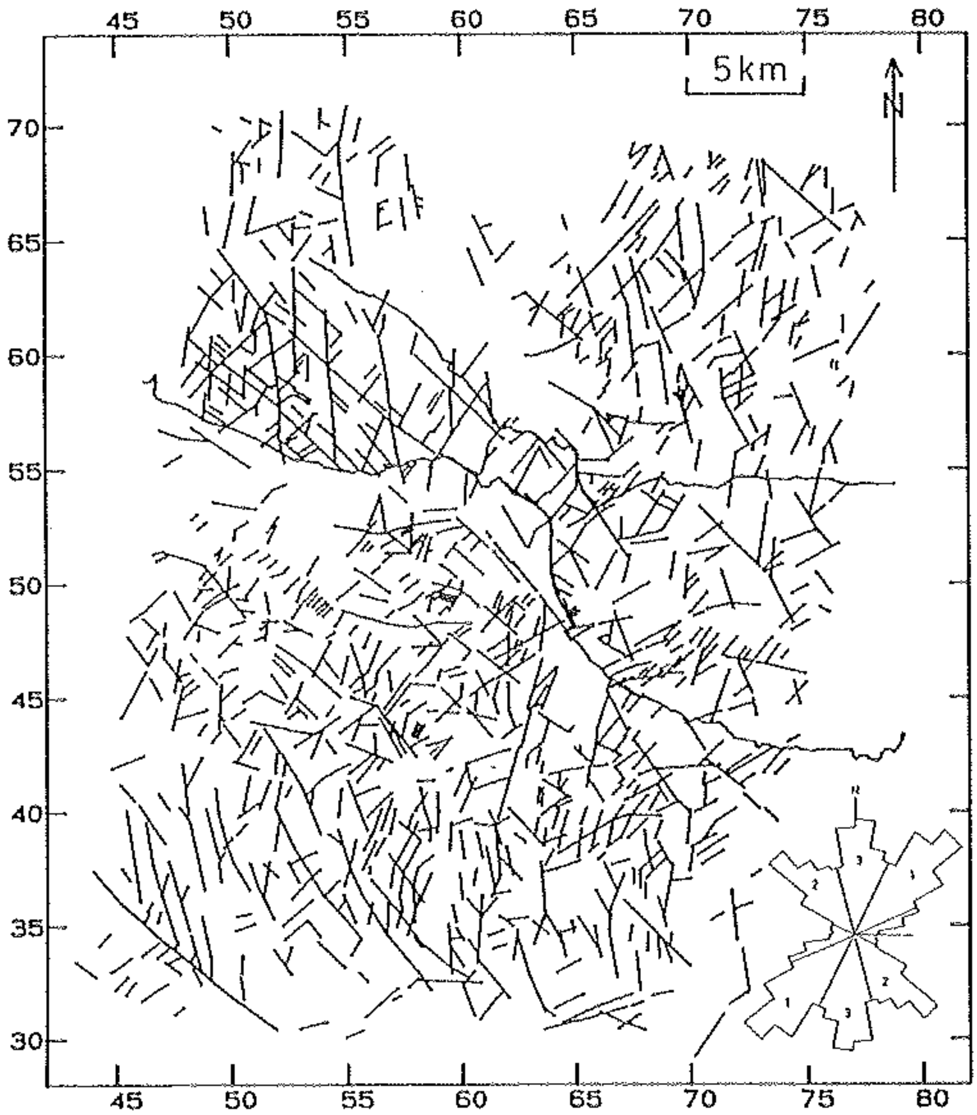

Figure 1.— Lineament map of the La Codosera area based on interpretation of Landsat TM imagery. Inset: rose diagram of lenght - weighted lineaments.

6. RELATIONSHIP BETWEEN LINEAMENTS AND FRACTURES

6.1. REGIONAL FRACTURE SURVEY

Over 1500 fractures were measured at various sites distributed within three main units: the Precambrian Complejo Esquisto - Grauvaquico (CEG), Palaeozoic metasediments and Alburquerque batholith.Due to the fairly homogeneous nature of the latter unit a more intensive study of granite fracturing has been carried out, details of which are summarized separately below, but the data is included in the regional fracture survey.

The fracture system comprises three clearly defined sets (Table 2, Fig. 3). The most dominant set trends approximately NE-SW and detailed studies demonstrate that it is made up of three distintc sub -sets with modal orientations of 020°, 040° and 065°. These fractures generally form barren quartz veins and are widely developed in both the granite and country rocks. A widely developed, although generally less dominant, set of fractures trend 165°. A less dominant, but clearly developed set of fractures trending 135° is found in all units, but is best developed in the granite.

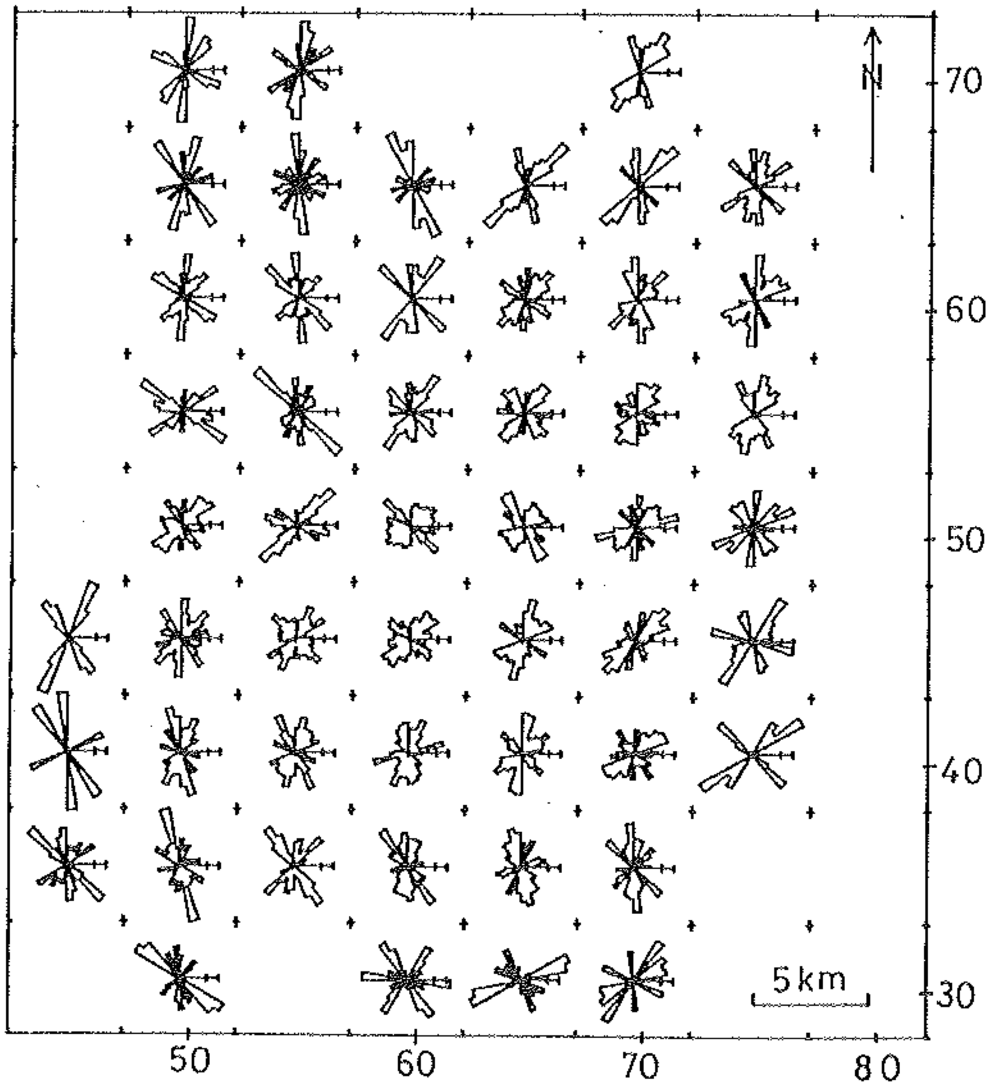

Figure 2.— Rose diagrams of Landsat TM lineaments for 5 x 5 Km sub - areas within the La Codosera area.

TABLE 2

Summary of the fracture sets sampled in ground surveys in the La Codosera area

Set	Mode	Range	Comments
NE-SW	020° 040° 065°	010 - 075	Dominant sets in both granite and country rocks
N-S	165° 105°	150 - 000 090 - 120	Minor set in granite and country rocks Subsidiary set in granite
NW-SE	135°	115 - 165	Well developed in granite but scarce in country rocks

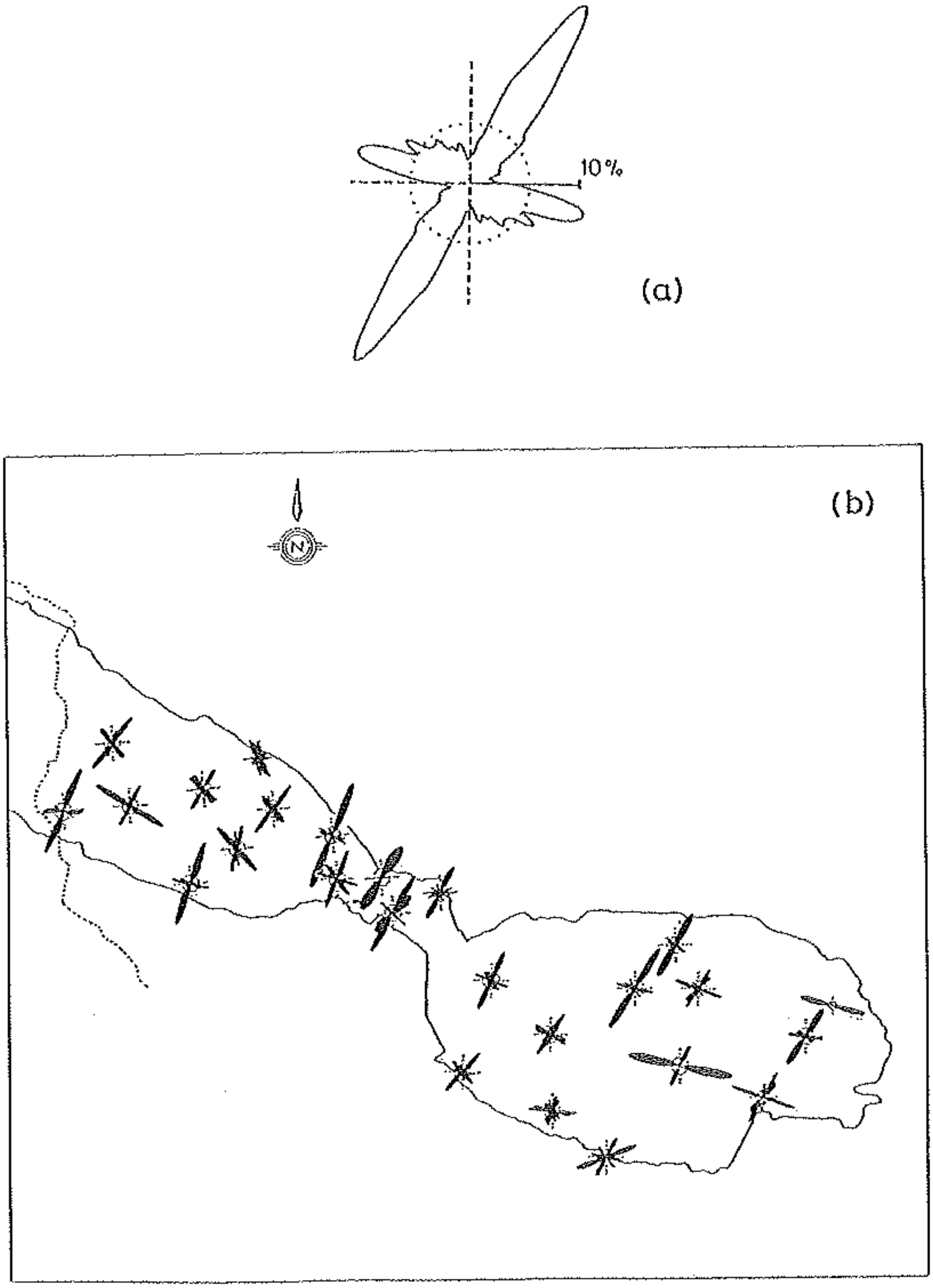

Figure 3. (a) Rose diagram of fractures measured at various sites within the La Codosera area.

(b) Rose diagrams of fractures measured at individual sites in and around the Alburquerque granite.

The good correspondence between the orientations of fractures and lineaments is apparent in Fig. 3a and this strongly supports a link between the two features. In studies of this sort one generally finds a good correlation between these data, but differences may arise through inclusion of other features in the lineament data, eg. bedding traces, etc.. In the present study care was taken to exclude bedding, particularly the prominent traces of the quartzite units.

Most of the fractures measured on the ground were extensión fractures and veins which need not always correspond to the trends of larger faults, the former usually representing extensional fractures, whilst the latter are zones of shearing often reactivated in several stress systems.

6.2. FRACTURING IN ALBURQUERQUE BATHOLITH

We have been investigating the ability of different sensing systems to sample fracture patterns in the Alburquerque batholith (Chinn and Sanderson, unpublished work). The sensing systems used were Landsat TM (generally reproduced at scale between 1:50,000 and 1:100,000), air photographs at a scale of 1:18,000 and outcrop mapping and measurement of fractures. The granite was chosen for this study because it represents a fairly homogeneous material within which fracturing has produced lineaments detectable at a wide range of scales. In addition the Alburquerque batholith, particularly to the west of San Vicente, is relatively free from other sources of lineaments, both geological (absence of bedding,, etc.) an cultural (few roads, field boundaries, etc).

For this study a total of 2681 fractures were measured at approximately 70 sites (average 38 fractures per site) arranged fairly evenly across the area (Fig. 3b). As most of the fractures are steeply inclined they may be represented by rose diagrams, which also facilitate comparison with remotely sensed lineaments. Summary diagrams of the fracture data show a dominance of NW-SE and NE-SW sets, with occasional N-S and WSW-ENE fractures; these correspond to the regionally developed fracture orientations (Table 2), a data set which also includes sites within the granite.

Air photographs covering c.350 km^2 at a scale 1:18,000 were examined stereoscopically and some 3000 lineaments extracted. These are mostly short (< 1 km) and form two prominent sets of fractures trending NE-SW (40°) and NW-SE (135°) (Fig. 4). The dominance of each set varies across the batholith, but their orientations remain very constant.

Sub-sets of lineaments interpreted from Landsat TM imagery covering the granite areas between Alburquerque and Valencia de Alcantara show the same modal orientations of 040°, 135° and N-S (Fig. 5). These are similar to those obtained in the regional study (Table 1), supporting the view that most of the fracturing post-dates granite intrusion.

In addition to these data, the drainage within the granite was digitized, and also the granite margin. These data indicate a close correspondende between TM lineaments and drainage, whereas the granite margin mainly follows E-W to WSW-ENE trends (Fig. 6). These observations strongly support an early (pre-granite) origin for E-W and WSW-ENE structures and a late (post-granite) origin for the other fractures. These conclusions are consistent with other geological evidence.

The various data sets allow us to evaluate the different characteristics of the fracture system recorded by the different sampling techniques. The conclusions of this analysis are summarized in Table 3.

These results confirm the conclusions of Sanderson & Dolan (1986), that the lenght of lineaments detected by various sensing systems is broadly related to the resolution of the system, the scale at which the imagery is analyzed, and the experience and objectives of the analyst.

Another approach to comparing lineaments and ground fracture patterns is to examine the spatial architecture of these data. Figure 7 shows schematically the fracture pattern deduced by different sensing systems. At all levels fractures sets abut and offsets one another, with relatively few cross-cutting set. Additional patterns include branching, offset and en echelon patterns. Similar architectures are seen in detailed maps of fault patterns especially in areas of extensive mining where faults many be traced in detail. We conclude that the more random, criss-crossing patterns of lineaments seen in some studies may be poor representations of the ground structure.

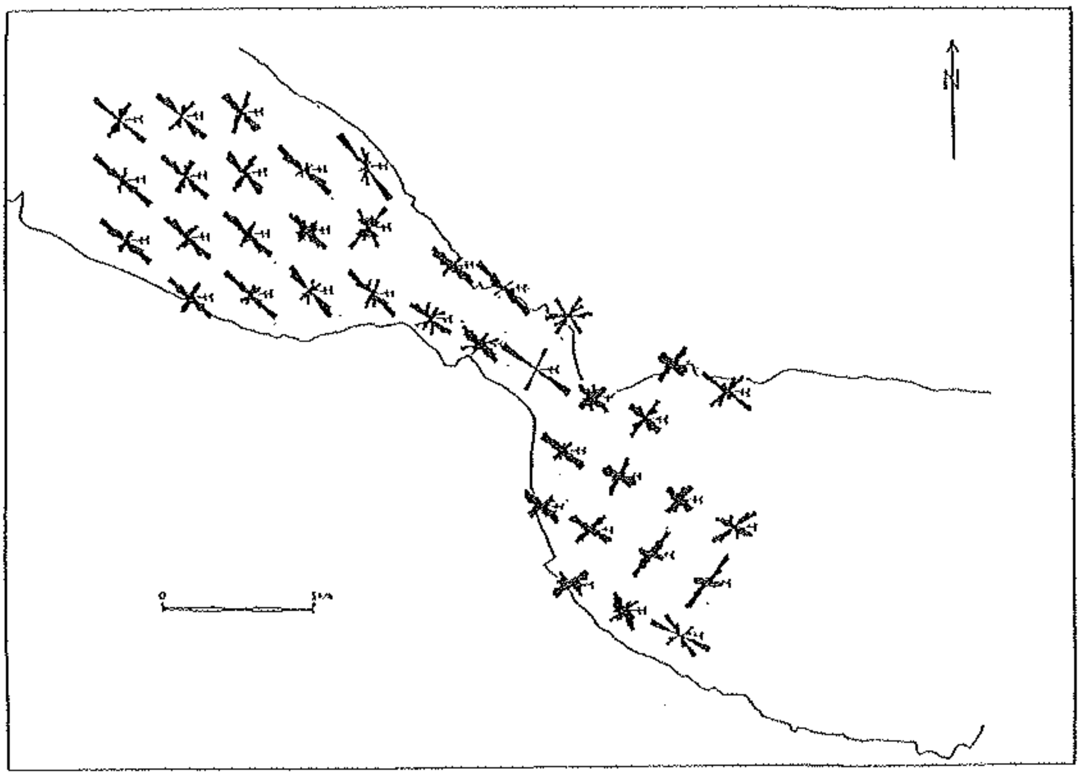

Figure 4.— Rose diagrams of lineaments interpreted from aerial photographs summarized for 2 x 2 km sub-areas.

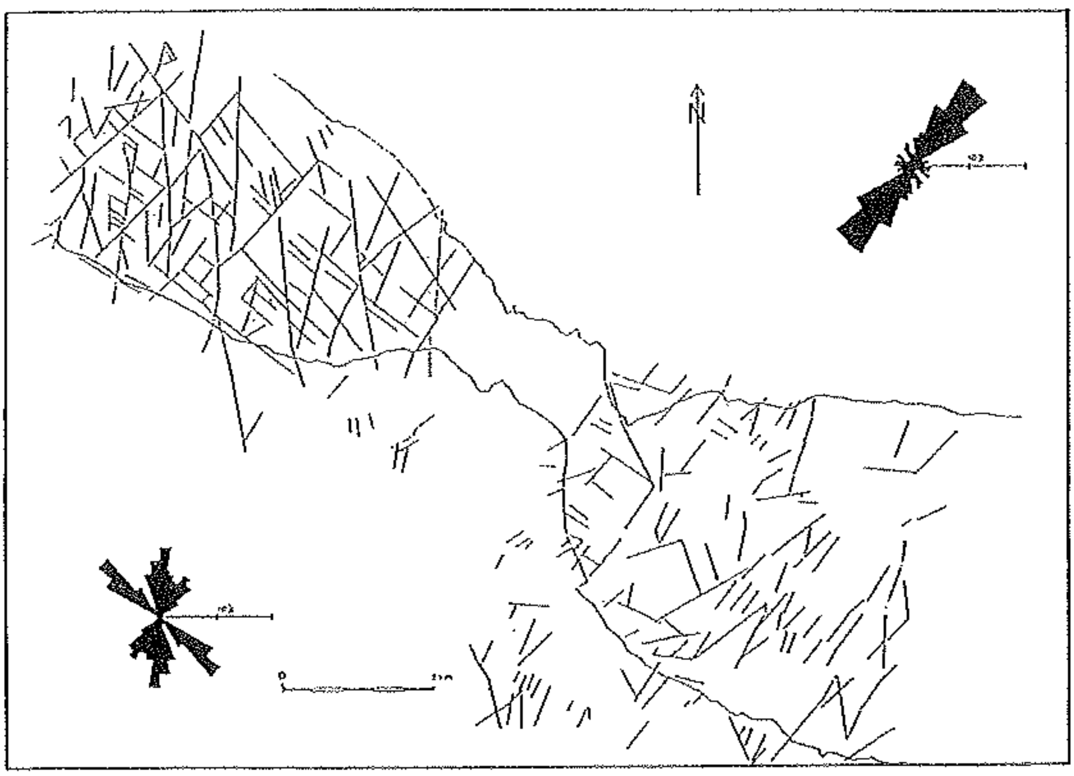

Figure 5.— Landsat TM lineaments within the Alburquerque granite. Rose diagrams summarize data from the Valencia de Alcantara (bottom - left) and Alburquerque (top - right) sub - areas.

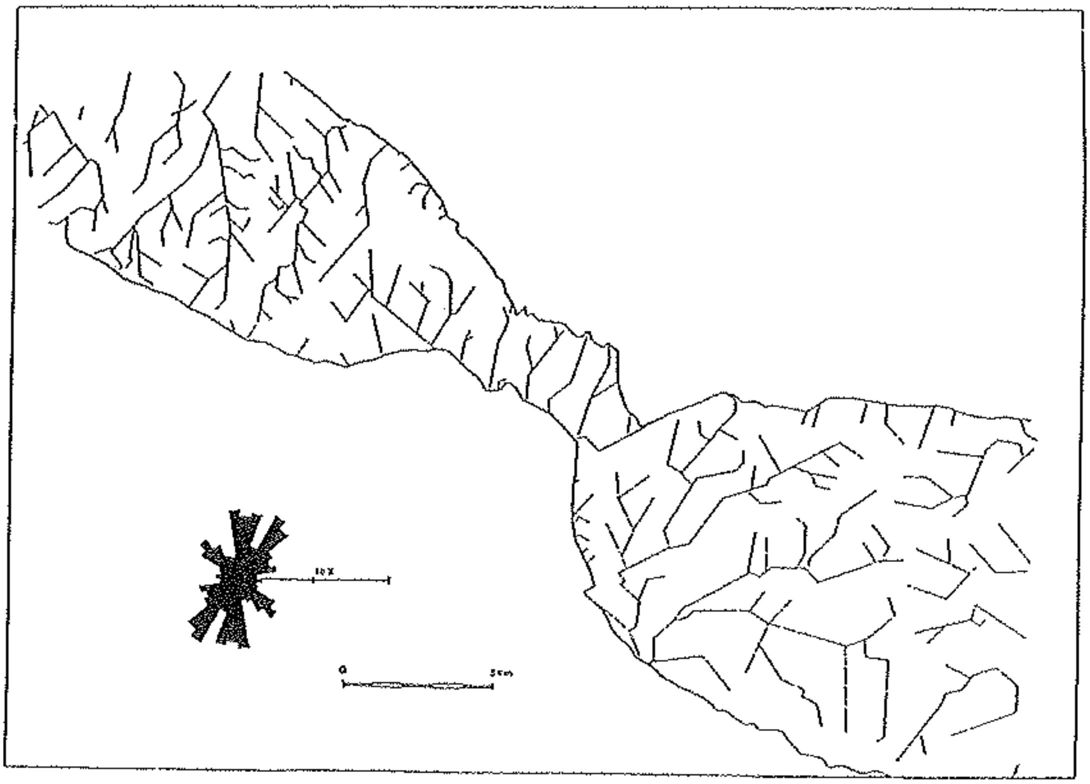

Figure 6.— Stylized drainage within the Alburquerque granite, derived by linearization of mapped streams.

TABLA 3

Summary of characteristc of fractures in the Alburquerque Batholith sampled by different sensing systems

Character	TM	Air photo	Ground
NE-SW set	Abundant	Abundant	Abundant
N-S set	Abundant	Absent	Weak
NW-SE set	Abundant	Dominant	Abundant
Length	10^{2}-10^{4}	10^{1}-10^{3}	10^{-2}-10^{2}
Width	10^{1}-10^{2}	10^{0}-10^{1}	10^{-3}-10^{0}
Within site variability	High	Low	High
Between site variability	Moderate	Low	High
Resolution	30 m	< 5 m	< 1 mm

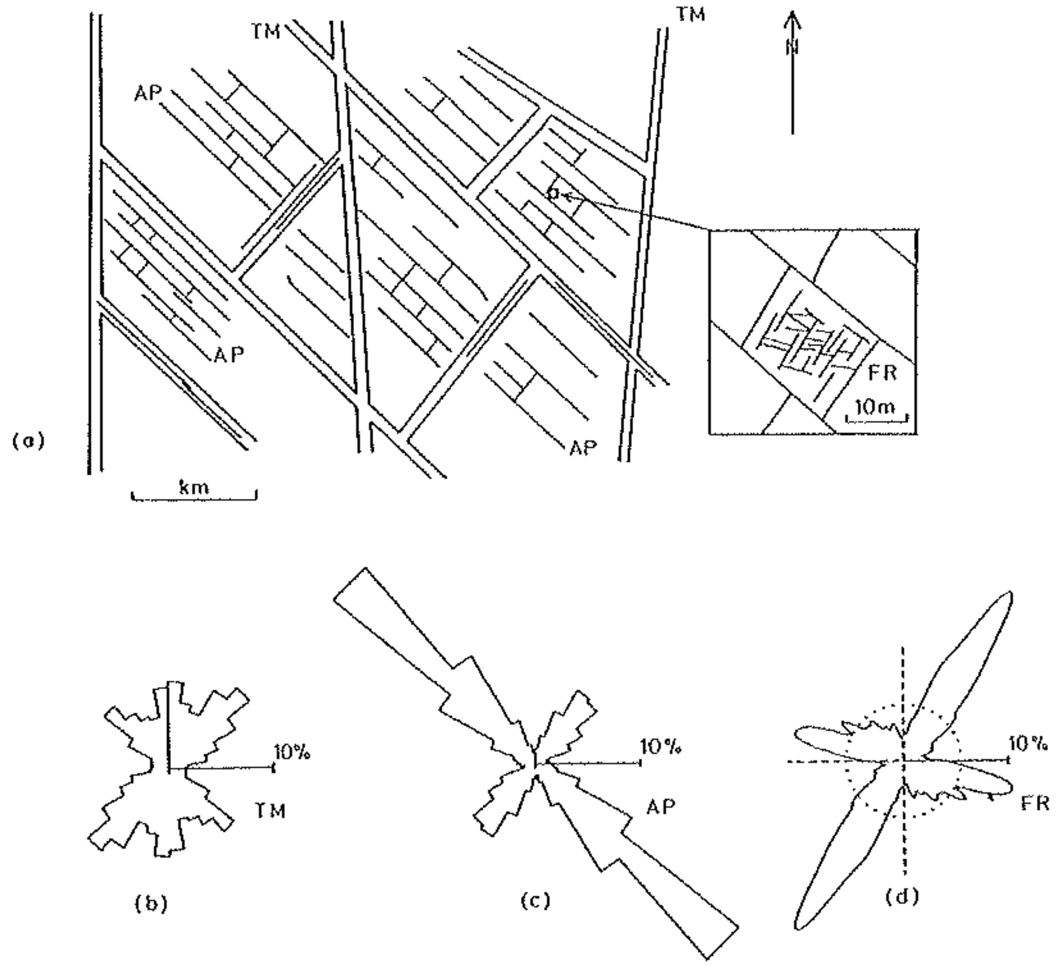

Figure 7.— (a) Schematic representation of the architecture of lineaments mapped from sensors of differing resolution. Rose diagrams of (b) Landsat TM, (c) air photograph and (d) ground fracture measurements.

The Alburquerque experiment has shown that fracture patterns sampled by different sensing systems are not scale invariant (ie. not self-similar), thus, suggesting that it is important to select the appropriate system to locate the required scale of lineament targets. For example, ground mapping might be the most appropriate method to investigate the role of fractures in small -scale engineering projects or in localizing mineralization within a mine, but satellite lineaments might be more significant in the location of major faults and fracture zones for earthquake, risk, hydrological studies, waste disposal, etc. and in the location of major mineral prospects within an area.

7. SPATIAL ANALYSIS OF LINEAMENTS

In general individual lineaments are easily assigned to one of the three main sets and for structurally controlled processing ranges specified in Table 1 have been used to sub-divide the data.

7.1. DENSITY

The density map (Fig. 8b), calculated for a 3 x 3 moving window, shows a fairly even spread of lineaments throughout the area, with highest values within the granite to the south of Valencia de Alcantara. Other patches of high density are developed sporadically in the country rocks.

7.2. DIRECTIONAL DENSITY AND DOMINANCE

By assigning lineaments to one of the three main sets (Table 1) it is possible to examine the directional density of each. Since almost all (c.87%) are assigned to one of the three sets, these maps have strong internal correlations. For example, within the fairly uniform densities of the CEG any region of high density of one set is likely to have low density for one or both of the other sets. This internal correlation becomes more acute in the dominance maps, where the closure forces many negative correlations.

The 135° lineament set includes several long lineaments, well developed within the western part of the granite and in the Badajoz Shear Zone (Fig. 9a). In the latter area they dominate the lineament pattern and are clearly related to faults which offset the quartzites of the Southern Ridge.

The directional density of the N-S lineaments (Fig. 10a) is highest in the western part of the granite, around Valencia de Alcantara, and in the southern part of the area, where this set dominates the lineament pattern in parts of the Southern Ridge and the Badajoz Shear Zone (Fig. 10b).

The NE-SW lineaments are fairly evenly developed throughout the area, being locally dominant in the Central Ridge and in the granite to the NW of Alburquerque (Fig. 11).

A general feature of the La Codosera area is that the three sets of lineaments have a widespread development throughout the different rock units. This is clear from the directional density and dominance maps as well as from the lineament map itself (Fig. 1) and the rose diagrams for sub-areas (Fig. 2). Thus we can conclude that the lineament pattern has a strong directional anisotropy, with three clearly defined sets, but a poor spatial variability. This in turn supports the view that the pattern was largely developed after the emplacement of the Alburquerque batholith.

8. USE OF LINEAMENT MAPS AS AND AID TO MINERAL EXPLORATION

The La Codosera area was suject to transpressional Hercynian deformation (Sanderson et al. in press), followed by granite plutonism and late (domino - style) faulting, with continued Mesozoic and Tertiary fracturing.

Using the Landsat data, combined with the ground structure, air photograph interpretation and gravity data, a clear picture of the fracture system has emerged. Three major sets of lineaments trend 045°, 135° and N-S (fig. 1) and these correlate well with extensional fractures, including those at known mineral prospects. In addition it has been possible to correlate Landsat lineaments with knwon faults in many parts of the area, particularly in the Southern Ridge. Thus the lineament analysis provides a useful dataset with which to augment the regional structural studies.

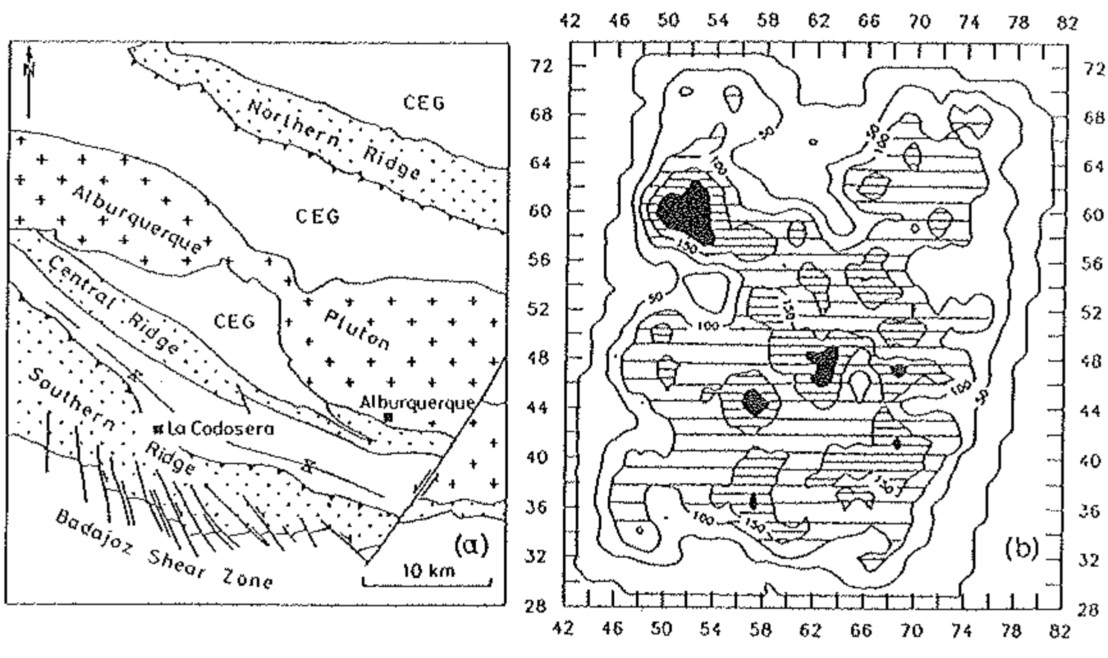

Figure 8.— (a) Outline geology of the La Codosera area, to same scale as density and dominance maps in Figs. 8b to 11.
(b) Density map of Landsat TM lineaments.

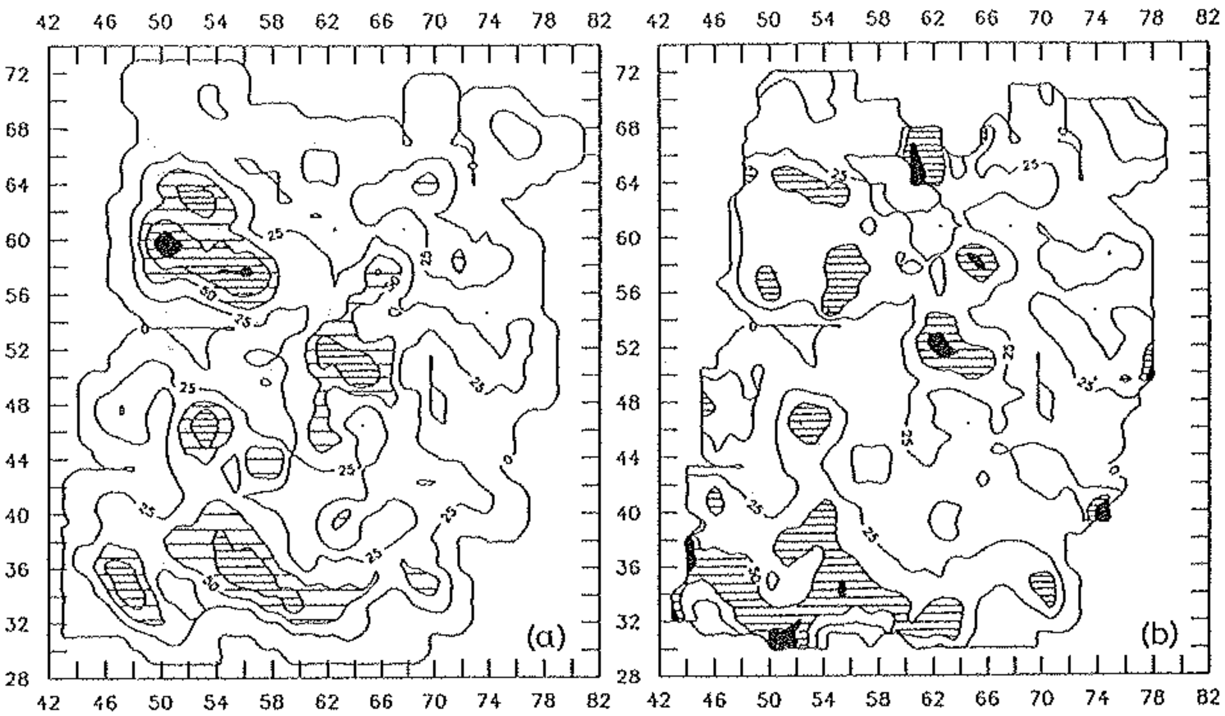

Figure 9.— Directional density (a) and dominance (b) maps of the 135° (115°-165°) lineament set.

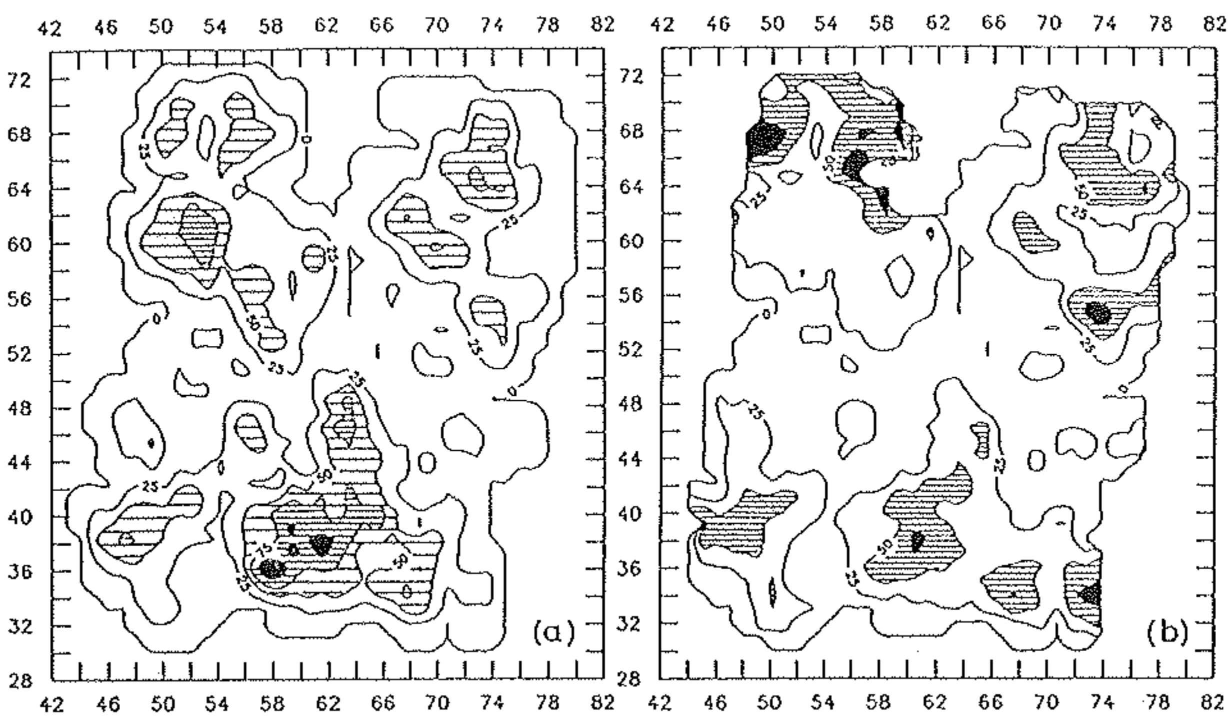

Figure 10— Directional density (a) and dominance (b) maps of the N-S (165°-025°) lineament set.

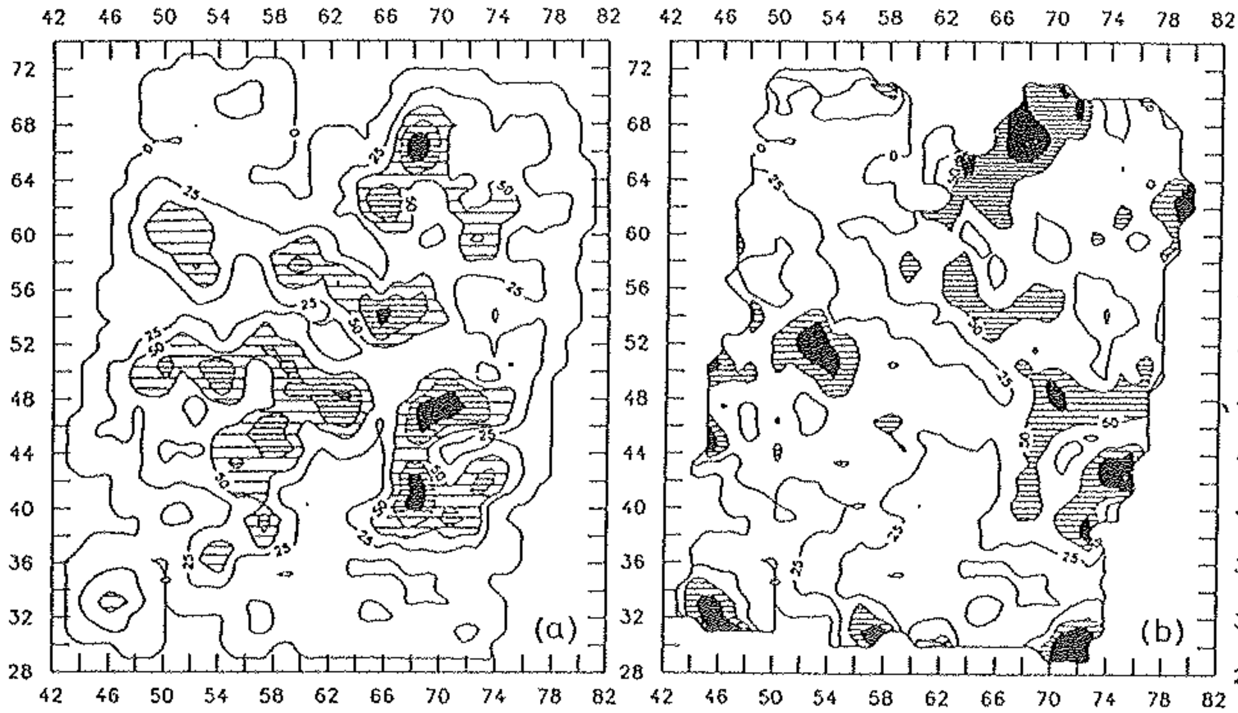

Figure 11.— Directional density (a) and dominance (b) maps of the NE-SW (025°-065°) lineament set.

In order to convert these data into viable exploration models it is necessary to understand and relate the nature and kinematics of the fracture control to the mineralization. Only then can full use be made of the mapping availabe from Landsat imagery, through the lineament map its self and the maps of density and dominance, as a basis for the definition of exploration targets.

8.1. U-P MINERALIZATION WITHIN THE GRANITE

Known U-P mineralization in largely confined to large 045° fractures, with vuggy and brecciated veins containing quartz, chalcedony, apatite, pitchblende, pyrite, etc.. Evidence from old U workings to the north of Alburquerque suggests that these veins form in arrays along 030° and 065° lineaments, many of which may be identified from Landsat. These lineaments would represent brittle transtensional shear zones with dextral and sinistral movement respectively. More work is needed to fully define this pattern, using both the ground mapping of fracture zones and air photograph interpretation. Initial results indicate a high dominance of NE-SW lineaments may be a guide to U prospectivity.

8.2. SN-W AND Li PROSPECTS

These mainly occur in the aureole of the Alburquerque granite and are located along both 135° and 045° fractures. There is some correlation between areas of high dominance of 045° + 135° lineaments (and hence low dominance of N-S lineaments - see Fig. 10) and the Sn-W mineralization within the granite aureole. The Lithium workings at Tres Arroyos also show the same correlation.

8.3. GOLD PROSPECTS IN THE CENTRAL RIDGE

The Central Ridge shows a fairly high proportion of 045° lineaments, but on the ground fractures of this trend tend to be barren. Several E-W lineaments cut the Central Ridge and appear to correspond with know mineral prospects of this trend.

8.4. GOLD AND ANTIMONY PROSPECTS IN THE SOUTHERN RIDGE

In the Los Algarbes area, the main prospects lie on steep N-S to NE-SW veins developed as extensional fractures with some left-lateral reactivation, sited at the terminations of the larger NE-SW faults. These major fracture zones (lineaments) provide connectivity between the shear zone and the Southern Ridge of Palaeozoic rocks which host the main Au-Sb mineralization.

Based on detailed observation of the structural setting of veins and investigation of their geochemistry and fluid characteristics, we have recognised a number of prospective settings (Fig. 12). The gold-bearing veins generally occupy N-S to NE-SW trending extensión fractures developed at the terminations (Fig. 12a) or offsets (Fig. 12b) of major NW-SE trending faults or where dilation was produced at intersections of these with their conjugate (NE-SW) set (Fig. 12c).

The NW-SE faults have a right - lateral component of slip and form part of an extensive "bookshelf" of "domino" system linking the Southern Ridge to the Badajoz Shear Zone. Maximum dilation will occur where the domino faults change orientation or have large displacement. It is significant that the main area of old Au workings at Los Algarbes occurs at the northwestern end of the main change in orientation of the domino faults and that the San Antonio antimony mine occurs at the NW extension of a large displacemente fault (Fig. 13). Using the known structural controls, the lineament map provides a basis from which to identify new target areas which show abundant N-S to NE-SW fracturing in a similar structural setting (Fig. 13). Recent drilling carried out by ITGE at Los Algarbes is within one of the proposed target areas and confirms that the gold is associated with NNE trending extensión veins, possibly developed as pinnates to a NE-SW fault, conjugate to the main NW-SE "feeder" faults.

This study has demonstrated a strong structural control to the mineralization of the La Codosera area. An understanding of the kinematics of these structures and the nature of the mineralizing fluid then allows exploration models to be developed. Remotely sensed data from Landsat TM, when combined with a good ground control can then be used to systematically define prospective targets. Thus remote sensing can provide a cheap and efficient way of mapping fracture systems and selecting targets for further exploration.

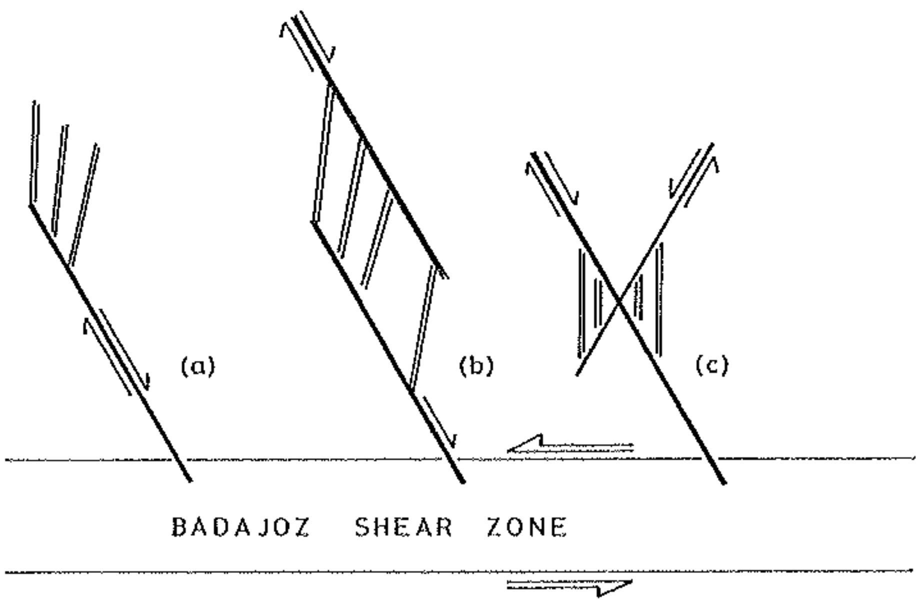

Figure 12.— Target types recognised in the Southern Ridge at (a) terminations and (b) offsets of NW-SE faults and (c) at dilational areas of intersecting faults.

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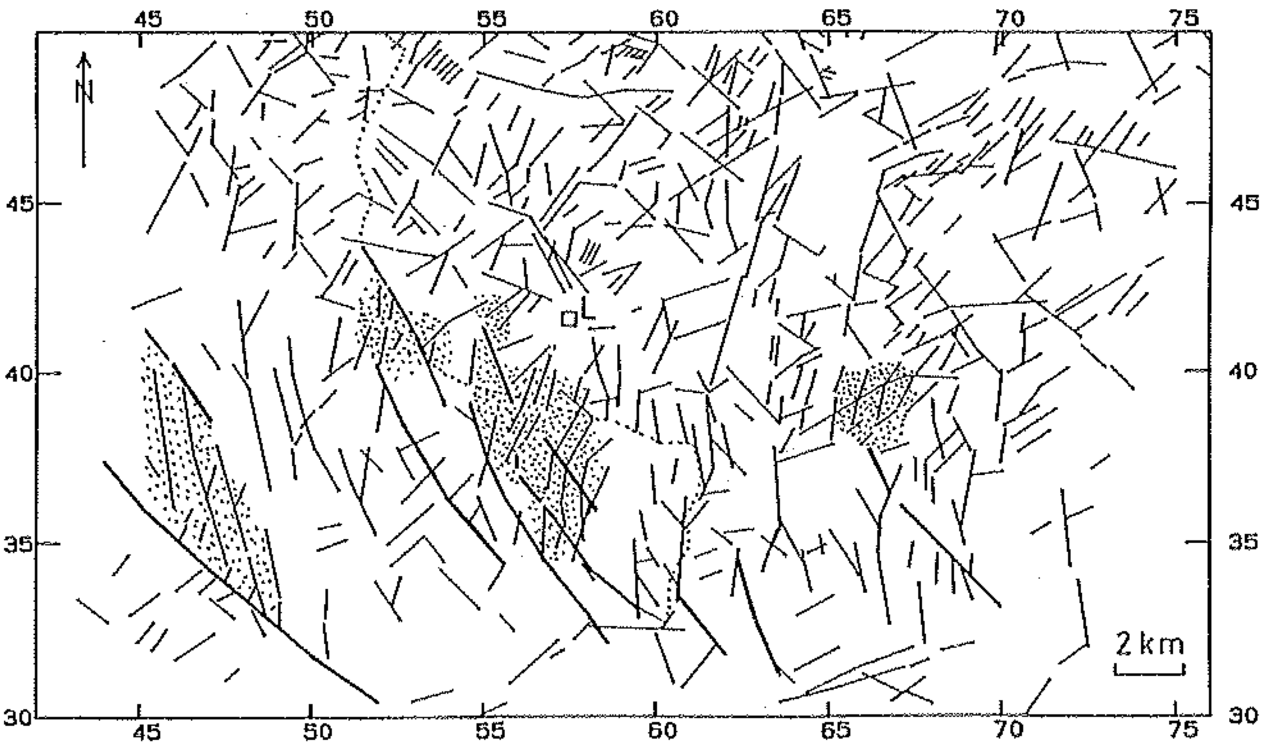

Figure 13.— Landsat TM lineament map of the southern part of the La Codosera area. Large NW-SE lineaments represent faults connecting the Southern Ridge to the Badajoz Shear Zone, which feed N-S to NE-SW extension fractures. Shading shows target areas based on the patterns in Fig. 12.

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