Measuring the effects of rheology and regional tectonics on the syntectonic rocks of a migmatitic complex from Cap de Creus

Efectos de la reología y de la tectónica regional en las rocas sintectónicas del complejo migmatítico de Cap de Creus

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Abstract

To deepen the understanding of the interactions between tectonics and magmatism in the mid to deep crust, a detailed petrostructural analysis has been performed in the southern area of Punta dels Farallons-Volt Andrau (Cap de Creus, Eastern Pyrenees). In this area, schists under high-grade conditions suffered partial melting while a sequence of intermediate to acid magmatic rocks were emplaced during the Variscan D2 transpressive deformation event. Both regional tectonics and rheological features controlled the way deformation localized in the various rocks of the migmatitic complex. Schists and migmatites have a penetrative sub-vertical foliation (S2). Strain measurements of deformed late veins and dykes have allowed us to determine the regional deformation post-dating their emplacement. Dextral transpression was associated to N-S sub-horizontal shortening and the principal extension direction switched from sub-vertical to sub-horizontal under bulk constriction to plane strain.

Key-words: Anatexis, Cap de Creus, deformation, granitoid, migmatite.

Introduction

Regional deformation during partial melting and magmatism has a major effect on the resulting rock structures (Sawyer, 2008). Moreover, the structural features of migmatitic terranes are also influenced by rheological parameters (Vanderhaeghe, 2009).

The Punta dels Farallons-Volt Andrau area is one of the migmatitic complexes in the Variscan basement of the north Cap de Creus (Fig. 1). The area consists of partially migmatized sillimanite schists, small heterogeneous bodies of quartz gabbro, quartz diorite and granitoids, and a widespread network of pegmatite dykes (Druguet, et al., 1995). The magmatic rocks are grouped in two associations: a calc-alkaline association that includes quartz gabbro, quartz diorite, tonalite, granodiorite and granite, and a peraluminous association represented by leucogranites and pegmatites. This later association is likely derived from partial melting of the pelitic peraluminous host schists (Damm et al., 1992; Druguet, et al., 1995), although an origin by fractionation of a granitoid magma is postulated by other authors (Alfonso and Melgarejo, 2003). Druguet and Hutton (1998) showed that local anatexis and magmatism (from basic to intermediate and acidic) in the Cap de Creus migmatitic complexes took place under the Variscan D₃ regional dextral transpression.

This paper analyzes the structural features of different lithologies around a transitional domain between high-grade sillimanite schists and migmatitic and magmatic rocks at the southern area of the Punta dels Farallons-Volt Andrau migmatitic complex. It is aimed to determine the rheological behavior of different materials, to estimate regional deformation and kinematics from deformed veins and dykes, and to
establish a petrostructural model for the evolution of the migmatitic complex.

**Petrostructure of South Volt Andrau**

The area is characterized by the presence of two types of high-grade schists. The most abundant type consists of mm-banded greywacke schists with quartz-feldspathic zones and darker zones rich in Bt±Crd±Sil. This layering has a sub-parallel foliation (S1) both being both folded by the D2 deformation phase (Fig. 2D). Fold axes are subvertical and parallel to L2 stretching lineation (Fig. 1C).

The migmatitic schists, which are predominant in the northeastern area, are stromatic and composed by coarse grained quartz-feldspathic bands (leucosome) of mm- to cm-thickness surrounded by mafic bands (melanosome), and bands of greywacke schists (mesosome). The relative percentages of leucosome, melanosome and mesosome vary around 30%, 15% and 55% respectively (Fig. 2A). This fact allows classifying these migmatites as metatexites (Sawyer, 2008). The stromatic banding is parallel to the regional E-W S2 foliation (Fig. 1). These migmatitic schists are interpreted as derived from partial melting of metapelites during D2.

The igneous rocks are heterogeneously distributed, although specially localized in the north (Fig. 1B). In this area, quartz diorites and tonalites predominate and form irregular elongated bodies in an E-W direction. They show a weak sub-vertical gneissic foliation that correlates with the S2 in the schists. These bodies are crosscut by all the others intrusive rocks. Granodiorite bodies have irregular to sub-tabular shapes and can be folded with the metamorphic host rocks, while they present a gneissic foliation parallel to the fold axial planes and the S2 in the schists, proving the syntectonic character of these rocks with D2 (Fig. 2B). The porphyritic granodiorite constitutes a S2-parallel E-W trending dyke of 2 m thickness. An E-W gneissic foliation overprints the porphyritic texture (Fig. 2C). The elliptical enclaves present in this dyke have a sub-vertical major axis that correlates with L2 in the schists.

The latest intrusions are leucogranites and pegmatites, which are present all over the study area. Leucogranites form a swarm composed by veins and dykes of variable dimensions, with lengths between a few cm and 20 m and thickness from a few mm up to 3 m, while pegmatites generally form larger bodies or dykes. According to their orientation (Fig. 1D), both leucogranites and pegmatites can be ptygmatically folded or boudinaged (Fig. 2D, E) and are generally devoid of internal planar fabric. The pegmatites have a predominantly E-W direction and cut all the previously described structures.

**Rheological aspects**

As described in the previous section, the diverse lithologies show different styles and degrees of deformation according to
their original shapes, orientations and times of emplacement with regard to D₂. In addition, it is envisaged that deformation also depends on rheological aspects, particularly on the competence contrast between different lithologies, which mainly depends on their mineralogical compositions and textural properties.

Meso- and micro-scale structures provide a qualitative indication about these rheological contrasts. Thus, different rock types can be ordered in an increasing degree of relative competence as: (1) migmatitic schists (melanosome and mesosome) and metagreywackes as the more incompetent rocks, (2) quartz-diorites and granitoids, (3) leucogranites and (4) pegmatites as the more competent rocks.

Fig. 2.- Field photographs from the study area in South Volt Andrau. A) Stromatic migmatite with differentiated leucosome, melanosome and mesosome layers. Layering is parallel to S₂ foliation. B) Folded sub-tabular granodiorite body showing an internal axial planar S₂ foliation. C) Detail of S₂ gneissic foliation in a porphyritic granodiorite. Feldspar phenocrysts are surrounded by the deformed matrix. D) A D₂ syntectonic leucogranite vein cross-cuts the folded schists. Both are coplanarly folded with a marked difference in strain: tight folds in the schists and open folds in the vein. E) Asymmetrically boudinaged leucogranite dyke. Boudins are delimited by dextral shear fractures.

Estimation of post-dyke strain

Because of the high competence contrast between leucogranites and schists,

![Fig. 3.- Ratios of A/λ and H/λ from measured fold profiles in leucocratic veins plotted in the strain contour map of Schmalholz and Podladchikov (2001). The solid lines refer to the competence contrasts and the dashed lines to the percentage of vein shortening.](image-url)
leucogranites become suitable as strain markers. Thus, a semi-quantitative strain analysis was performed from 22 stretched (folded and boudinaged) veins on sub-horizontal outcrops to determine the \( D_2 \) post-dyke strain ellipse, based on the method by De Paor (1988). From this 2D analysis, a 3D strain ellipsoid was then determined by assuming constant volume deformation \((X\times Y\times Z=1)\), which is reasonable for mid to deep crustal levels. The results are depicted in figure 4. It should be noticed that the obtained 25% \( D_2 \) regional shortening and bulk axial ratio \( R_{XZ} = 1.83 \) post-dating the dykes represent minimum values of strain, since the method assumes that the veins or dykes have not any homogeneous deformation.

Model of emplacement and deformation

The performed field analysis allows us presenting a model of the petrostructural evolution of the migmatitic complex in four main stages (Fig. 4).

1. Intrusion of quartz diorite and tonalite bodies induced partial melting of pelitic schists in a \( D_2 \) dextral transpressive regime involving sub-vertical extension (see Fig. 1C).

2. Sub-tabular bodies of granodiorite were emplaced during progressive \( D_2 \) deformation.

3. Leucocratic magmas (leucogranitic and pegmatitic veins and dykes) represent the latest intrusions. They were emplaced either into NW-SE trending extension fractures, or following the E-W oriented S2 foliation.

4. \( D_2 \) deformation post-dating the emplacement of leucogranites and pegmatites was characterized by progressive transpression with the main extension direction switching from sub-vertical to sub-horizontal, as indicated by the performed strain analysis. Dykes and veins of high competence were folded or boudinaged depending on their initial orientation. Post-dyking shortening associated to regional transpression was >25%, with a N-S trending main shortening direction.

Conclusions

The field observations and structural analyses in a domain of the Punta dels Farallons-Volt Andrau migmatite area, depicted in diagrams, stereonets, strain ellipsoid and Flinn (1962) diagram. \( X, Y, Z \) are the maximum, intermediate and minimum strain axes respectively and \( R_{XZ} \) is the axial ratio of the bulk strain in the sub-horizontal section. See the main text for further explanation.

Acknowledgments

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References


Fig. 4.- Four-stages model of the petrostructural evolution of the South Volt Andrau migmatite area, depicted in diagrams, stereonets, strain ellipsoid and Flinn (1962) diagram. \( X, Y, Z \) are the maximum, intermediate and minimum strain axes respectively and \( R_{XZ} \) is the axial ratio of the bulk strain in the sub-horizontal section. See the main text for further explanation.

Fig. 4.- Modelo en cuatro estadios de evolución petrostructural del área migmatítica al sur de Volt Andrau, representado en diagramas, estereogramas, elipsoide de deformación y diagrama de Flinn (1962). \( X, Y \) y \( Z \) son los ejes máximo, intermedio y mínimo de deformación respectivamente, y \( R_{XZ} \) la relación axial de deformación global en el plano sub-horizontal. Ver explicaciones en el texto principal.