Discriminating Variscan and Alpine deformation in the Eastern Pyrenees. Insight from an AMS study in the Sant Llorenç-La Jonquera pluton

Discriminando las deformaciones varisca y alpina en el Pirineo oriental. Evidencias basadas en un estudio ASM en el plutón de Sant Llorenç-La Jonquera

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RESUMEN

Las fábricas anisótropas magmáticas en el plutón de Sant Llorenç-La Jonquera, determinadas mediante la técnica de la anisotropía de la susceptibilidad magnética (ASM), presentan una dirección predominante NE-SW y responden al emplazamiento sintectónico de una secuencia de granitoides durante la fase varisca transpresiva F_2. La foliación magmática se encuentra localmente perturbada por el efecto de dos eventos tectónicos de naturaleza y edades distintas. Un primer tipo de perturbación es la derivada de la presencia de zonas de cizalla tardi-variscas (F_3) de dirección NW-SE, como es el caso de la banda milonítica de El Pertús. El otro tipo de perturbación consiste en un basculamiento de eje WNW-ESE, localizado en el borde meridional del batolito y atribuible al plegamiento alpino. El presente estudio contribuye a esclarecer cuales son los efectos de la orogenia alpina en el zocalo varisco de los Pirineos.

Palabras clave: *ASM, granito sintectónico, orogenia alpina, orogenia varisca, Zona Axial Pirenaica*

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Introduction

The application of the anisotropy of magnetic susceptibility technique (AMS) to the Axial Zone of the Pyrenees, and more specifically to granitoids, has contributed much to prove the syntectonic character of a majority of the Variscan plutons (Gleizes *et al.*, 1997, 1998a; Olivier *et al.*, 2008). Moreover, with the AMS method and other conventional structural analysis techniques, it has been widely demonstrated that these plutons were emplaced and subsequently deformed after their emplacement under a bulk Variscan transpressive regime (Leblanc *et al.*, 1996; Gleizes *et al.*, 1998b, 2001; Carreras *et al.* 2004; Auréjac *et al.*, 2004).

In this work we present some preliminary results from an AMS analysis of granitoids from the Sant Llorenç-La Jonquera pluton (Eastern Pyrenees). We focus on the variations in the orientation of magmatic fabrics and examine to which extend such variations are related to post-emplacement deformation structures and what is the nature and age of such structures.

Main features of the Sant Llorenç-La Jonquera pluton

The Sant Llorenç-La Jonquera (SL-LJ) pluton is one of the largest Variscan calc-alkaline, mainly granitoid plutonic complexes in the Pyrenees, extending for about 400 km^2 in the east Canigó, Roc de Frausa and west Albera massifs (Fig. 1) and arranged in roughly sheet-shaped intrusions (Autran *et al.*, 1970; Estevez, 1973; Liesa, 1988; Liesa, 1994; Debon *et al.*, 1996). Compositionally, the intrusive suite ranges from minor mafic (gabbroid) facies to intermediate (diorites, tonalites, granodiorites, Fig. 2a) and felsic types (e.g. Sant Llorenç-Boadella granite and Agullana leucogranite dyke swarm). The whole plutonic complex cuts different structural levels and metamorphic zones. The mafic intrusions are emplaced in high-grade schists and gneisses, whereas the felsic types (except the anatectic granites) are emplaced in low-grade metasediments. Liesa and Carreras (1989) and Liesa (1994) showed that the intrusive sheets, together with the main foliation in the host rocks, were affected by two late deformation episodes that were responsible for the dome geometry of the Roc de Frausa massif. According to Vilà *et al.* (2005, 2007), contact metamorphism features indicate that these magmatic rocks were emplaced during the regional D_2 deformation event, which is coeval with the metamorphic climax.

The magmatic rocks of the SL-LJ pluton are also locally affected by NW-SE trending dextral-reverse shear zones, developing into mylonites (Fig. 2b, Carreras *et al.* 1980; Liesa and Carreras, 1989). The El Pertús mylonitic band, located north of La Jonquera, is the broadest shear zone system that affected the magmatic rocks (Fig. 1a) which has been interpreted as late Variscan by Maurel *et al.* (2004).

In the southern part of the pluton, the granitoids are unconformably overlain by a Mesozoic-Tertiary sedimentary

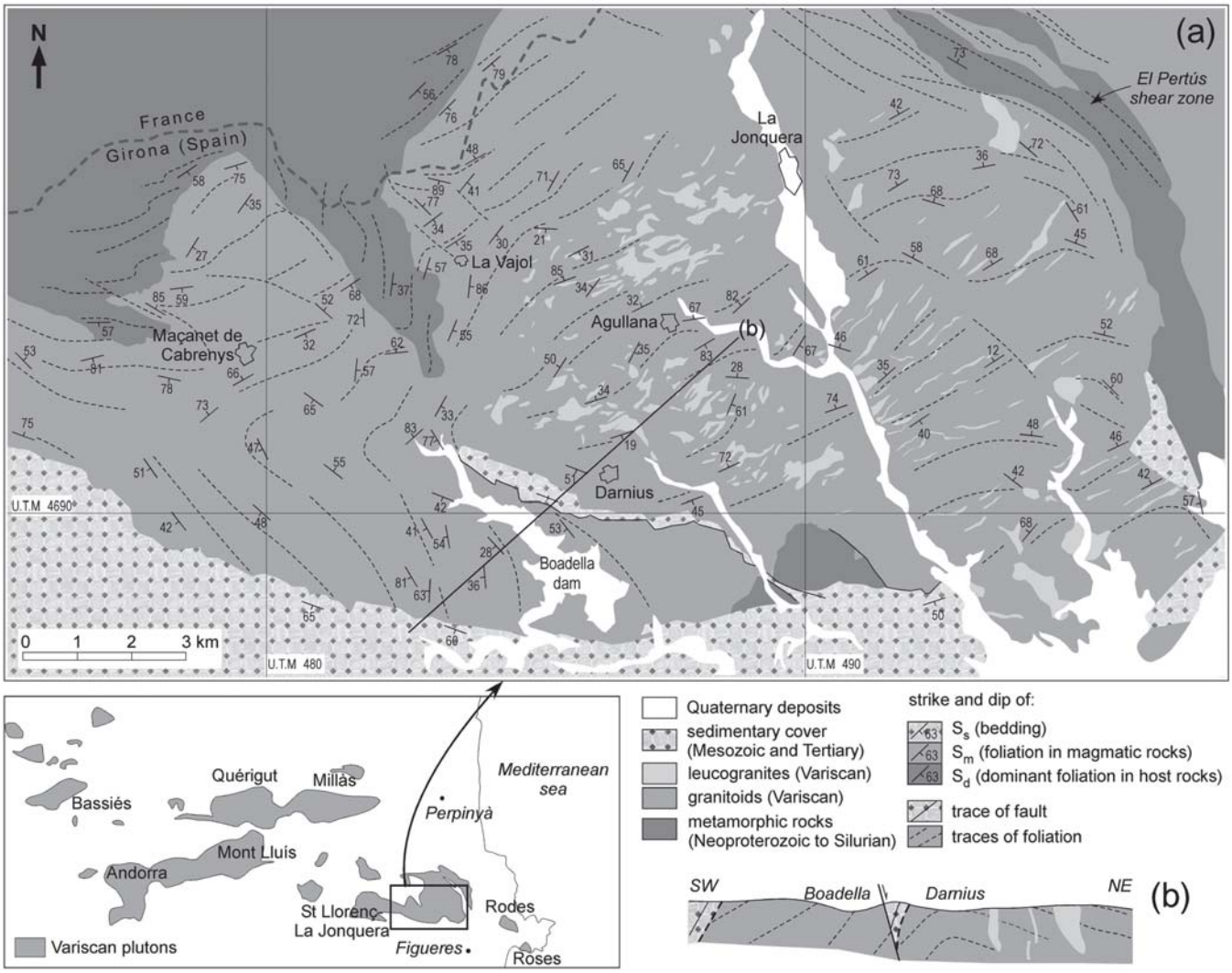

Fig. 1.- (a) Schematic structural map of the central part of the Sant Llorenç-La Jonquera pluton showing the trajectories of foliation deduced from the AMS study and direct field measurements. Main lithological units and contacts are compiled from Cirés *et al.* (1994), Liesa *et al.* (1994) and Debon *et al.* (1996). (b) Cross section through the pluton's southern margin, showed as a line in (a).

Fig. 1.- (a) Mapa structural esquemático de la parte central del batolito de Sant-Llorenç-La Jonquera donde se muestran las trayectorias de la foliación deducidas a partir del estudio ASM y de mediciones directas en el campo. Las principales unidades litológicas se han compilado a partir de Cirés et al. (1994), Liesa et al. (1994) y Debon et al. (1996). (b) Corte esquemático del sector meridional del pluton, indicado como línea en (a).

sequence (Figs. 1, 2c, Cirés *et al.*, 1994; Liesa *et al.*, 1994). Whereas the rocks of the sedimentary cover are affected by Alpine folds and thrusts, the effect of Alpine deformation on the Variscan basement remains subject of debate (Liesa *et al.*, 1994).

Structural trends from the AMS study

A distinct feature, already observed in earlier studies on the SL-LJ pluton (Liesa and Carreras, 1989; Liesa, 1994), is its complex deformation history. In order to gain insight into this history, a magneto-structural study is currently being carried out. Here we present results and interpretations derived from the first stages of the project, which focussed in the central part of the batholith (Fig. 1a).

We measured magnetic susceptibility and anisotropy of magnetic susceptibility of about 100 granitoid samples. The AMS technique is based on the relationship that exists between magnetic and mineral fabrics in rocks (Borradaile and Henry, 1997; Bouchez, 1997, 2000). AMS measurements performed with a Kappabridge KLY-3 susceptometer allow the determination of the orientations and magnitudes of the three main axes $K1 \geq K2 \geq K3$ of the magnetic susceptibility ellipsoid. From this mean ellipsoid, the average susceptibility ($Km = (K1 + K2 + K3)/3$), magnetic lineation (K1) and foliation (plane normal to K3) are determined. To characterize the deformation rate, we have used the magnetic anisotropy parameter $Ppara\% = 100*[(K1-D)/(K3-D)-1]$, where D is the diamagnetic contribution.

In general, the magnetic fabric is characterized by low anisotropy values (the average value of the parameter Ppara% is 2.2%). These magnitudes contrast with the higher values recorded in other Variscan plutons in the Pyrenees, such as e.g. the Mont Lluís-Andorra (average Ppara% = 3.5%, Bouchez and Gleizes, 1995) and Quérigut (average Ppara% = 3.4%, Auréjac *et al.*, 2004). Moreover, anisotropy values decrease from north to south consistently with the observed main petrographic zonation and distance from the pluton floor. The highest anisotropies are recorded close to the contact with the metamorphic host rocks (mean Ppara% = 3.5%,), where tonalites and granodiorites have a visible

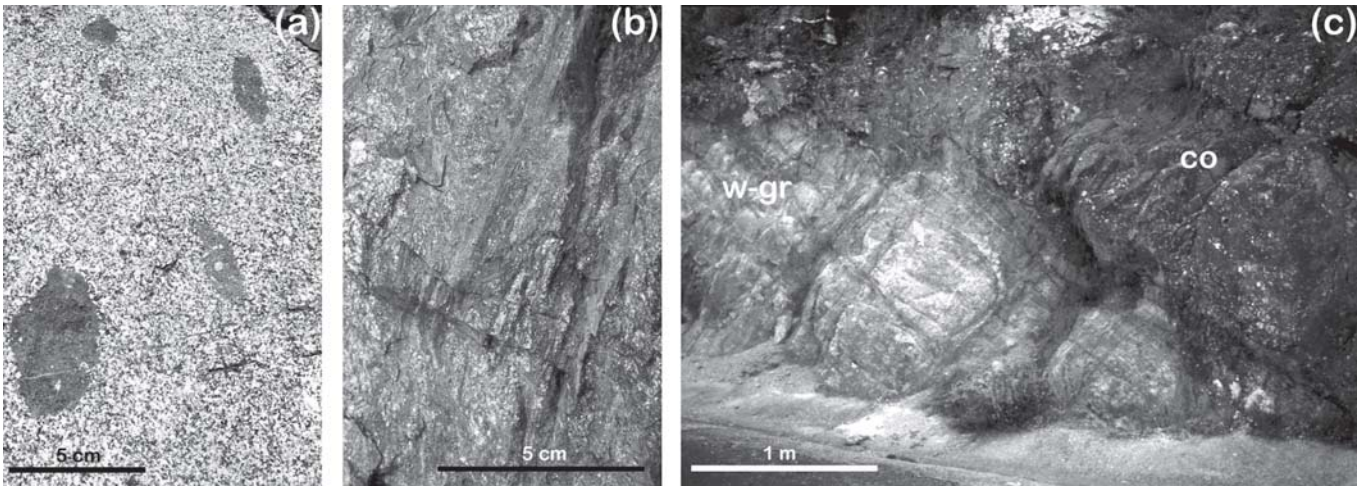

Fig. 2.- Field photographs. (a) Tonalite-granodiorite with elongate microgranular mafic enclaves that define a magmatic foliation. North of La Vajol. (b) Mylonitic tonalite characterized by the presence of a penetrative foliation developed at greenschist facies conditions. North of La Vajol. (c) Tilted unconformable contact between the Sant Llorenç-Boadella granite and the basal conglomerates attributed to the late Cretaceous - Early Paleogene (Garumnian facies; Cirés *et al.*, 1994). South of Boadella dam. w-gr = weathered granite (paleosol), co = conglomerates.

Fig. 2.- Fotografías de campo. (a) Tonalita-granodiorita con enclaves microdioríticos elongados que definen la foliación magmática. Norte de La Vajol. (b) Tonalita milonítica caracterizada por la presencia de una foliación penetrativa desarrollada en condiciones de facies esquistos verdes. Norte de La Vajol. (c) Contacto inconformable basculado entre el granito de Sant Llorenç-Boadella y los conglomerados basales atribuidos al Cretácico terminal - Paleógeno basal (facies garumniense; Cirés et al., 1994). Sur del embalse de Boadella. w-gr = granito alterado (paleosuelo), co = conglomerados.

magmatic fabric (Fig. 2a) defined by the alignment of amphibole and feldspar crystals and mafic enclaves. The weakest anisotropies are recorded in the large granitic bodies that wrap around the southern and eastern parts of the pluton (mean Ppara% = 1.1%).

In a large part of the pluton, the magmatic foliation inferred from AMS has a prevalent NE-SW trend with both NW and SE dips (Figs. 1a and 3a). These orientations can be correlated with the high-temperature foliations developed in the high-grade schists and migmatites from the Roc de Frausa massif. The magmatic lineations have a mean sub-horizontal N45º trend (Fig. 3b). Both magmatic foliations and lineations are comparable with fabrics determined in other plutons in the Pyrenees, which have been related to syntectonic granitoid emplacement during the Variscan D_2 transpressional event (Gleizes *et al.* 1998a, 2001; Auréjac *et al.*, 2004).

In the domain near the northeastern side of the mapping area, the trajectories of magmatic foliation form a sigmoidal deflection, with orientations ranging from NE-SW to E-W and finally NW-SE when approaching the El Pertús mylonitic shear zone. In other localities within the pluton, a similar pattern may be observed, clearly associated with the presence of D_3 retrograding mylonitic bands. The variation in trend and plunge of the magmatic lineation in the central part of the pluton (Fig. 3b) can also be attributed to the same D_3 event.

In the domain located south of Darnius and Maçanet de Cabrenys, the inferred magmatic foliations have anomalous NW-SE to N-S trends (Fig. 1a and 3c). Magmatic lineations also differ in orientation from those in the mean central domain, having moderate plunges towards the SW in the south domain (Fig. 3d). Mineralogy and microfabrics, however, remain unaltered.

The effects of the late Variscan and Alpine deformation events

The dominant NE-SW trending magmatic foliation inferred from the AMS analysis is locally perturbed by the effect of two post-emplacement structures of a different nature. One is responsible for the rotation of the magmatic fabric into parallelism with the NW trending D_3 dextral shear zones and also the local transformation of granitoids into mylonites (Fig. 2b), such as in the El Pertús mylonitic band. The other deformation structure can be deduced from the orientation of the magmatic foliation in the southern domain. This change in orientation of the magmatic foliation defines a WNW-ESE trending km-scale antiform (Fig. 1). The Tertiary unconformity, which outcrops only on the southern limb, is tilted southwards with a rather constant dip (H»60º, Fig. 2c). We removed the effect of tilting by coaxial rotation of the unconformity surface (S_5) to the initial orientation (horizontal) together with the mean magnetic foliation and lineation in the southern domain (Fig. 3e). The resulting untilted foliation and lineation have orientations close to those in the main domain (Fig. 3a, b). Thus, the present attitude of the magnetic foliation in the southern domain probably resulted from local southwards tilting (along a N110º axis) of the granites coupled to the cover rocks during the Alpine orogeny. According to Cirés *et al.* (1994), the Alpine folds and faults in the so-called «Darnius syncline», located south of Darnius (Fig. 1), extend westwards as mylonitic bands through the granitoids. However, we found no evidence that supports such a link. The antiformal structure described here is comparable to the one observed in the South Cap de Creus Peninsula at Roses (Carreras, 2001, his Fig. 4b). In that case, not only the axial planes of Variscan folds display an anomalous southward dip, but also the D_3 mylonitic bands affecting the Roses Granodiorite. Like the Southern Cap de Creus case (Carreras, 2001), the south-verging Alpine thrust affecting the Bielsa granite in the central Pyrenees (Casas *et al.*, 2003), the south tilting of Variscan foliations in the southern central Pyrenean Axial Zone (Hartevelt, 1970; Berastegui *et al.*, 1993) or the northwards tilting of Variscan fabrics in the Agly North Pyrenean massif (Olivier *et al.*, 2008), the SL-LJ case likely represents another piece of evidence for Alpine tilting of Variscan structures along the margins of the Axial Zone.

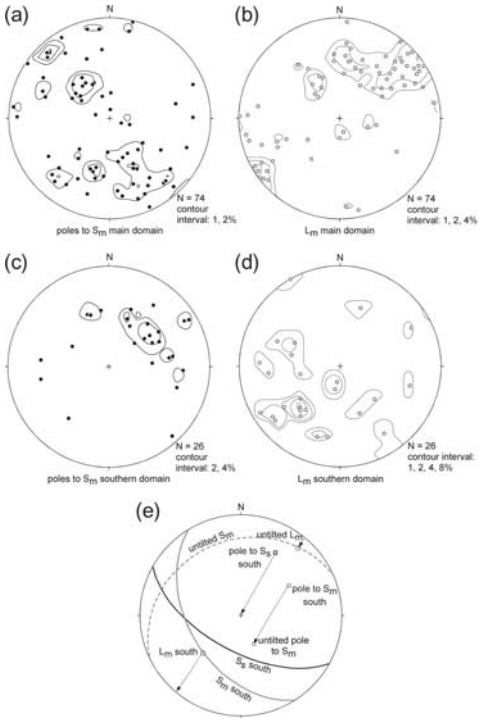

Fig. 3.- Equal area, lower hemisphere stereoplots of the analyzed structural elements. (a) and (b) magnetic foliations (S_m, poles) and lineations (L_m) from the main domain. (c) and (d) magnetic foliations (S_m, poles) and lineations (L_m) from the southern domain. (e) Removing the effect of tilting by coaxial rotation of the unconformity surface (S_s) together with the mean magnetic foliation and lineation in the southern domain. See the text for further explanation.

Fig. 3.- Estereogramas equiareales realizadas en el hemisferio inferior de los elementos estructurales analizados. (a) y (b) foliaciones (S_m, polos) y lineaciones (L_m) magnéticas del dominio principal. (c) y (d) foliaciones (S_m, polos) y lineaciones (L_m) magnéticas del dominio sur. (e) Restitución del basculamiento mediante rotación coaxial de la superfície de inconformidad (S_s) junto con la foliación y lineación promedio en el dominio sur. Ver explicación en el texto.

Conclusions

The AMS analysis performed in the SL-LJ batholith reveals the presence of magmatic mainly NE-SW trending foliations and shallowly NE plunging lineations, which are interpreted to result from the syntectonic emplacement of a granitoid sequence during the Variscan D_2 transpresive tectonic event.

The magmatic fabrics are locally perturbed by the presence of NW-SE trending late Variscan D_3 shear zones. Separate from this, magmatic fabrics at the southern margin of the pluton were folded together with the sedimentary cover due to the Alpine N-S compression. Thus, this study helps to discriminate Variscan and Alpine deformation in the basement of the Eastern Pyrenees.

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