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 F2. 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-varisca (Fj) 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-SEE, 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., 1996a; 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 km² 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 anatetic 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 D2 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. 2004; 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
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 magnetostructural study is currently being carried out. Here we present results and interpretations derived from the first stages of the project, which focused on 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 \( K_1 \geq K_2 \geq K_3 \) of the magnetic susceptibility ellipsoid. From this mean ellipsoid, the average susceptibility \( K_m = (K_1 + K_2 + K_3)/3 \), magnetic lineation \( (K_1) \) and foliation (plane normal to \( K_3 \)) are determined. To characterize the deformation rate, we have used the magnetic anisotropy parameter \( P_{para\%} = 100\%[(K_1-D)/(K_3-D)-1] \), where D is the diamagnetic contribution.

In general, the magnetic fabric is characterized by low anisotropy values (the average value of the parameter \( P_{para\%} \) is 2.2%). These magnitudes contrast with the higher values recorded in other Variscan plutons in the Pyrenees, such as e.g. the Mont Lluis-Andorra (average \( P_{para\%} = 3.5\% \), Bouchez and Gleizes, 1995) and Quérigut (average \( P_{para\%} = 3.4\% \), 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 \( P_{para\%} = 3.5\% \)), where tonalites and granodiorites have a visible
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Vajol. (b) Mylonitic tonalite characterized by the presence of a penetrative foliation developed at greenschist facies conditions. North of La Vajol.

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the pluton (Fig. 3b) can also be attributed to the plutonic (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 D1 transpressional event (Gleizes et al. 1998a, 2001; Auréjac et al., 2004).

In the domain located south of Darnius and Maçanet de Cabrenys, the inferred magmatic foliations have an 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 D1 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=60°, Fig. 2c). We removed the effect of tilting by coaxial rotation of the unconformity surface (Sj) 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 magmatic foliation in the southern domain probably resulted from local southwards tilting (along a N110° 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 D1 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.
Conclusions

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

The magmatic fabrics are locally perturbed by the presence of NW-SE trending late Variscan D3 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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