STRUCTURAL GEOLOGY OF THE RIBERA DEL FRESNO WINDOW (BADAJOZ-CÓRDOBA SHEAR ZONE)

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RESUMEN

En el presente trabajo se realiza un estudio estructural y cinemático detallado de la Ventana Tectónica de Ribera del Fresno (Zona de Cizalla de Badajoz-Córdoba). En el autóctono relativo de esta estructura aflora el Ortogneiss de Ribera del Fresno, el cual presenta una deformación extensiva en condiciones cercanas a la cizalla simple. Esta deformación tuvo lugar, teniendo en cuenta el tipo de microestructuras observadas en cuarzo y feldespatos, en condiciones moderadas de temperatura (alrededor de 500° C) durante una fase de deformación claramente Hercínica. El estudio estructural y cinemático revela un comportamiento reológico diferente entre el Ortogneis y los materiales gneísicos alóctonos que lo recubren (Gneises de Azuaga), así como un mecanismo de sub-cabalgamiento coetáneo con un cizallamiento sinistroso en régimen transpresivo como principal responsable de la deformación. Esta evolución tectónica se superpone a una fase previa claramente pre-Hercínica registrada en el encajante metapelítico del Ortogneiss de Ribera del Fresno y en los Gneises de Azuaga.

Palabras clave: Análisis estructural, cinemática, deformación finita, ventana tectónica, ortogneis, Hercínico, pre-Hercínico, Zona de Cizalla de Badajoz-Córdoba, Ossa-Morena, SW España.

ABSTRACT

A detailed structural and kinematic study of the Ribera del Fresno Window (Badajoz-Córdoba Shear Zone) is carried out in this paper. In the autochthonous of this structure the Ribera del Fresno Gneiss crops out, holding a pervasive deformation under conditions close to simple shear. This deformation took place, on the basis of quartz and feldspar microstructures, under moderate conditions of temperature (about 500° C) during a clearly Variscan deformation phase. The structural and kinematic study reveals a contrasted rheological behavior between the Ribera del Fresno Gneiss and the overlying allochthonous gneissic materials (the Azuaga Gneisses), as well as underthrusting coeval with a sinistral shearing mechanism in a transpressive regime as chief responsible of deformation. This tectonic evolution is superimposed on a previous and clearly pre-Variscan phase recorded in the metapelitic host of the Ribera del Fresno Gneiss and in the Azuaga Gneisses.

Key words: structural analysis, kinematics, finite strain, tectonic window, gneiss, Variscan, pre-Variscan, Badajoz-Córdoba Shear Zone, Ossa-Morena, SW Spain.

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1. INTRODUCTION. GEOLOGICAL SETTING

The Ribera del Fresno Window constitutes a 25 km long and 2 km wide structure located among the localities of Hinojosa del Valle, Llera, Ribera del Fresno and Valencia de las Torres (Badajoz Province). This is a relatively long and narrow antiform (Fig. 1) where the tectonic boundary between the allochthonous unit of the Badajoz-Córdoba Shear Belt (Azuaga Gneisses) and its para-autochthonous crops out, being such contact staked out by an up to 200 m thick unit of serpentinized ultramafic rocks. Within the autochthonous, the so called Atalaya Fm. (Chacón, 1979) appeares intruded by a gneissified granite, the Ribera del Fresno Gneiss (RF Gneiss), which occupies most of the outcropping surface. The RF Gneiss holds a chemical composition ranging between hyper-alkaline and subaluminic (Chacón *et al.,* 1980), with a markedly homogeneous character. Minor masses of aplites and greisens are also present at the NW closure of the Window

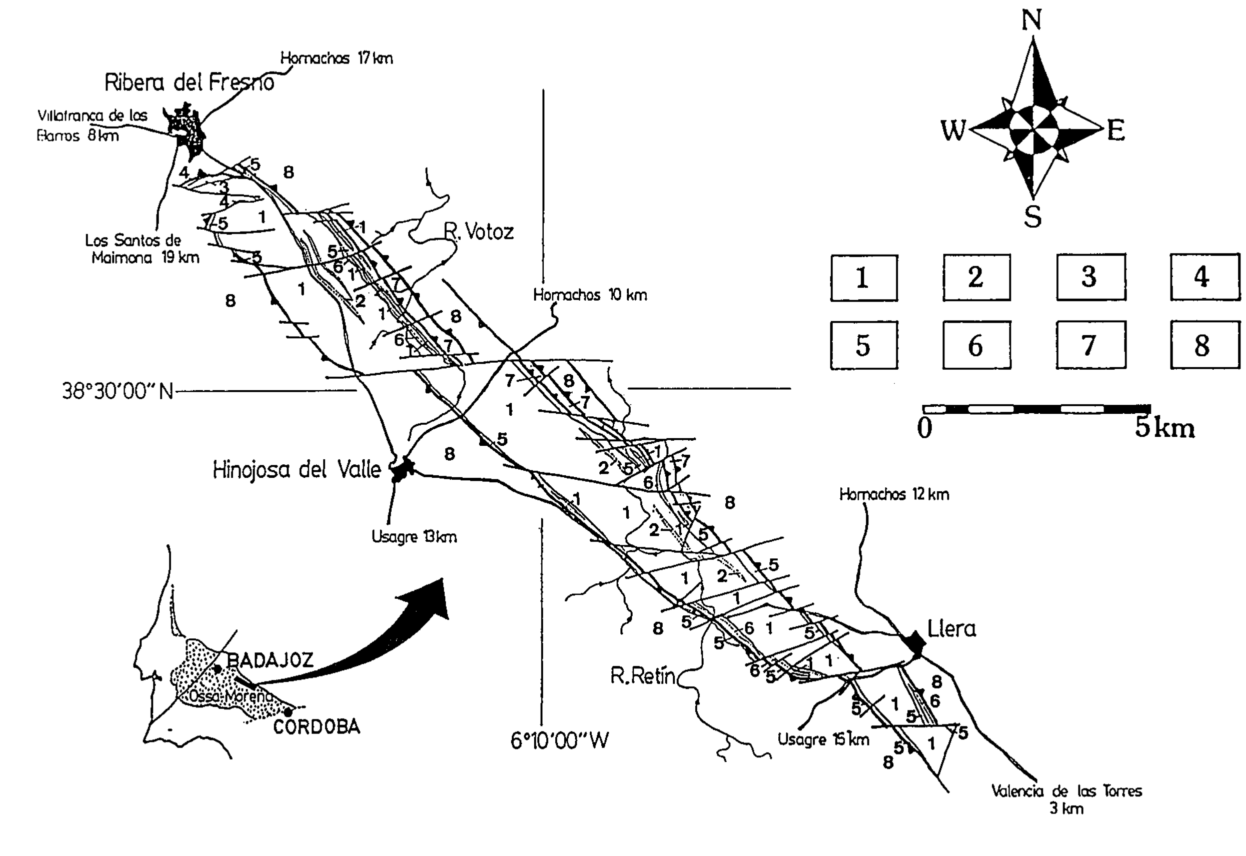

Fig. 1.-Geological map of the Ribera del Fresno Window. 1: Ribera del Fresno Gneiss, coarse-grained gneisses; 2: Ribera del Fresno Gneiss, fine-grained gneisses; 3: aplites; 4: greisens; 5: Atalaya Fm., schists; 6: Atalaya Fm., quartzschists and quartzites; 7: serpentinized ultramafic rocks; 8: Azuaga Gneisses.

Fig. 1.-Esquema geológico de la Ventana Tectónica de Ribera del Fresno. 1: Ortogneis de Ribera del Fresno, facies común; 2: Ortogneis de Ribera del Fresno, facies de grano fino; 3: aplitoides; 4: gréisenes; 5: Fm. Atalaya, micaesquistos; 6: Fm. Atalaya, cuarzoesquistos y cuarcitas; 7: rocas ultramáficas serpentinizadas; 8: Gneises de Azuaga.

(Arriola *et al.,* 1983; Abalos *et al.,* in press). Both the RF Gneiss and its host were deformed after the first was settled, then giving rise to an homogeneous orthogneiss of porphyroid appearance which has been correlated to the Ollo de Sapo Fm. (Parga and Vegas, 1974; Herranz *et al.,* 1977). According to this correlation, the gneissic body here studied was considered as the Precambrian Series lowermost unit from the Badajoz-Córdoba Shear Belt and, thus, from the Ossa-Morena (Herranz, 1983, 1984a and 1984b). Notwithstanding the forementioned suggestions, radiometric data point towards a Silurian age for the RF Gneiss intrusion (Rb/Sr whole rock 423 ±38 M.y., García Casquero *et al.,* 1985), being its pre-hercynian age supported by the Lower Carboniferous age (Ar/Ar 330-335 M.y., Blatrix and Burg, 1981) of pervasive deformation. These data are in agreement with the Apalategui *et al.,* (1983) hypothesis on the presence of two main tectonic units in the Badajoz-Córdoba Shear Belt: an allochthonous one, the Azuaga Gneisses, of likely Upper Proterozoic age, and the para-autochthonous, composed of the Atalaya Fm. metapelites and the RF Gneiss, both of likely Lower Paleozoic age.

All the above stated features make the RF Gneiss an interesting subjet of study in order to characterize the nature of the Variscan deformational events in the para-autochthonous units of the Badajoz-Córdoba Shear Belt.

2. LITHOSTRATIGRAPHY.

The RF Gneiss is constituted by coarse grained pinky augen gneisses whose igneous origin is evidenced by features such as the presence of metapelitic xenoliths, granitic dykes in the host, chemical composition (Muñoz and Vegas, 1974; Chacón *et al.,* 1980) and petrographic-microtextural evidences (perthitic feldspars, zircon morphologies; Chacón *et al.,* 1980). From a mineralogical point of view these gneisses are made of sigmoidal perthitic K-feldspar and Na-rich plagioclase porphyroclasts embedded in a quartz and biotite-rich strained matrix. Zircon, titanite, rutile, garnet and apatite are accesories. C-S structures and fabrics are widespread. Two gneissic facies have been recognized in the field: coarse-grained gneisses, the most ubiquitous, and fine-grained ultramylonitic gneisses, the latter restricted to highly strained longitudinal bands. At the NW closure of the Window, an ensemble of mylonitized aplites and topaz-bearing greisens crop out. The crystallochemical study of topaz in these rocks evidences they were settled under low pressure (2-3 kbar) and high temperature (about 800 C) conditions (Abalos *et al.,* in press).

The Atalaya Fm. is the host of these gneisses. This is a metapelitic unit made of garnet-muscovite-rich schists with minor quartzschists and quartzites. Schists use to contain garnets of different generations together with biotite, chlorite, muscovite, quartz, kyanite and opaques. The effects of contact metamorphism are evidenced by the presence of misoriented static garnet and biotite neoblasts.

The Azuaga Gneisses constitute a complex ensemble of gneisses and amphibolites of likely volcano-sedimentary origin. These gneisses are affected by a widespread medium-grade tectonothermal event and is ac-

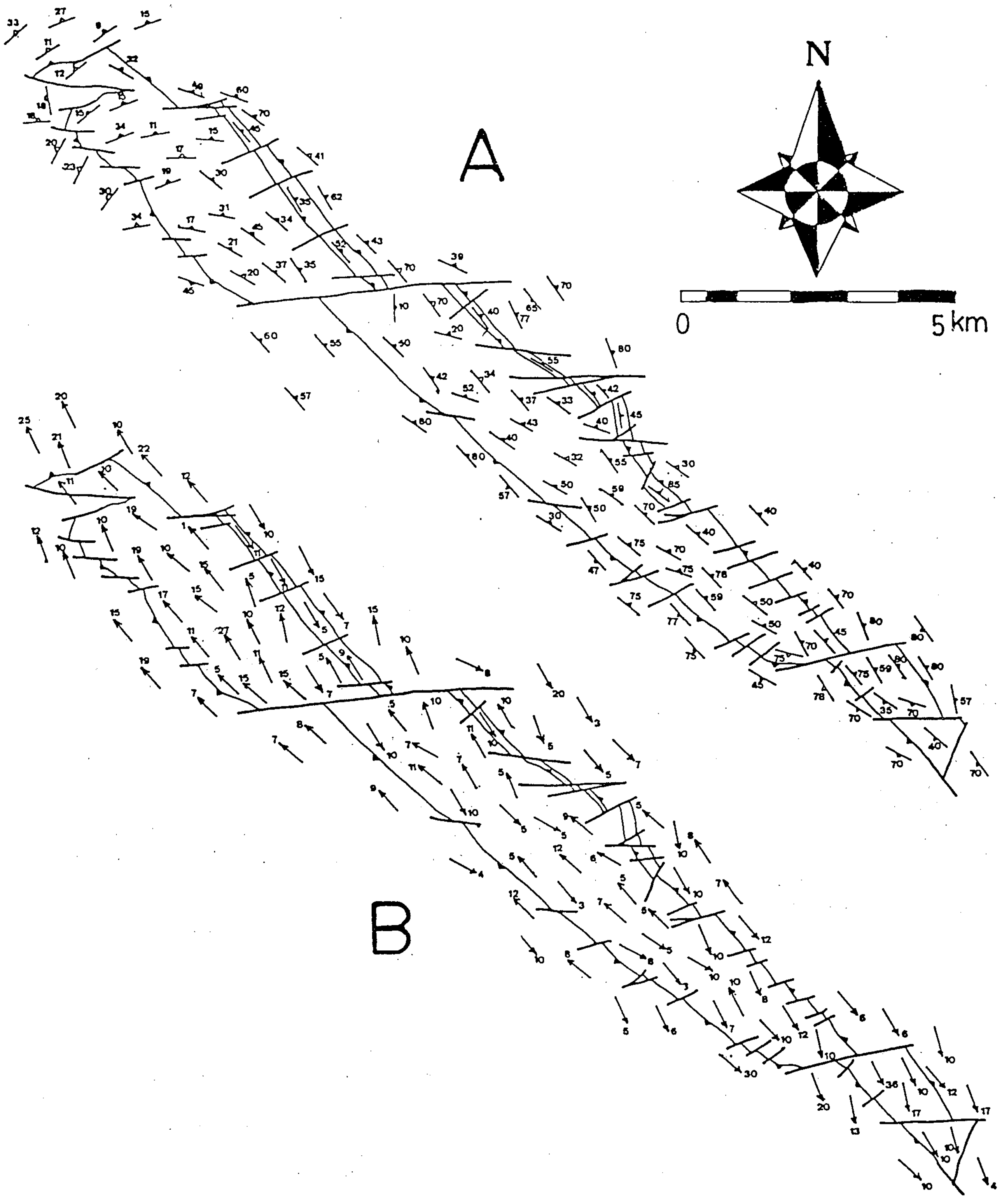

Fig. 2.-A: regional D2 foliation map; B: D2 stretching lineations map.
Fig. 2.-A: mapa de foliaciones de segunda fase regional; B: mapa de lineaciones de estiramiento de segunda fase.

companied of a pervasive mylonitic deformation.

3. STRUCTURAL FRAMEWORK

The RF Gneiss records only the deformation phase responsible for the development of the extended S-C fabrics. C planes and the stretching lineations on them show the same strike as the regional structural trends (N130E). These planes are variably dipping surfaces parallel with the S_2 planes in the host. In fact, the host records a previous deformation phase, D1, evidenced by a S_1 schistosity diversely affected by D2 folding and shearing. In the Atalaya Fm. D1 occurred under high-T low-grade metamorphic conditions (syntectonic Gt and Ky in schists), probably related to large recumbent folds (author's unpublished data). S_1 schistosity is also recorded in the form of aligned quartz inclusions inside garnets. Misoriented garnet and biotite neoblasts seal S_1 in the biotite-rich layers. This feature should represent the effects of contact-metamorphism related to the emplacement of the primary RF granite. Both S_1 and contact metamorphism structures previously signed are largely affected by folds, crenulations, schistosity boudinage, development of shear planes (S_2 schistosity) and C' surfaces in the most strained zones (thinned limbs of sheath folds) in a general scheme of increasing strain. S_2 and L_2 stretching lineations parallelize C planes and lineations from the RF gneisses, showing the same kynematic criteria as well. Conversely, L_1 in the host departs from the regional structural trends, as its trend is close to N160E.

The Azuaga Gneisses are characterized by widespread mylonitic foliations and stretching lineations developed under medium-grade metamorphic conditions. These structures are similar to the D2 structures in the RF Gneiss host both in strike and kinematics. In this case, the previous and higher grade D1 structures appear mostly recorded as quartz aligned inclusions within garnets, as pervasive D2 deformation obliterates almost completely D1 structures. Nevertheless, the observed microtextural and paragenetic relations evidence such high-grade event. D1 foliations and lineations have been found in other areas from the allochthonous unit (authour's unpublished data) with patterns similar to the above exposed for the Atalaya Fm.

4. FOLIATION AND LINEATION LAYOUTS

In the RF Gneiss C planes show a faintly variable orientation (Fig. 2). At the NW area, C planes are gently dipping to the NW, while southeastwards they are steeply tilted, then with a N130E strike and a mainly NE dip. Stretching lineations, measured on the C planes, are the same orientation all over the RF Gneiss outcrop (N130-140E), being their plunge to the NW at the NW area, statistically subhorizontal at the central area, and to the SE southeastwards (Fig. 3). These features define an elongated dome-like shape for the structure of both the RF Gneiss and RF Window structure.

In the host, S_2 planes are more steeply dipping than in the centre of the structure, while D2 stretching lineations are parallel with the RF Gneiss lineations. This may be found in the Azuaga Gneisses as well. Due to the fact that D2 structures are not only geometrically but also genetically related, both in the autochthonous and the allochthonous, the above explained attitudes of D2 foliations could be referred to the presence of D3 folds with large cuvature radii or the result of a primary attitude due to the proximity of a competent orthogneiss massif (Burg *et al.,* 1981).

5. STATE OF STRAIN FROM MICROSTRUCTURES

Microstructural features of deformation in the RF Gneiss are due to the presence of three types of minerals with different rheological properties. Therefore, it is to be signalized the presence of feldspar (alkalic and plagioclase) sigmoidal porphyroclast systems (sigma-type from Passchier and Simpson, 1986) around which a quartz-ribbon and biotite layer-rich groundmass wraps, giving rise to the classical S-C mylonites (Lister and Snoke, 1984).

The feldspathic porphyroclasts contain a less-strained core and a discontinuous coat of dynamically recrystallized subgrains and new grains, as well as myrmekite blebs (likely strain-related myrmekites from Simpson, 1985). Brittle breakage structures are also present in some feldspars.

Biotite agregates are made of lots of small biotite neoblasts recrystallized from previous and coarser grained biotites (often remaining as relicts). Muscovite crystals appear always strained, either intensely folded, or showing evidences of intracrystalline creep along basal (001) planes, in the latter case giving rise to mica-fish.

Quartz agregates arrange pollycrystalline ribbons which may be displayed along both C and S surfaces. Quartz ductile strain is widespread, and evidenced by microstructures such as ondulous extinction, development of sub-boundaries, subgrains, dynamically recrystallized new grains, shape fabrics and quartz C-axis preferred orientations.

All the forementioned microstructures characterize the coarse-grained gneisses as well as the fine-grained types. In the case of the mylonitic fine-grained gneisses, the contained megablasts are smaller in size and scarcelly spreaded. Moreover, microstructures sometimes evidence larger strain than the recorded in the coarser grained gneisses.

All these microstructural features point to a deformation process taking place under T conditions of upper-greenschists to epidote-amphibolite facies (Simpson, 1985) and should be the result of a moderate deformation. Following Burg and Laurent (1978), this deformation should represent shear strain values larger than 1 and X/Z ratios of the finite strain ellipsoid ranging between 2.6 and 7.1. In any case, this strain would not be so strong as the one suffered by the overlying

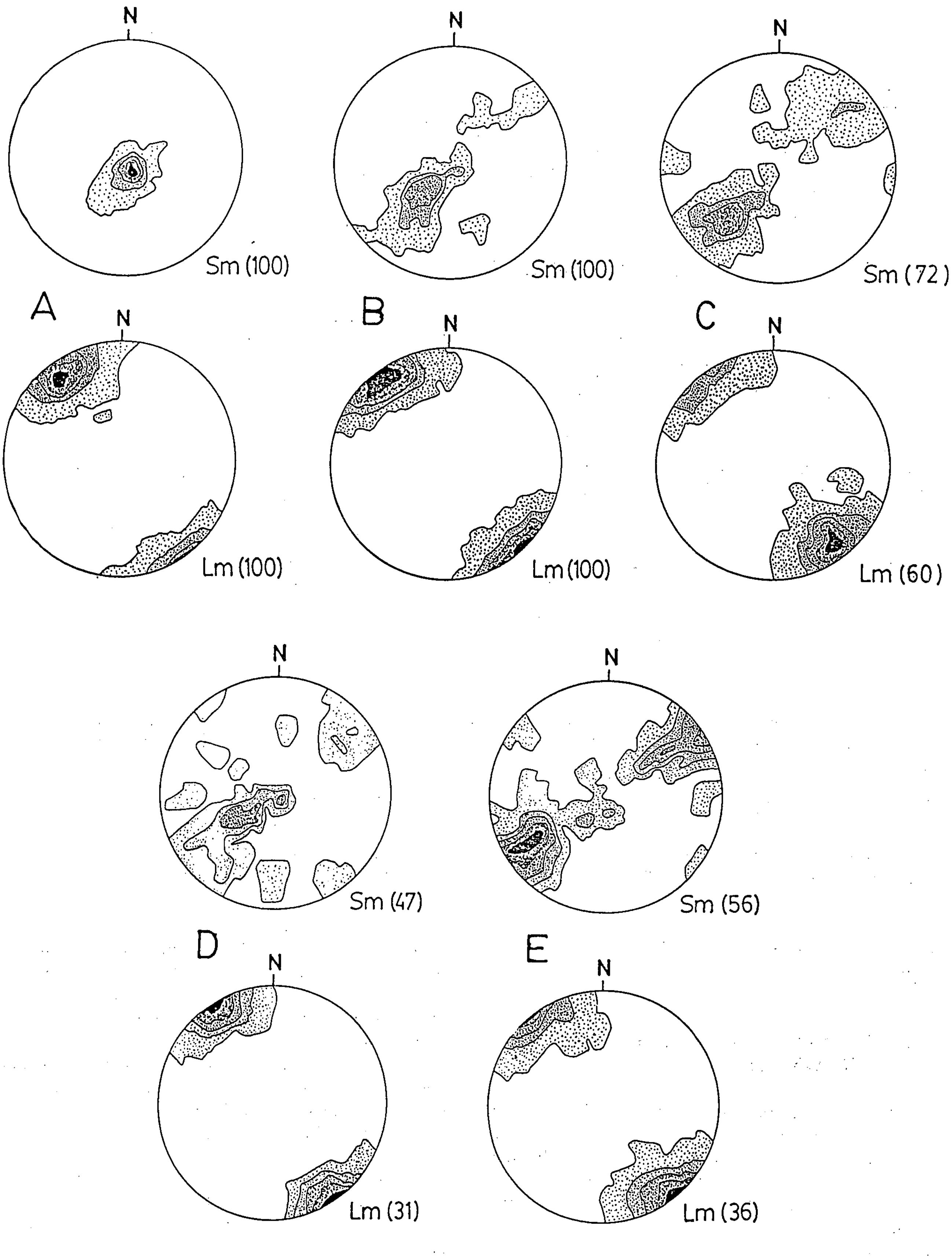

Fig. 3.-D2 foliation pole (Sm) and lineation (Lm) diagrams (Schmidt-Kalsbeek stereonets, lower hemisphere). A, B and C correspond, respectively, to the NW, central and SE areas of the Ribera del Fresno Gneiss. D, Atalaya Fm.; E, Azuaga Gneisses. The numbers between brackets indicate the number of measures employed in each diagram.

Fig. 3.-Diagramas de polos de la foliación milonítica de segunda fase (Sm) y de las lineaciones de estiramiento asociadas (Lm) en el hemisferio inferior de las redes de Schmidt-Kalsbeek. A, B y C corresponden, respectivamente, a las porciones NW, central y SE del Ortogneiss de Ribera del Fresno. D, Fm. Atalaya; E, Gneises de Azuaga. Los números entre paréntesis indican el número de medidas utilizadas para construir cada diagrama.

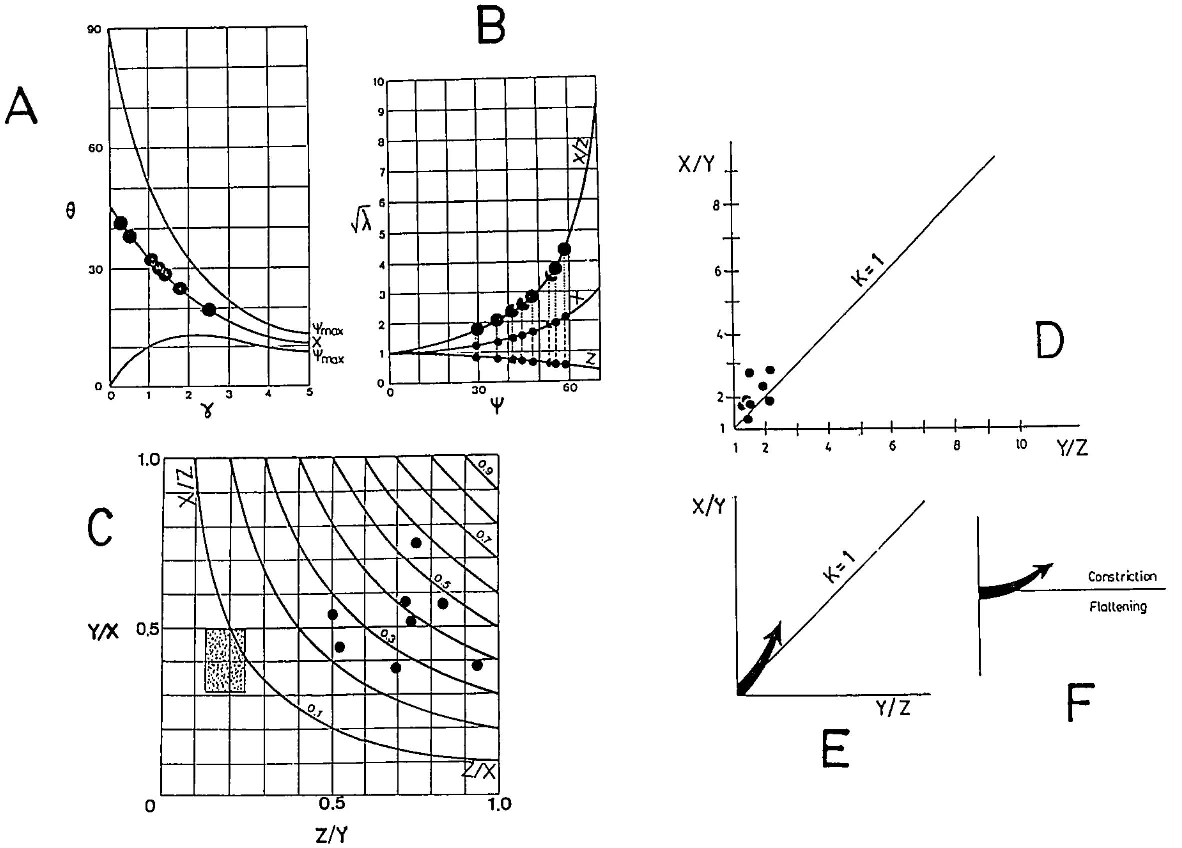

Fig. 4.-Graphic plotting of the finite strain ellipsoids obtained through the Fry (1979) technique in samples from the Ribera del Fresno Gneiss. A: angle between S and C surfaces versus shear strain; B: chief extensions and X/Z ratios versus shear angles; C: Y/X versus Z/Y ratios (the dotted square corresponds to the area where the strain ellipses of a gneiss from the allochthonous unit, the Mina Afortunada Gneiss plot); D: Flinn's diagram; E, F: strain paths.

Fig. 4.-Representaciones gráficas en diversos diagramas de los elipsoides de la deformación finita obtenidos mediante la tcnica de Fry (1979) en muestras del Ortogneiss de Ribera del Fresno. A: ngulo entre superficies C y S (ordenadas) frente a deformación por cizalla (abscisas); B: extensiones principales y relaciones X/Z (ordenadas) frente a ángulo de cizalla (abscisas); C: rela ciones Y/Z frente a Z/Y (el recuadro punteado corresponde al área donde se representan los elipsoides de la deformación referidos a un ortogneiss en la unidad alóctona, el de Mina Afortunada); D: diagrama de Flinn; E, F: strain paths.

Azuaga Gneisses, but took place under similar or slightly lower T conditions.

6. FINITE STRAIN DETERMINATION IN THE RF GNEISS.

The boundary between the Azuaga Gneisses and its para-autochthonous occurs either directly with the RF Gneiss or with the Atalaya Fm. schists. In the first case, it may be observed in the field a slight but progressive decrease in grain size of the RF gneisses, thus giving rise to striped mylonitic gneisses. Particularly, this is the case in the aplites and greisens from the NW closure of the Window. In the secondly mentioned case, the development of C planes is more evident in the neighbourhood of the basal thrust boundary, being the strain gradation less marked.

In order to quantify the state of strain of the RF Gneiss there have been carried out finite strain estimates following the Fry's (1979) method on XZ and YZ sections (regarding S surfaces as XY planes and the enclosed stretching lineation as the X axis of the structural framework) and using feldspar centres as markers. The strain ellipsoids obtained (Fig. 4) display a not too marked ellipticity, as X/Z ratios from the Fry's plot voids do not attain values larger than 6 in the more intensely deformed samples. In the same manner, Y/Z ratios average 1, thus resulting Flinn's k parameters close to 1.

The plotting of these ellipsoids on the Flinn's diagram show they are displayed along the K=1 line, with a faint deviation towards the constrictional field in the case of the more strained samples (Fig. 4d). The resulting strain path (Figs. 4e and f) may therefore be considered of plane strain type, although the occurrence of a slightly constrictional deformation at the end of the major tectonic event is also evidenced. The angles between the X direction (stretching lineation on S planes) and the C direction of the two-dimension strain ellipses resulting from the Fry (1979) plots on XZ sections have been used to calculate the aproximate values of shear strain (Figs. 4a and b). The figures for the shear angles average 30-60°, thus being shear strain values comprised between 0.58 and 1.73, respectively. These results are the same magnitude as those calculated from the angles between S and C planes on XZ sections of the samples (Berthé *et al.*, 1979; Ramsay, 1980), which range between 0.30 and 2.50. Both X/Z ratios and shear strain figures are higher in the case of fine-grained mylonitic gneisses, while the mean shear strain averages 1-1.5 in the coarse-grained gneisses (Fig. 5). In this way, the areal distribution of deformation could be related to the wrench and thrust tectonics responsible for the emplacement of the Azuaga Gneisses over the RF Gneiss ans its country rocks.

Strain evaluation through the Fry (1979) technique has been so far carried out on gneisses or deformed granitoids (Lacassin and Van Den Driessche, 1983; Davidson, 1983, respectively), being proposed by the two first authors as a powerful device in strain analysis. Notwithstanding, the results obtained should be carefully interpreted in terms of the observed microstructural strain criteria and strain partitioning among the different minerals (Ramsay and Huber, 1983). In our study, the results above commented on should be considered as minimum values due to the fact that, as microstructural features suggest, deformation within the groundmass was larger than within the porphyroclasts (supposed to be whole rock strain markers). Therefore, finite strain estimates are likely to be closer to the porphyroclasts strain than to the whole rock finite strain (interactions among them lessening the ellipticity of the voids resulting from the Fry's plot).

7. DISCUSSION. BULK KINEMATICS OF VARISCAN DEFORMATION.

The obliquity between S and C planes make possible the establichement of shear criteria at a mesoscopic scale in the RF Gneiss, while S-C relations together with asymmetry of sheath folds make it possible at the same scale in the Atalaya Fm. (Fig. 6). Microstructural criteria provide a powerful tool to decipher the sense of the tectonic movement in the forementioned units, but mainly do in the case of the Azuaga Gneisses. In any case, a sinistral strike-slip kinematic framework is found in plant view. This pattern remains unaffected eiter if C planes are steeply NE-wards, SW-wards or gently dipping surfaces. In the NW closure of the Window C planes are subhorizontal, and shear sense criteria indicate a NW-directed tectonic transport. Meanwhile, most of the Window inward is characterized by NE-dipping C planes, and by a NW-directed tectonic movement of the upper blocks respect the lower ones (sinistral shearing). This fact should indicate that, first, the Azuaga Gneisses were settled from SE to NW, or,

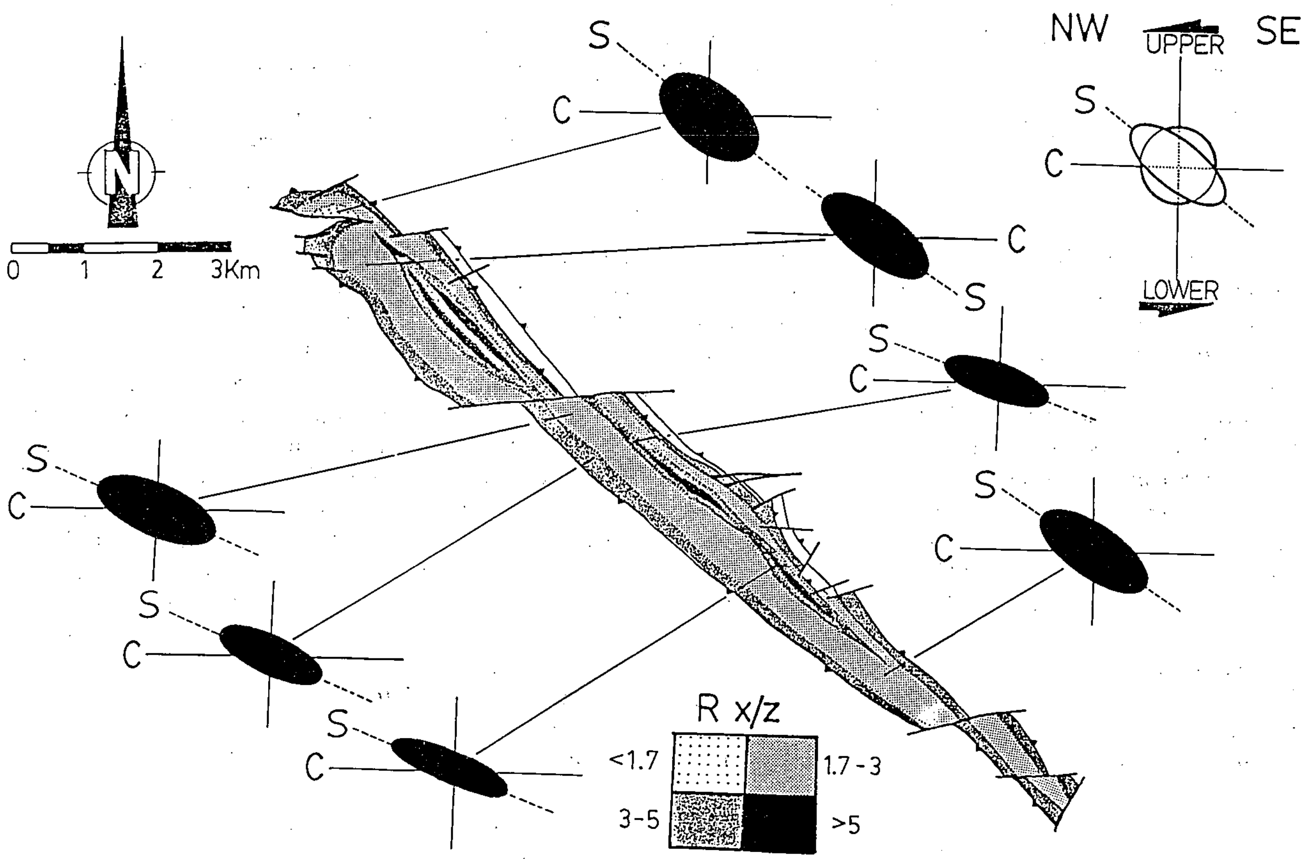

Fig. 5.-Areal distribution of strain in the autochthonous of the Ribera del Fresno Window from the results obtained of the application of the Fry's method. The different line screens correspond to the indicated XZ ratios.

Fig. 5.-Distribución areal de la deformación en el autóctono de la Ventana de Ribera del Fresno a partir de los resultados obtenidos mediante la aplicación del método de Fry. Las diversas tramas corresponden a los valores indicados de las relaciones X/Z de los elipsoides.

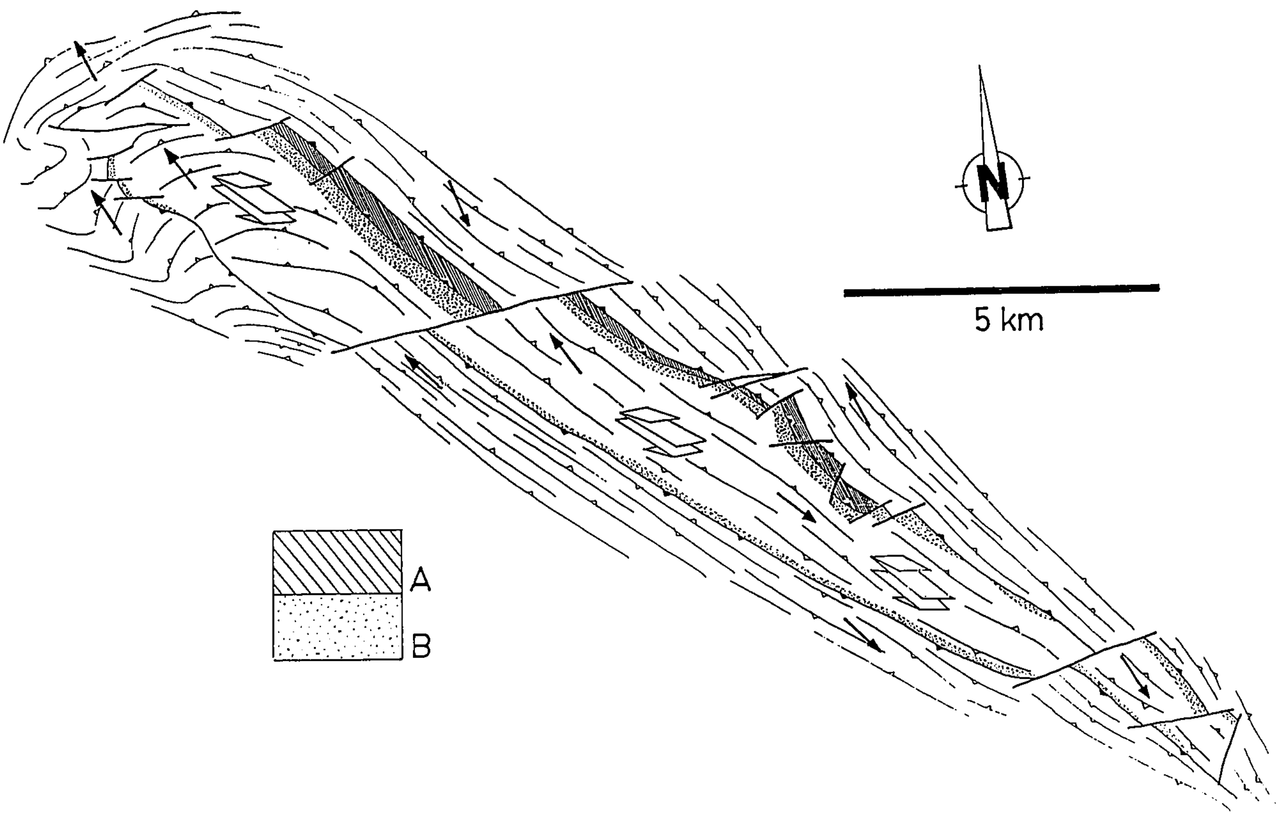

Fig. 6.- Kinematic sketch map for the Ribera del Fresno Window where the trajectories of D2 mylonitic foliation, the principal lineations (single arrows) and the senses of tectonic transport (double arrows) are represented. A: serpentinized ultramafic rocks; B: Atalaya Fm.

Fig. 6.-Esquema cinemático de la Ventana de Ribera del Fresno donde se representan las trayectorias de la foliación milonítica D2, las lineaciones (flechas simples) más frecuentes y los sentidos de movimiento tectónico (flechas dobles). A: unidad de rocas ultramáficas serpentinizadas; B: Fm. Atalaya.

second, a significative underthrusting took place, in such a way that although both the autochthonous and its tectonic gneissic cover underwent an intense sinistral shearing, it was the lower plate movement towards the SE the leading force which guided the bulk sinistral wrenching. The two posibilities agree with the general scheme of sinistral wrenching in the Badajoz-Córdoba Shear Belt, at least from a geometrical point of view. Nevertheless, in the author's opinion, the second posibility accounts better for the regional tectonic framework of the Badajoz-Córdoba Shear Belt and the Ossa-Morena stablished so far (c.f. Burg *et al.*, 1981, 1987).

At the Window scale the effect of the different behavior of the lower and the upper unit is clear, as shown in figure 7. In the Window inwards the strain trajectories net has been constructed from the traces of C planes and the shear strain angles calculated before for the RF Gneiss. The trajectories in the Window outwards correspond to the traces of D2 mylonitic foliation in the Azuaga Gneisses. The inner grid evidences, firstly, the inhomogeneous character of deformation in the RF Gneiss, as strain increases towards the contact with the Azuaga Gneisses (thrust boundary) and within the inner band of fine-grained mylonitic gneisses; and secondly, the strain partitioning between the window inwards and outwards. It is easilly accepted that the Azuaga Gneisses underwent a deformation larger than the RF Gneiss, being such feature specified in the layout that mylonitic foliation trajectories display around the latter. The bulk strain pattern involves, thus, a relatively strong and less-strained gneissic core surrounded by a largely strained unit which wraps on all sides of such core (the Azuaga Gneisses). This scheme could be regarded as a plurikilometric oblong "megaclast system", geometrically similar to the sigma-type porphyroclast systems from Passchier and Simpson (1986), the latter evidencing a non-coaxial flow in a continuum surrounding an isolated rigid object. In any case, the resulting strain pattern and strain partitioning between the RF and Azuaga Gneisses should be considered as a consequence of: first, different rheological bahavior of the RF Gneiss respect the Azuaga Gneisses; second, a transpressive sinistral shear regime; and third, underplatting of the lower unit beneath the allochthonous gneissic cover.

The composition of the tectonic motions magnitude in the RF Gneiss from the previously calculated

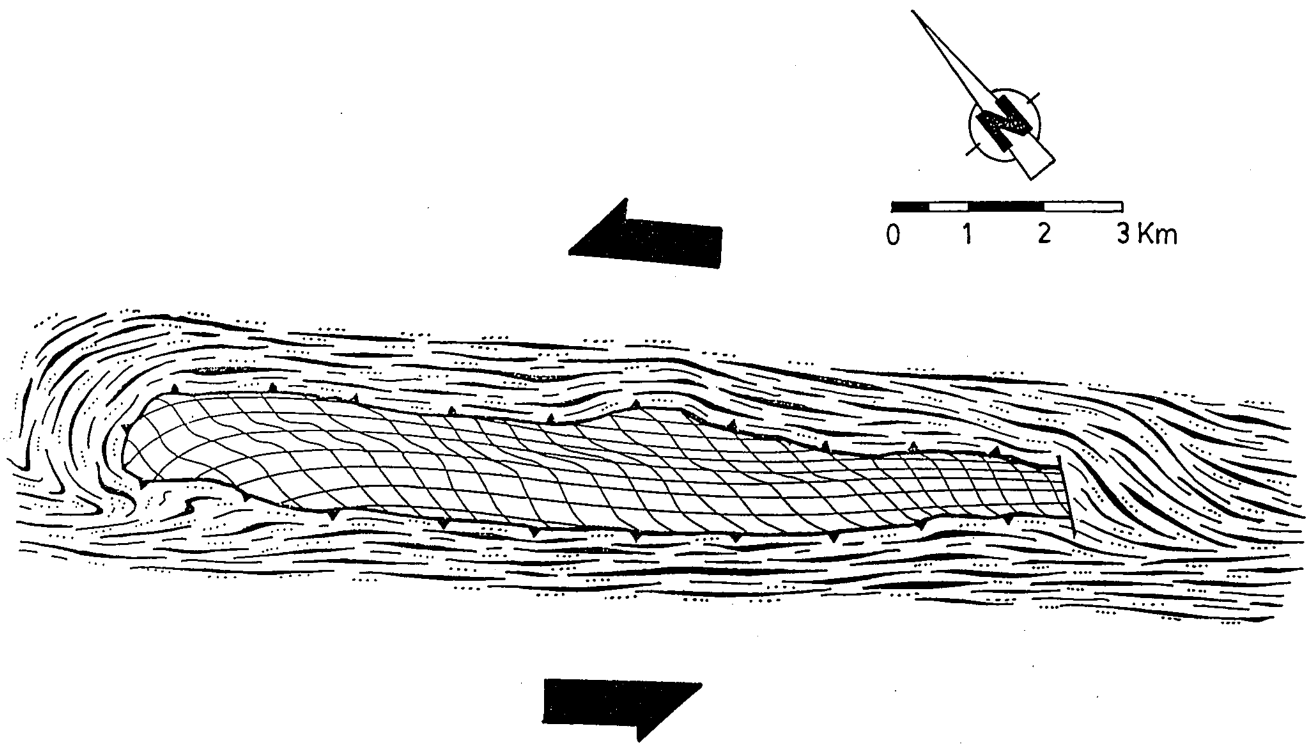

Fig. 7.-Idealized structural sketch where the trajectories of Variscan mylonitic deformation in the Azuaga Gneisses (allochthonous) are represented together with the strain field net in the autochthonous.

Fig. 7.-Esquema estructural idealizado donde se representan las trayectorias de la foliación milonítica Hercínica en los Gneises de Azuaga (alóctono) junto con la red correspondiente al campo de deformación en el autóctono relativo.

shear strain values, the strain grid and the gneiss thickness perpendicular to the C planes yields 3.0-3.2 km. These figures should be minimum values of the relative displacement of the NE boundary autochthonous-allochthonous respect the SW limit. From these results, a tectonic displacement much more larger than 25 km should have taken place between the Hornachos and the Azuaga Faults during Variscan ductile strike-slip tectonism. Burg *et al.,* (1978) calculated 72 km for such displacement from quartz C-axis fabrics and considering the transverse structure of the Badajoz-Córdoba Shear Zone formed by mylonitic rocks with an uniformly subvertical mylonitic foliation. It is to be signed here that quartz C-axis fabrics are not only sensitive to shearing, but also to flattening, and the angle between the inferred C planes (basal plane criterion from Berthé *et al.,* 1979 and Bouchez and Pécher 1976 and the mylonitic foliation should not be expected to reflect plane strain solely, as pointed by Schmid and Casey (1986), unless other evidences of plane strain are available, which is not our case. In the same way, the transverse structure of the Badajoz-Córdoba Shear Zone proposed by Burg *et al.,* (1981) does not seem to be realistic from our data here presented. Therefore, in the author's oppinion, the Burg *et al.,* (1981) estimation should be disregarded.

8. CONCLUSIONS

The structural and kinematic study carried out in this paper evidences special features of deformation under transpression. The RF Gneiss underwent sinistral shearing during Variscan times and was deformed together with a gneissic polimetamorphic tectonic cover under high-T greenschist to low-T amphibolite facies conditions. The contrasted rheological behavior between these two units was responsible for the strain partitioning observed, resulting what has been labelled "megaclast system". Kinematic inferences suggest that underthrusting in a transpressive regime could account for both the observed structural framework and the so far known regional tectonic evolution of the Badajoz-Córdoba Shear Belt.

It is to be signed here that the tectonic evolution here ascribed to Variscan tectonothermal events is the unique process recorded by the RF Gneiss structural features. Notwithstanding, there exist a group of structural criteria to deduce that both the host of the RF Gneiss (the Atalaya Fm.) and the tectonically overlying Azuaga Gneisses suffered a previous, and thus pre-Variscan, deformational and metamorphic event which has to be described and characterized.

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