ABSTRACT

To deepening 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 Puntadels 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 migmatic 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 transgression 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 migmatic terranes are also influenced by rheological parameters (Vanderhaeghe, 2009).

The Punta dels Farallons-Volt Andrau area is one of the migmatic complexes in the Variscan basement of the north Cap de Creus (Fig. 1). The area consists of partially migmatised 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 Mélgar, 2003).

Druguet and Hutton (1998) showed that local anatexis and magmatism (from basic, to intermediate and acidic) in the Cap de Creus migmatic complexes took place under the Variscan D2 regional dextral transpression.

This paper analyzes the structural features of different lithologies around a transitional domain between high-grade sillimanite schists and migmatic and magmatic rocks at the southern area of the Punta dels Farallons-Volt Andrau migmatic 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 sub-vertical 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 a 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.

For a more accurate estimation of competence contrast (m) we have applied the technique of Schmalholz and Podladchikov (2001) estimating strain and competence contrast for the leucogranitic veins emplaced in various country-rocks. This is obtained from the relations between fold amplitude (A), fold wavelength (λ) and thickness (H) and plotting them on a strain contour map (Fig. 3). The highest competence contrasts (average m = 150) are observed in leucocratic veins (leucosome s and leucogranites) emplaced in schists, with a maximum value of m = 150. The competence contrast decreases for the leucogranitic veins emplaced in (or cutting) the granodioritic host rock (m = 25), and is even smaller in a tonalitic host rock (m = 10). These results are consistent with the presence of pytymatic folds and boudins in veins emplaced into schists, a fact that contrasts with the scarcity of folds and, instead, the presence of a weak internal planar fabric in those veins which are intruded into granitoids or quartz-diorites. The shortening values obtained by this method vary between 20% and 55%.

**Estimation of post-dyke strain**

Because of the high competence contrast between leucogranites and schists,
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 $S_2$ 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 migmatitic complex (Cap de Creus) corroborate the syntectonic emplacement of a sequence of intermediate to acid magmatic rocks during the Variscan dextral transpressive deformation event ($D_2$).

The performed measurements of deformed late leucocratic veins and dykes have allowed us to determine the regional strain and kinematics post-dating their emplacement. Dextral transpression was associated to sub-horizontal regional shortening $>25\%$, with the principle extension direction switching from sub-vertical to sub-horizontal under bulk constrictional to plane strain conditions.

This study also emphasizes the role of rheological contrasts in the structural evolution of complexly deformed migmatitic terranes.

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References


