Estudios geol., 45: 361-367 (1989)

LINEAMENT ANALYSIS ON LANDSAT IMAGERY IN THE CENTRAL BADAJOZ-CORDOBA SHEAR ZONE. ARGUMENTS FOR BRITTLE STAIN PARTITIONING AND BLOCK ROTATION UNDER TRANSPRESSION

B. Abalos*, R. Ramón-Lluch* y L. M. Martínez-Torres*

RESUMEN

Se realiza un estudio estadístico de los tecto-lineamientos observados por tres analistas diferentes sobre una fotografía de satélite de la porción central de la Zona de Cizalla de Badajoz-Córdoba (Macizo Ibérico Meridional). Los resultados alcanzados permiten establecer la presencia de dos dominios estructurales separados entre sí por una banda central que coincide con el afloramiento de las rocas más metamórficas de la Zona de Cizalla. Cada uno de estos tres dominios tiene una distribución particular de lineamientos estructurales, explicándose el conjunto en el marco de un cizallamiento sinistroso en régimen transpresivo en una banda que se ajusta bastante a la distribución conocida para ese área de fallas y accidentes tardi-hercínicos de desgarre y a la posición de una anomalía gravimétrica de Bouguer.

Palabras clave: *teledetección, lineamientos, cizalla, transpresión, zona de Cizalla de Badajoz-Córdoba.*

ABSTRACT

In the present work we deal with the statistical study of the lineaments drawn by three different analysts on the same LANDSAT image on a geologically well-known portion of the southern Iberian Massif: the Badajoz-Córdoba Shear Zone. The results obtained let us establish the presence of two structural domains separated by a central band coinciding with the outcrop of the most metamorphic rocks of the central Badajoz-Córdoba Shear Zone. Each of these domains hold a distinctive lineament distribution arrangement, the whole being ascribable to a scheme of transpressive sinistral shearing within a band which rather fits a Bouguer gravity anomaly and a set of late-hercynian wrench faults.

Key words: *remote sensing, lineaments, shearing, transpression, Badajoz-Córdoba Shear zone.*

Introduction. Remotely-sensed lineaments: Applications and constraints

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 (Antón-Pacheco & Sanderson, 1989; Martínez-Alonso *et al.,* 1989; Tsombos & Kalogeropoulos, 1989; Widdowson, 1989) and groundwater exploration (Sanz 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 *et al.,* 1985). As a consequence of this, the lineament tectonics rises as an independent branch of Structural Geology and Geotectonics in which consideration is given to the structural lineament analysis of ancient and modern mountain belts, platforms, sedimentary basins, as well as to the lineament genesis

---

* Departamento Estratigrafía, Geodinámica y Paleontología, Universidad del País Vasco. Apdo. 644, 48080 Bilbao, Spain.

and its relationships to the characteristics and annomalies 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 lineament swarms rather than individual lines, and the rejection of some linear elements while others are combined into lineament zones or lineament frameworks. The interpretation of lineaments is based on the spatial 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 object, generating the remote-sensing image from the better known to the less studied areas (Trofimov, 1985).

The detection of lineaments holds a series of scarcity sources, a group of image features (such as spectral range of wavelength, illumination angle or restitution) as well as environmental (point of observation, quality of lightning) or psicological conditions (optical illusions, knowledge of the studied area, prejudgments) should be considered as a cause of scattering in the studies of this type (Farrow, 1975). Moreover, every analyst holds its own way of photointerpretation, and this constitutes an additional source of scatter. As a consequence of all this, bearing in mind the influence of the so-called «human component» on photointerpretation, three different analysts have performed a statistical study of photolines on a geologically well known area of the Iberian Massif: the Badajoz-Córdoba Shear Zone. This area occupies most of the central part of the picture 25DEC81 2-218-33 7 01 1143-1800 A 06MAY85 processed by TELESPAZIO for ESA-EARTHNET.

The aim of this paper is to contribute to the knowledge of the Badajoz-Córdoba Shear Zone in order to ascertain either the presence of fault-bounded blocks, the characteristics of the relations between late-hercynian faulting and remotely sensed lineaments, and the tectonic regime involved in the variscan orogenic closing-stages.

Geological features of the study area

As it was pointed above, the study area constitutes (fig. 1; fault distribution taken from Apalategui & Higueras, 1983; Apalategui *et al.*, 1983; Arriola *et al.*, 1983 and Odriozola *et al.*, 1983) the central part of the Badajoz-Córdoba Shear Zone, which is located within the Hercynian Iberian Massif to the SW of the Iberian Peninsula. 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 (García-Casquero *et al.*, 1985 and 1988; Quesada, 1989; Shafer *et al.*, 1989). The different episodes involved initial eclogitic metamorphism (Abalos & Gil Ibarguchi, 1989) and large scale thrusting followed by an extensional tectonic regime during Lower Paleozoic times, and then a major transpressive sinistral evolution from ductile (Abalos, 1989) through brittle conditions. The latter episode masks all the previous structures (as shown in the Upper Paleozoic fault distribution map from fig. 1) and imprints the characteristics of a sinistral intracontinental shear zone to the whole area (Arthaud & Matte, 1975 y 1977).

Fault distribution and the lineament analysis

The roses of lineament orientation distribution maxima shown in fig. 2 have been constructed from the fault distribution shown in fig. 1. They correspond to 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, may be used here to ascertain either the main fault systems involved (rose C) and 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.

The most obvious and widespread fault system is the N120-130E, either to the NE and SW of the fault boundary between the Ossa-Morena and Central-Iberian Zones. The faults of this system are Lower Paleozoic thrusts separating tectonic units with associated normal or inverted metamorphic jumps. These faults are reactivated during a sinistral wrenching episode during Lower Carboniferous times, and are cross-cut by broadly E-W sinistral faults (N90E system) and N-S (systems N20E and N170E) apparently dextral faults. The latter are common in a NW-SE-trending band at the central area of fig. 1, and cross-cut the Lower Carboniferous materials of the Matachel Basin. NE-SW systems occur as minor faults all over the studied area but, from cartographic evidences, they do not seem to play a significative role.

The lineament frameworks of the analysts A (R.R.LL.; label A in fig. 3), B (B.A.; label B) and C

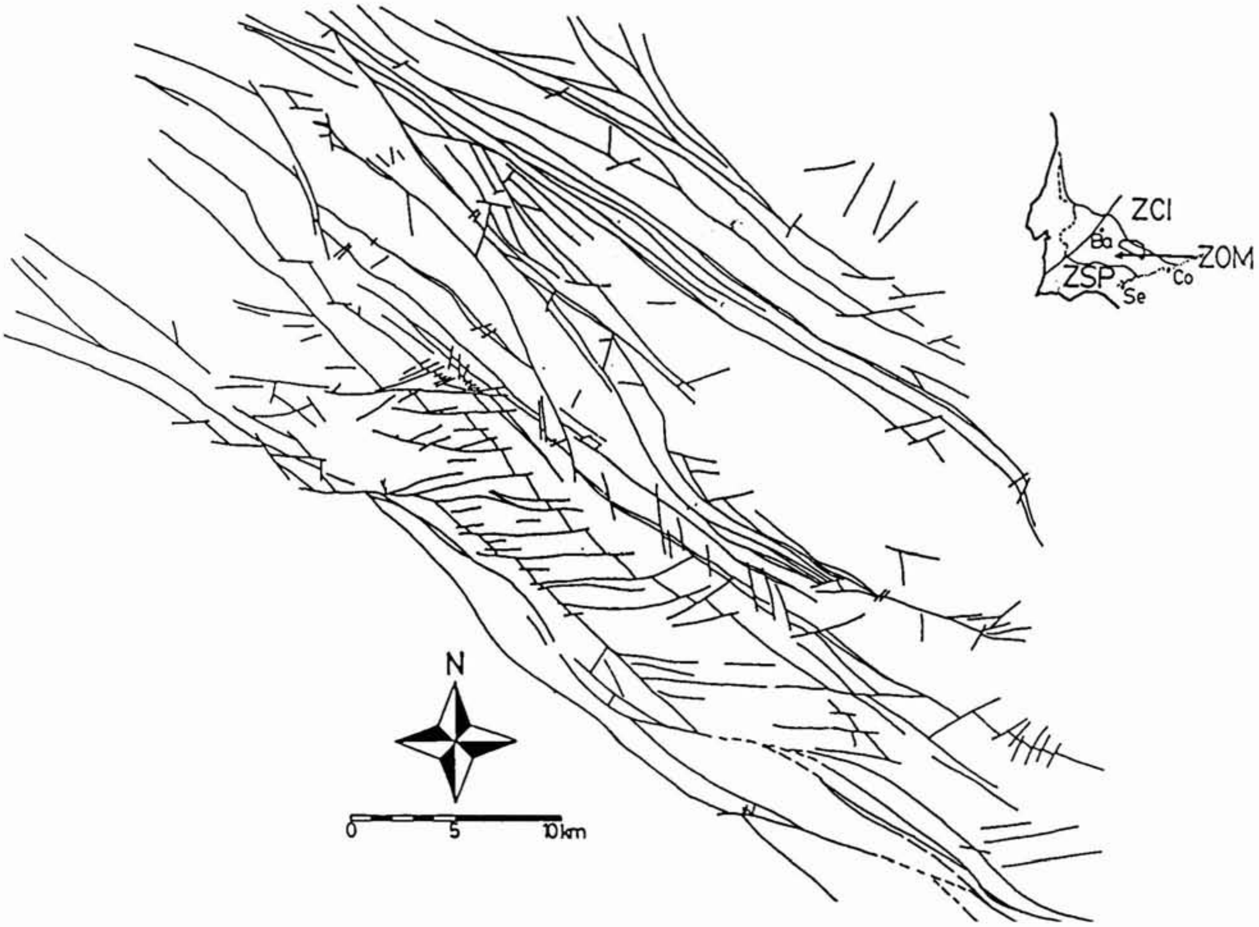

Fig. 1.—Hercynian and late-hercynian fault distribution map for the central part of the Badajoz-Córdoba Shear Zone. Most of the NW-SE-trending faults are Lower Paleozoic thrust structures carrying high grade metamorphic rocks. ZCI, Central-Iberian Zone; ZOM, Ossa-Morena Zone; ZSP, South-Portuguese Zone; Ba, Badajoz; Co, Córdoba; Se, Sevilla.

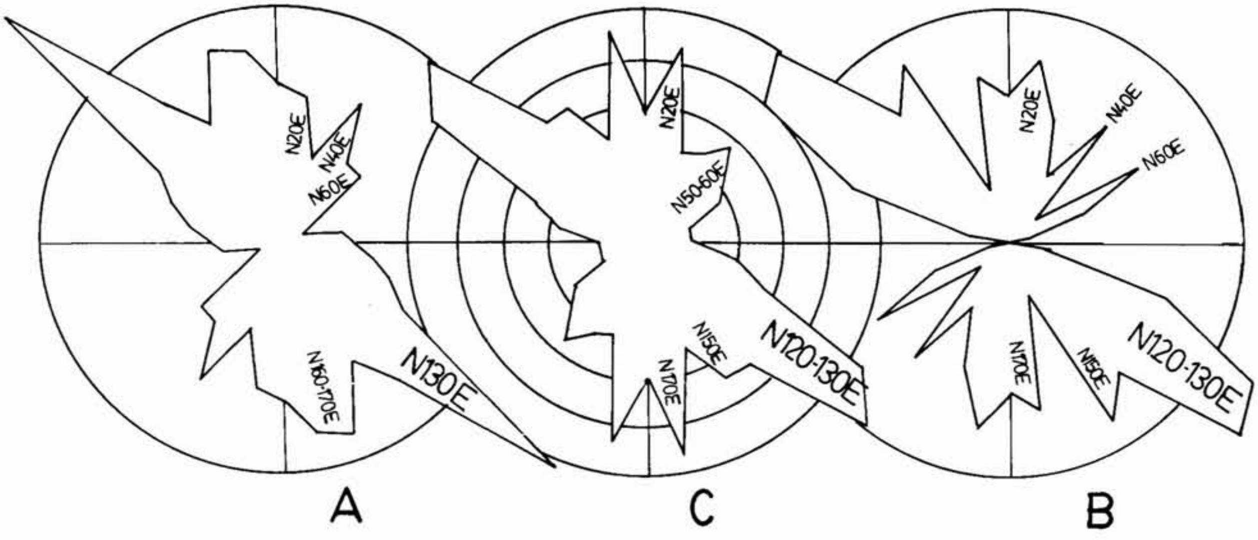

Fig. 2.—Orientation distribution diagrams of faults and tectonic boundaries in the study area (rose C), and to the NE (rose B) and SW (rose A) of the fault separating the Central Iberian and Ossa-Morena terranes. The main fault systems are signaled.

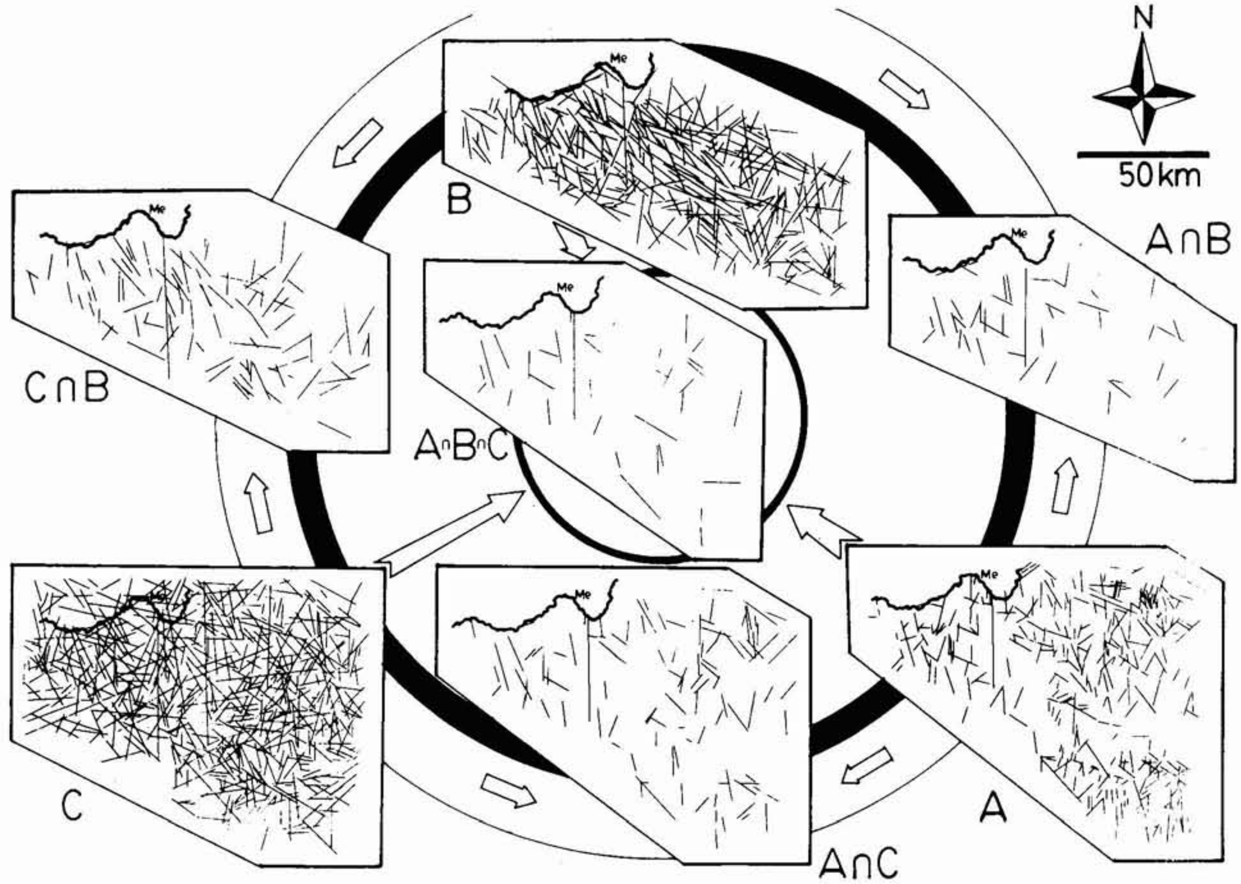

Fig. 3.—Lineament frameworks corresponding to the study area (references are the Guadiana River and the town Mérida, here labelled Me). A, B. and C are, respectively, the lineament frameworks interpreted by analysts A, B and C. The frameworks A ∩ B, B ∩ C and A ∩ C contain the lineaments deduced by the two analysts involved by the labels, while the one situated at the center of the figure contains the lineaments observed by the three.

(L.M.M.T.; label C) have been constructed to be compared between them with the aim of ascertaining results of geologic relevance. The orientation distribution patterns based on field geology, when compared with the orientation diagrams of fig. 3, let establish that the lineament systems observed by every analyst may be interpreted in terms of the above explained fault systems despite the quantitative differences among them.

Structural-kinematic interpretation and geodynamic implications

The lineament density contour map (fig. 4) provided by lineament framework B in fig. 3 was drawn (by hand) on the basis of the areal distribution of the intersections among different photolines. From a tectonic point of view, the kinematic inferences supported by the information yielded by this lineament density contour map (bearing in mind field Geology data) may be easily interpreted in terms of the presence of a N120-130E trending sheared area close to

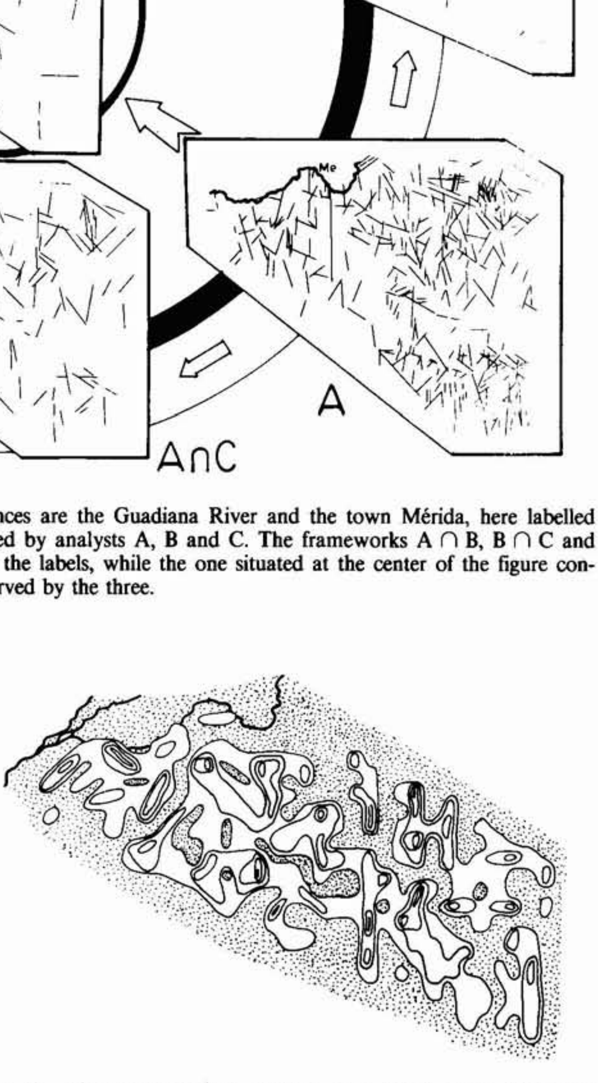

Fig. 4.—Lineament density contour map based upon lineament network labelled B in Fig. 3. Isoline intervals are 1, 2, 3 and 4%.

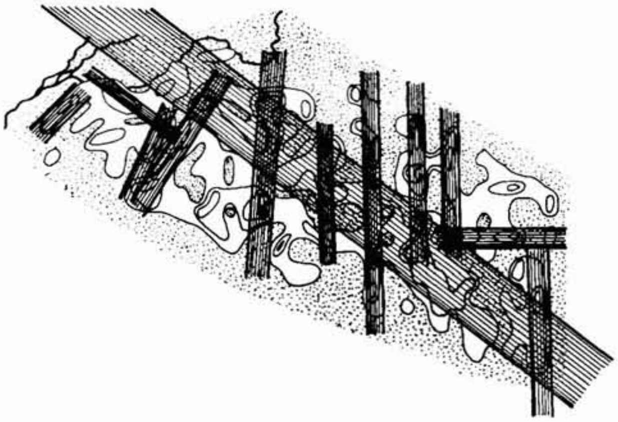

Fig. 5.—Corridors of high density lineament deduced from the density contour map of Fig. 4.

the boundary Ossa-Morena-Central-Iberian Zone (fig. 5) and subsidiary N-S corridors of lineament high density, which could thus represent the presence of a sinistral transpressive deformation regime for the area. The N120-130E band separates two zones with different lineament patterns and constitutes a domain boundary. Within each of the domains referred above, the lineaments contained show a relatively constant arrangement which lets the deffinition of tectonic blocks with more or less sharp boundaries (Vegas *et al.,* 1987). In fact, field geology may support these inferences, as large N130E sinistral faults define a group of NW-SE bands containing alternately minor E-W dextral faults or N-S-trending dextral ones. These lineament arrangements (fig. 6) may explain the strain partitioning necessary to the accomodation of the deformation due to a E-W shortening between two major blocks by means of block rotations (Garfunkel & Ron, 1985) along NW-SE bands. The minor blocks contained in the NW-SE bands undergo clockwise or anticlockwise rotations as a result of the orientation of the more widespread minor faults involved respect the E-W general direction of shortening.

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. As shown in fig. 6, the more successful combinations involve lineaments of the systems N120-130E, N-S and N40E. The latter, together with those of the N-S system, define a conjugate array from wich an appro-

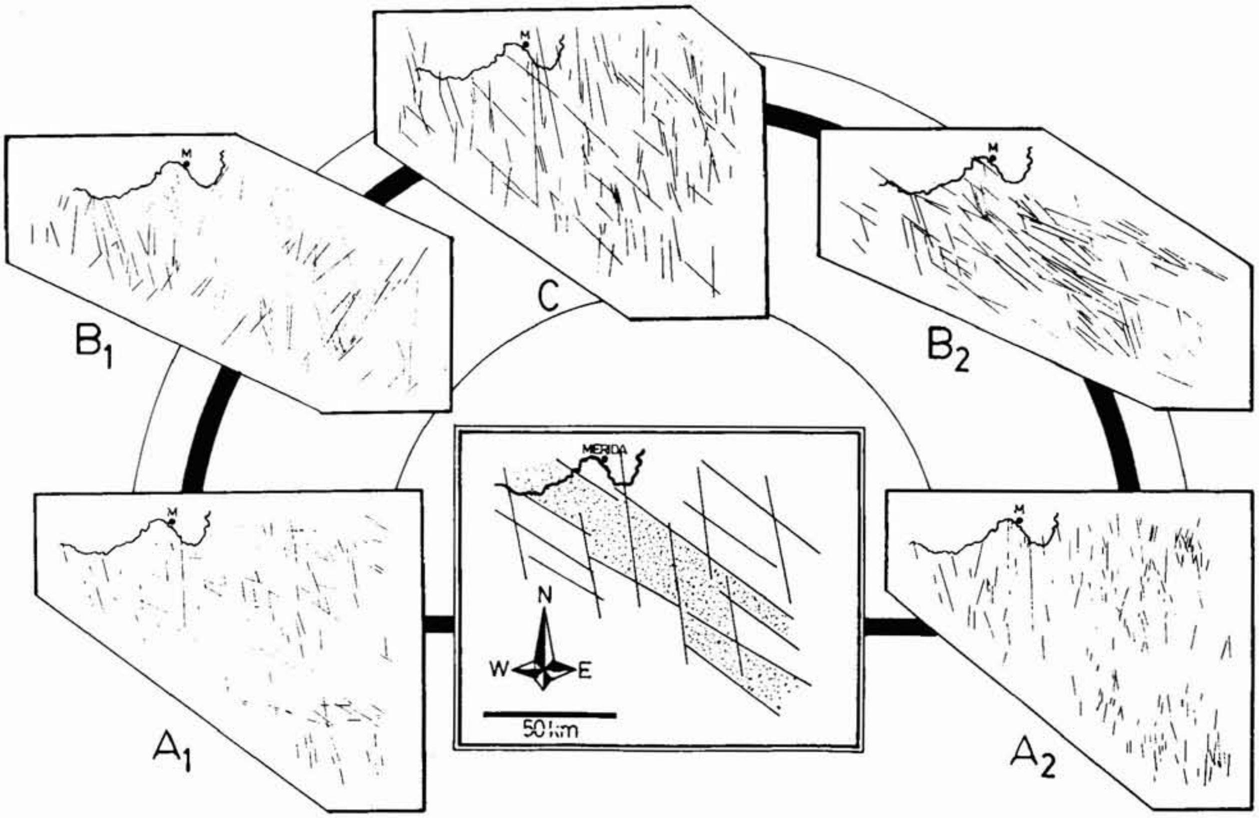

Fig. 6.—Lineament arrangements based upon frameworks A (A1 and A2), B (B1 and B2) and C (C) from Fig. 3 enhancing the presence of domains separated by an area (central dotted area in the squared graph) occupied by dominantly N130E-trending lineaments.

ximately NNE-SSW compressional stress component may be deduced. Lineaments of the two first systems not only define lozenge-shaped areas or domains, they are arranged in subparallel lineament swarms as follows: the N120-130E swarms are bounded by N-S lineaments and occupy areas devoided of lineaments which strike is close to N-S (see B1, B2 and A2 networks in fig. 6). On the contrary, the N-S lineaments display N120-130E-trending arrangements and are cross-cut by N120-130E lineaments. These facts, together with the presence of lozenge-shaped domains nearly lacking lineaments, which boundaries 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. 6) separating a northern area coinciding with the Central-Iberian Zone and a southern one which corresponds to the Ossa-Morena Zone.

In this way the presence of a clear block tectonism may be inferred from remotely sensed lineament analysis. This block tectonism takes place at a escale larger than the reported above in relation with fault distributions. In fact, the central dotted band in the squared map from fig. 6 contains some of the NW-SE-trending domains involving clockwise and anticlockwise fault-bounded block rotations cited in a preceding paragraph.

This conclusion, which is not evident from field geology (but is supported by the fault distribution map of fig. 1) is strengthened by the additional fact that a N130E Bouguer gravity anomaly (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 (Gaibar, 1976).

Conclusions

The structural-kinematic model discussed in the previous section rather agrees with the tectonic regime involved in the E-W shortening of a roughly NW-SE crustal band situated between two larger and harder blocks: the Ossa-Morena and Central-Iberian crustal blocks. This band constitutes a restrained intracontinental plate boundary and records a transpressive sinistral wrenching which involves the generation and relative motion/rotation of large fault-bounded domains. This deformation process took place during the Lower Carboniferous and might explain the occurrence of extensional areas fullfilled by the deposition of terrigenous and volcanic sequences then shortened as a result of the progressive readjustment of crustal blocks. The location of this weak crustal band should not be considered as a suture due to the collision between two plates during the Upper Paleozoic. On the contrary, the tectonic, petrologic and geochronological data available support the hypothesis that the forementiond suture zone resulted from the Precambrian-Lower Paleozoic collision between the Ossa-Morena and a northern plate. Nevertheless, as a result of such plate convergence, a weak crustal band was created which would acommodate later deformations, acting during the Upper Paleozoic as a ductile-brittle intracontinental shear zone.

AKNOWLEDGEMENTS

We are thankful to P. Tsombos at the Institute of Geology and Mineral Exploration of Athens (Greece) for the stimulating encouragement which made possible the realization of this paper and to an annonimous referee for comments and suggestions to the original manuscript.

References

Abalos, B. (1989): Structural Geology of the Ribera del Fresno Window (Badajoz, Badajoz-Córdoba Shear Zone). *Rev. Soc. Geol. España*, 2, 103-112.

Abalos, B. and Gil-Ibarguchi, I. (1989): P-T Metamorphic evolution of the Badajoz-Córdoba Medium Grade Shear Belt (Iberian Variscan Fold belt, SW Spain). *Terra Abstracts*, 1, 299.

Antón-Pacheco, C. and Sanderson, D. J. (1989): Use of Landsat Thematic Mapper data in mineral exploration, Alburquerque-La Codosera area, Southwest Spain. *Terra Abstracts*, 1; 131-132.

Apalategui, O. e Higueras, P. (1983): Hoja nº 855 (Usagre) del Mapa Geológico Nacional a escala 1:50.000 (MAGNA) y memoria explicativa. Publ. del IGME, Madrid, 72 págs.

Apalategui, O y Quesada, C. (1987): Transversal geológica Zona de Ossa-Morena. Libro guía Excursión IGME-Ossa-Morena. Publ. IGME, Madrid.

Apalategui, O.; Garrote, A.; Higueras, P.; Odriozola, J. M. y Peón, J. (1983): Mapa y memoria explicativa de la Hoja 1:50.000, nº 877 (Llerena) del Mapa Geológico Nacional (MAGNA). Instituto Geológico y Minero de España (IGME), Madrid.

Arriola, A.; Chacòn, J.; Eraso, A.; Eguiluz, L.; Garrote, A.; Soubrier, R. y Vargas, I. (1983): Mapa y memoria explicativa de la hoja 1:50.000, nº 829 (Villafranca de los Barros) del Mapa Geológico Nacional (MAGNA). Instituto Geológico y Minero de España (IGME), Madrid.

Arthaud, F. et Matte, Ph (1975): Les décrochements tardiherciniennes du sud-ouest de l'Europe. Géometrie et essai de reconstitution des conditions de la déformation. *Tectonophysics*, 25, 139-171.

Arthaud, F. and Matte, Ph (1977): Late Paleozoic strike-slip faulting in Southern Europe and Northern Africa: result of a right-lateral shear zone between the Appalachians and he Urals. *Geol. Soc. Am. Bull.*, 8, 1305-1320.

Farrow, J. B. (1975): The influence of the atmosphere on remote sensing measurements. *ELDO/ESRO Scient. Tech. Rev.*, 7, 1-28.

Gaibar, A. (1976): Variaciones del espesor crustal y grado de equilibrio isostático asociables a las anomalías de Bouguer en la España Peninsular. *Bol. Geol. Min.*, 87, 372-401.

García Casquero, J. L.; Boelrijk, N. A. I. M.; Chacón, J. and Priem, H. N. A. (1985): Rb-Sr evidence for presence of Ordovician granites in the deformed basement of the Badajoz-Córdoba belt, SW Spain. *Geologische Rundschau,* 74, 379-384.

García Casquero, J. L; Boelrijk, N. A. I. M.; Priem, H. N. A. and Chacón, J. (1988): Isotopic dating of the mylonitization of the Azuaga Group in the Badajoz-Córdoba belt, SW Spain. *Geologische Rundschau,* 77, 483-489.

Garfunkel, Z. and Ron, H. (1985): Block rotation and deformation by strike-slip faults II. The properties of a type of macroscopic discontinuous deformation. *Jour. Geophys. Res.,* 90: 8598-8602.

Kats, I. G.; Poletaev, A. I. and Rumiantseva, E. F. (1986). *Elements of lineament tectonics.* Izdatel'stvo Nedra, Novosibirsk, 144 págs.

Koronovskii, N. V.; Zlatopolskii, A. A. and Ivanchenko, G. N. (1986): Computer-aided interpretation of space images with the aim of structural analysis. *Issledovannie Zemli iz Kosmosa,* 111-118.

Martínez-Alosno, S. E.; Lorenzo, R.; Bautista, R. and Solé-Sugrañes, L. (1989): Use of TM images to relate tectonic structures and geochemical annomalies in western Galicia. *Terra Abstracts,* 1, 133.

Mekarinia, A.; Peroin, J. P. and Chorowicz, J. (1989). Microtectonic and remote sensing analysis of the Lias fracturing in the western boundary of the mesozoic south-eastern basin (France). *Terra Abstracts,* 1; 134.

Odriozola, J. M.; Peón, A. y Vargas, I. (1983): Mapa y memoria explicativa de la hoja 1:50.000, nº 854 (Zafra) del Mapa Geológico Nacional (MAGNA), Instituto Geológico y Minero de España (IGME), Madrid.

Poscolieri, M. and Salvi, S. (1985). Lineament analysis in a test area of Northern Mozambique. Abstract. *International Geoscience and Remote Sensing Symposium,* 141-146.

Quesada, C. (1989): Collisional Acado-Hercynian orogenic events in Iberia. *Terra Abstracts,* 1, 13.

Sanz de Galdeano, C.; Fernández-Rubio, R. y Fernández-Lorca, S. (1985): Fracturación y fotointerpretación en el sector de Albuñol-La Rábita (Granada, Conjunto Alpujárride, Cordilleras Béticas). *Bol. Geol. Min.,* 96, 3-9.

Schäfer, H. J.: Gebauer, D. and Nägler, Th. F. (1989): Pan-African and Caledonian ages in the Ossa-Morena Zone (Southwest Spain): a U-Pb zircon and Sm-Nd study. *Terra Abstracts,* 1, 350-351.

Trofimov, D. M. (1985): Problems and principles of the geological interpretation of remote sensing data. In: *Methods of combined air and space remote sensing studies of Siberia,* 5-8.

Tsombos, P. I. and Kalogeropoulos, S. I. (1989): Remote sensing as applied to mineral exploration in the Chalkidiki Peninsula, North Greece. *Terra Abstracts,* 1, 131.

Vegas, R.; Barranco, L. M. y Vázquez, J. T. (1987): Tectónica de bloques en el SE de España; aplicación de la teledetección a un límite de placas de tipo intracontinental. *Geogaceta,* 3, 17-19.

Weber, C. (1985): Geological remote sensing: quo vadis? *I.T.C. Jour.,* 4, 227-241.

Widdowson, M. (1989): Large-scale structural lineaments and residual deposits distribution, western Ghaths, India 16º-18º N: an initial interpretation using Landsat MSS data. *Terra Abstracts,* 1, 133.

Wise, D. V.; Grady, L. T. and Salvini, F. (1985): Topographic lineament domains of the Appalachians. Some new methods and techniques for paleostress analysis. Abstract, *International Geoscience and Remote Sensing Symposium,* 125-130.

Recibido el 25 de abril de 1989
Aceptado el 13 de octubre de 1989