Deformed porphyry dikes in the Spanish Central System

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Abstract. — This work studies different types of deformational fabrics in porphyry dikes, which trend EW in the Spanish Central System. These fabrics may be ascribed to two different stress regimes: intrusion-related and tectonic-related. Most of the fabrics belong to the first type and they are due to stresses arising within the dike/host-rock interface. Some of these structures are used as kinematic indicators of the sense of intrusion. Lastly, some of the properties of the dikes are discussed, and a regional interpretation for their intrusion is proposed.

Key words: Porphyry dikes, deformational fabrics, intrusion-related, tectonic-related, sense of intrusion.

FILONS PORPHYRIQUES DEFORMES DANS LE SYSTEME CENTRAL ESPAGNOL

Résumé. — Nous étudions différents types de fabriques de la déformation, dans des réseaux EW de filons porphyriques du Système Central Espagnol. Ces fabriques répondent à deux régimes d'efforts différents: l'intrusion magmatique et la déformation tectonique. La plupart de celles-ci appartiennent au premier groupe et sont dues aux efforts qui se concentrent sur les contacts filon/encaissant. Différentes figures structurales sont utilisées comme indicateurs cinématiques du sens de l'intrusion. Finalement, nous discutons quelques unes des propriétés des filons, et nous proposons une interprétation régionale pour leur intrusion.

Mots cles: Filons porphyriques, fabriques de la déformation, efforts intrusifs, efforts tectoniques, sens de l'intrusion.

Introduction

This paper studies a variety of deformational fabrics displayed by EW trending dike swarms (probably Permian in age), which transect 340-275 Ma old late Hercynian granitoids (Ibarrola et al., in press) in the Spanish Central System (Fig. 1). These dikes are mainly calc-alkaline in composition (microdiorites to leucogranites), but some K_2O-rich monzonitic types also exist (Huertas & Villaseca, 1987). Within the calc-alkaline group, quartz porphyry dikes (s.l.) are the most abundant, while microdiorites and some aplites are subordinate.

The deformational structures observed in these dikes correspond to two different stress regimes: intrusion-related stresses, that characterize dikes with deformed borders and undeformed cores; and tectonic-related stresses, giving rise to S and C planes (as defined by Berthe et al., 1979) across the whole volume of the dikes. The three types of fabrics observed in these dikes (flow, mylonitic, and brittle structures) are strongly heterogeneous, both in their amount of deformation and their degree of penetrativity. Hence, any structural type may be found in a given dike, with no predictable pattern. Such an heterogeneity seems to be related to the changing rheological behaviour of the magma, spatially due to the complexely-shaped dike conduits, as well as temporally during solidification of the magma. Many of the intrusion-related structures that develop at the dike/host-rock interface, have proved to be useful flow-sense indicators (this topic has been investigated by some authors, such as Blanchard et al., 1979; Blumenfeld, 1983; Chown & Archambault, 1987; Baer & Reches, 1987 and Ubanell & Doblas in press).
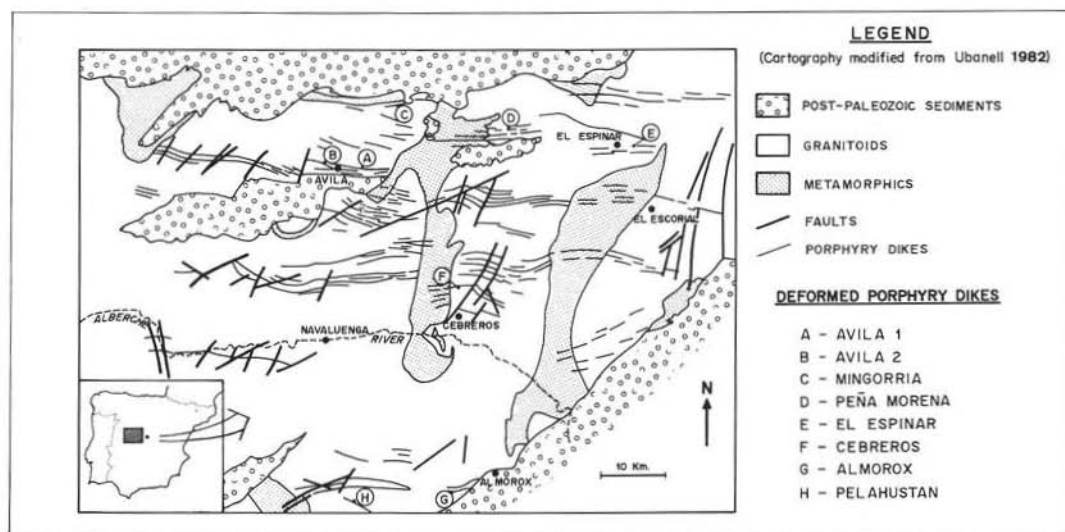
Lastly, some of the rheological properties

Fig. 1. — Geological setting of studied area.

of the dikes are discussed, and a possible regional interpretation for their intrusion is proposed.

Observed deformational fabrics

A) Intrusion-related structures

The intrusion of the magmatic materials within the dike conduits leads to different types of structures typically found in two zones: within the dike borders, or within the host-rock. The central part of the dikes is usually structureless, except in cases of very thin dikes (BARRIERE, 1976; ROSS, 1986). As we will see, some of these deformational fabrics are useful kinematic indicators of the sense of injection, (Fig. 2).

The intrusion-related structures found within the dike borders belong to two groups: flow structures, and mylonitic/brittle structures.

Flow structures develop in the dike borders as a result of inner and hot magmas sliding against the passive and cold host-rocks. They are heterogeneous at all scales, microscopic to metric, with no predictable pattern. The different structures that are encountered are schematized in Figure 2A: n.1 and 2: complex rheomorphic or isoclinal folds (see also Fig.

3A), often found in wedges penetrating into the host-rocks; n.3: heterogeneously folded veins intruding the host-rocks; n.4: autobrecciated margins probably due to several pulses disrupting the previously consolidated margins; n.5: flow layering, locally disturbed by border irregularities; and n.6: asymmetric folds with opposite vergences at the two margins of the dikes, indicating the sense of the magma flow.

Mylonitic and brittle structures that occasionally appear on the dike borders are interpreted as due to the forcible flow of the magmatic material, which locally triggered high strain gradients between the margins and the center of the dikes (as stated by WISE et al., 1984, mylonites and cataclasites are not exclusively related to fault environments). Different mesoscopic and microscopic structures, which also may indicate the sense of flow, develop as represented in Figure 2B: n.1, and 3): SC composite planar fabrics (BERTHE et al., 1979), with opposite senses of shear in the two borders (see also Fig. 3B and C); n.4: chilled margins with rheomorphic folds grading inwards into SC fabrics; n.5: ultramylonites, often displaying relict SC planes; n.6: slickenside striations on the dike/host-rock marginal planes, indicating the direction of flow; n.7: microscopic SC
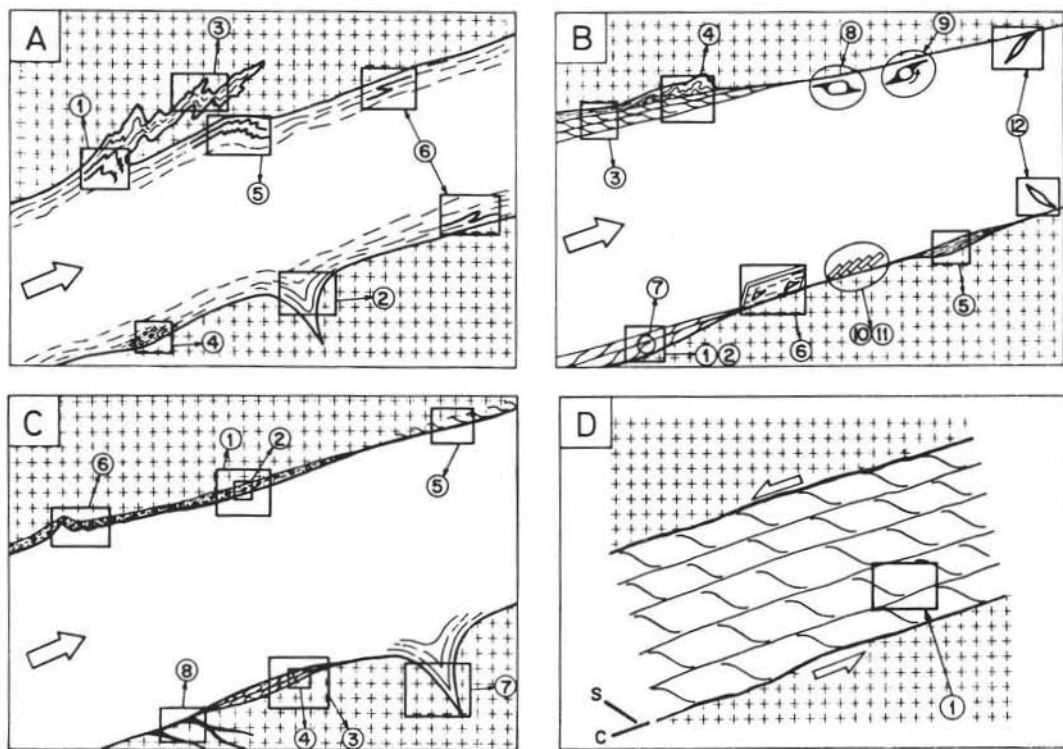
Fig. 2. — Idealized diagrams showing main types of deformational fabrics observed in porphyry dikes (see details in text). A) Flow structures. B) Mylonitic and brittle structures. C) Host-rock structures. D) Tectonic-related structures. Crosses: Host-rocks.

sigmoidal patterns; n.8: locked phenocrysts with synthetic/asymmetric tails; n.9: rotated phenocrysts with antithetic/asymmetric pressure-shadows; n.10: shear-stepped fractured phenocrysts with antithetic microfractures (see also Fig. 3D), as defined by BLANCHARD et al. (1979) and BLUMENFELD (1983); and n.12: tension gashes filled with siliceous material, exhibiting opposite vergences in the two borders (CHOWN & ARCHAMBAULT, 1987).

Some intrusion-related deformational fabrics are also observed in host-rocks, in their immediate contacts with the dikes, probably resulting from high stress concentration induced by the forcible flow of the intrusive material. The following structures were observed, and they are schematically represented in Figure 2C; n.1: cataclastic borders with occasional development of a single mylonitic foliation; n.3: SC composite

planar fabrics (indicating the flow-sense), that are locally cross-cut by extensional shear planes (see also Fig. 3E); n.5: a single mylonitic S foliation, which also indicates the sense of intrusion; n.6 and 7: characteristic wave-shaped dike/host-rock interfaces, with the tips pointing outwards from the dikes (see also Fig. 3F), often displaying wedge-shaped intrusions of magma into the wall-rocks; and n.8: oblique cataclastic/pseudotachylitic veins oriented as synthetic R Riedel fractures, which also indicate the sense of flow.

B) Tectonic-related structures

One of the dikes studied here (dike H) exhibits pervasive SC composite planar fabrics, always indicating the same sense of shear (sinistral; Fig. 2D). These SC structures are ascribed to tectonic stresses because intrusion-related SC fabrics only affect the
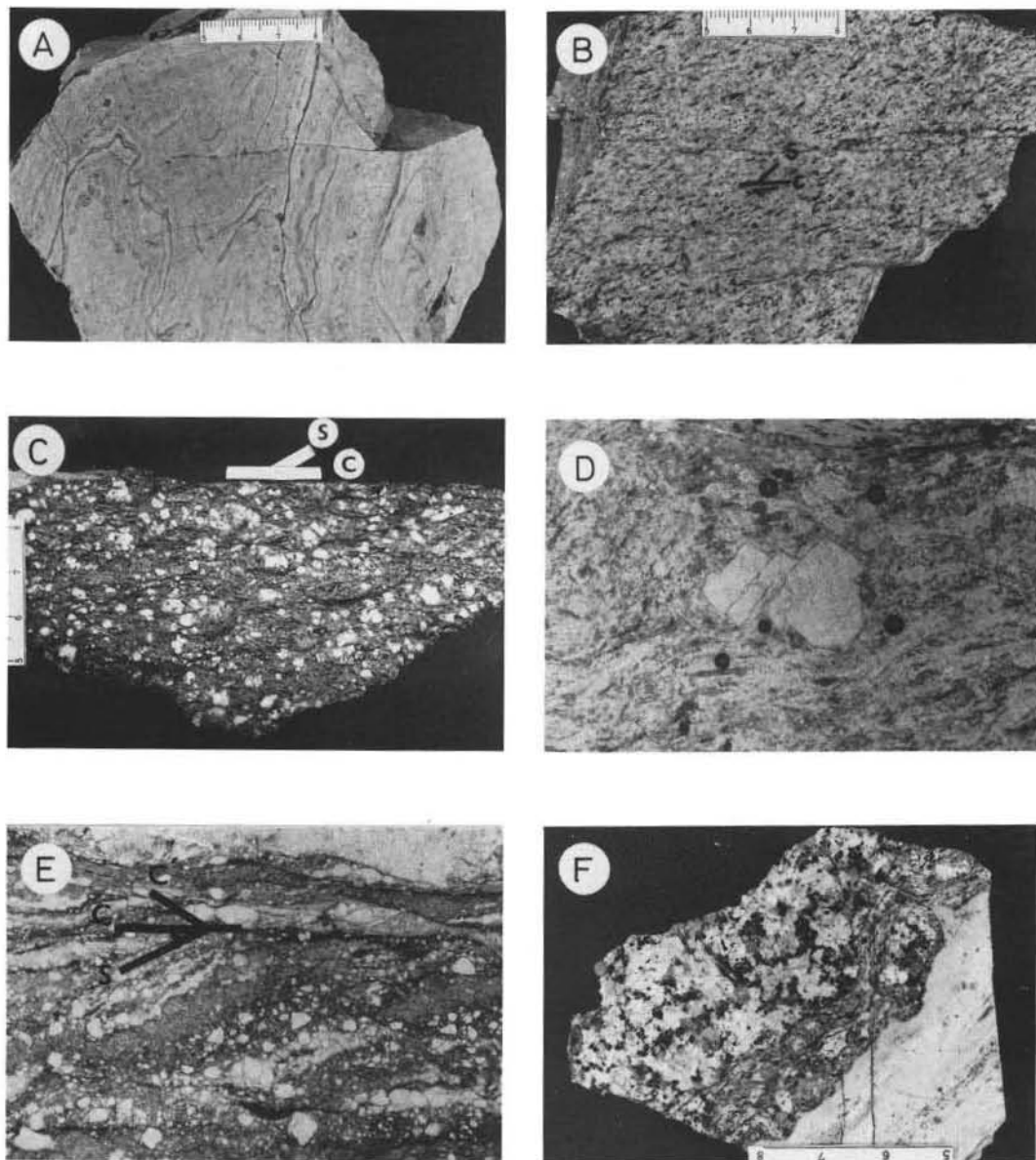
Fig. 3. — Examples of deformational fabrics found within dikes. A) Complex rheomorphic folds (dike G). B) SC composite planar fabrics (aplitic dike C). C) SC composite planar fabrics (porphyry adamellitic dike D). D) Shear-stepped fractured phenocryst (dike D; size of microphotograph: 0.95×0.65 mm). E) SC composite planar fabrics disrupted by Ć extensional shear planes (dike F). F) Cataclastic wave-shaped dike/host-rock interface (dike A).

dike/host-rock interface with opposite senses of shear on the two borders, leaving the center of the dikes undeformed. On the contrary, the intrusion of dike H probably happened during the sinistral motion of a shear zone, because no evidence of similar deformation is found in the host-rocks (TALBOT, 1982).

Nature of flow in the dikes

Development of intrusion-related structures at the dike/host-rock interface, is probably related to the nature of the magma flowing through the conduit. The basic and intermediate varieties do not show any

TABLE 1

Chemical analysis, and estimated densities and viscosities of dike melts

	1	2	3
SiO2	75.41	68.76	73.75
Al2O3	12.89	14.99	13.84
Fe2O3	1.09	3.60	0.24
FeO	---	---	1.20
MnO	0.04	0.08	0.03
MgO	0.09	0.76	0.42
CaO	0.30	2.60	0.43
Na2O	3.44	3.23	3.10
K2O	4.74	4.00	5.44
TiO2	0.01	0.51	0.22
P2O5	---	0.14	---
H2O	0.83	0.77	1.20
	98.84	99.44	99.87
Densities (qm/cc)	2.37	2.46	2.41
Viscosities (poises)	10^9	10^6	10^8

1) *Porphyry leucogranite.* 2) *Porphyry adamellite.* 3) *Aplite. Chemical data from* BRANDERBOURGER *(1984). Estimations based on methods of* BOTTINGA & WEILL *(1970) and* SHAW *(1972), for temperatures between 700°-800° and low water contents (2-3% wt)*

deformational structures; on the contrary, they are frequent in the acid dikes. The minimum viscosities have been calculated in Table 1, taking into account the porphyricity index which reaches values of 0.4 to 0.5 in the porphyry dikes. The crystallinity index of these magmas (θ) may increase the viscosity up to seven times the reference value, if the effective viscosity (η_e) calculation is applied (ROSCOE, 1953; WICKHAM, 1987): $\eta_e = \eta$ $(1-1.35 \; \theta)^{-2.5}$. The non-porphyritic aplite dikes, which are generally richer in H_2O (Table 1) might display the lowest viscosity values. From the calculated Reynolds' numbers (Re) in Table 2, we may infer that the flow within the dikes was always of the laminar type (the flow is turbulent if Re exceeds a critical value which is aproximately 2000). This behaviour is due to the high viscosities of these magmas, flowing in narrow conduits (dike width ≤ 30 m). The laminar regime of the flow, and the consequent generation of chilled margins, would avoid disruption and significant

contamination/assimilation of the conduit walls (CAMPBELL, 1985). The progressive solidification from the border to the center of the conduit increases substantially the magma viscosity, enhancing the subsolidus deformation of the outer rigid margins.

Discussion

Informations on flow-senses in dikes may be decisive in establishing models concerning the magmatic pattern and the geodynamic evolution of a region. A classification of the different flow-sense criteria that have been observed in our dikes at all scales is here proposed (Fig. 4). These criteria are based on the asymmetric/oblique character of the structures with respect to the dike walls, that are opposite on the two margins. Additionally, the magmatic flow-direction is revealed by slickenside-striated planes along the dike borders. These kinematic indicators are found at the dike/host-rock interface, while the inner part of the dike remains undeformed.

Knowledge of the magmatic flow-senses for the studied area, combined with the regional dike pattern, allow us to propose the following integrated macroscale interpretation for their intrusion (Fig. 5). The porphyry dike swarms, which emplaced parallel to the regional EW trends, would represent «mega-tension gashes» corresponding to a stress-field with an EW trending $\sigma 1$ axis, and a NS trending $\sigma 3$ axis. One of these dikes (G in Fig. 5) is

TABLE 2

Nature of flow in the dikes (Re calculated for the two extreme rheological conditions evaluated in Table 1)

Viscosities (poises)	10^9	10^6
Dikes widths (m)	Reynolds numbers	
1	3×10^{-5}	3×10^{-2}
10	9×10^{-4}	9×10^{-1}
30	5×10^{-3}	5
Densities (qm/cc)	2.37	2.46

Calculated Reynolds' numbers (Re) are given by: $Re = (g\Delta\varrho/k)^{1/2} \; d^{3/2} v^1$; *g: gravity acceleration, 980 cm/s²; ϱ: density; $\Delta\varrho$: 0.01 g/cc; K: friction coefficient = 0.03; d: dike width; v: kinematic viscosity*

sigmoidally deformed by a transcurrent shear band, whose dextral displacement is compatible with this stress-field, as suggested by UBANELL (1976), and UBANELL & DOBLAS (in press). This stress-field is also compatible with the emplacement and tectonic deformation of dike H along a NW-SE trending sinistral shear zone. This late Hercynian stress regime corresponds to the «ductile transcurrent episode» defined at a regional scale by DOBLAS (1987), FERNANDEZ & DOBLAS (1987), and UBANELL & DOBLAS
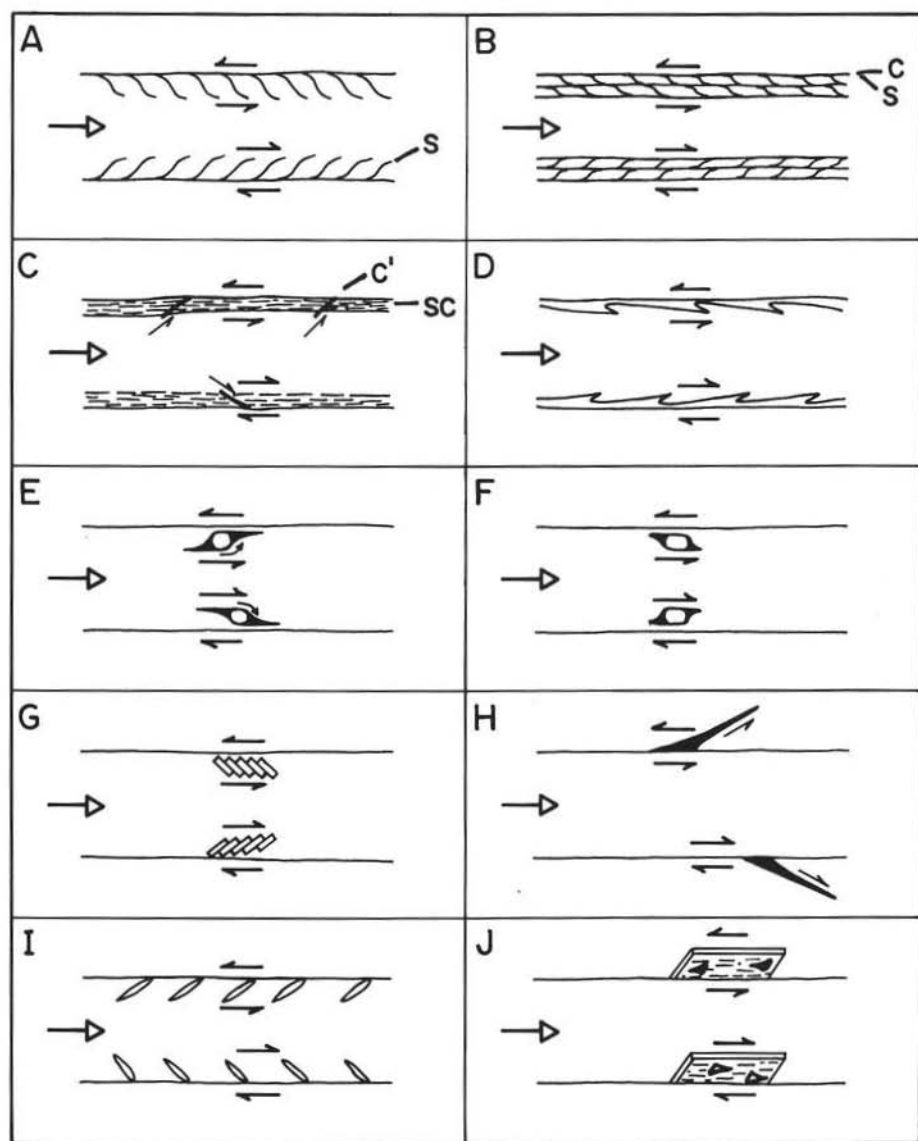

Fig. 4. — Schematic diagram showing some flow-sense criteria. A) S mylonitic foliation. B) SC composite planar fabrics. C) Ultramylonites with S and C parallel, and isolated Ć extensional shear planes. D) Asymmetric folds. E) Rotated phenocrysts with antithetic/asymmetric pressure-shadows. F) Locked phenocrysts with synthetic/asymmetric tails. G) Shear-stepped fractured phenocrysts. H) Cataclastic/pseudotachylitic veins oriented as synthetic R Riedel fractures. I) Tension gashes. J) Slickenside features on planes parallel to dike borders, with striations indicating flow-direction, and steps indicating flow-sense. Crosses: Host-rocks.
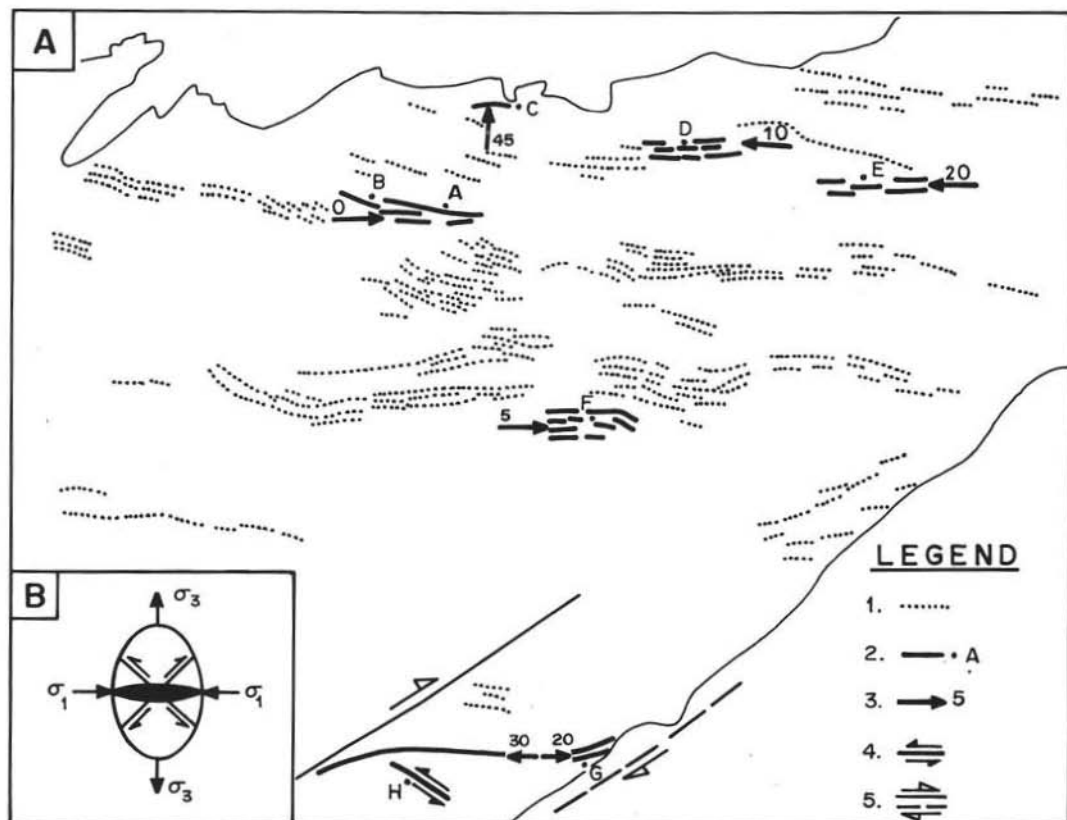
Fig. 5. — Proposed regional interpretation for dike intrusion. A) Legend of map: 1) Porphyry dikes; 2) Deformed porphyry dikes; 3) Sense and direction of dike intrusions, with indication of plunge (dipping downwards); 4) Sinistral shear zone where dike H was synkinematically emplaced; 5) Dextral mega-shear band. B) Proposed regional stress-field for dike intrusion.

(in press). This event post-dates a NS trending extensional one (with a vertical σ 1 axis), that has been interpreted by DOBLAS (1987) as a large-scale detachment dipping to the N, with a northward extensional motion.

The localization of these dike swarms along a specific 40 km wide EW trending belt in the studied area, may be a consequence of the detachment, which possibly triggered an EW trending domal-shaped structure (DOBLAS, 1987). This dome, due to the upward arching of the detachment surface by tectonic denudation and isostatic rebound, facilitated the preferred intrusion of the dike swarms (DOBLAS, 1987). The magmatic flow-senses and directions of Figure 5 tentatively suggests that the northern and southern areas exhibited, respectively, convergent and divergent magmatic flow lines.

Much field, laboratory, and experimental work remains to be done, in order to fully understand the following points: 1) Why such deformational fabrics on the dike/host-rock interface are so heterogeneous and have no predictable pattern?; 2) What are the dynamical conditions of the magma that determine the presence of deformational structures in this interface?; 3) What is the regional flow pattern of the dikes?

Conclusion

Different deformational fabrics are described in some EW trending porphyry dikes in the Spanish Central System. These structures may be ascribed, either to tectonic,

or to intrusion-related stresses. One contribution of this paper may be the description of new intrusion-related structures that have proved to be useful kinematic indicators of the magmatic sense of flow.

The existence and type of intrusion-related deformational fabrics at the dike/host-rock interface probably depends on different factors, the main one being the strongly laminar character of the magmatic flow patterns.

All these dike swarms are interpreted as «mega-tension gashes» corresponding to a regional late Hercynian EW compressional regime. The dikes were probably intruded along an EW band, defined during a previous extensional event.

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