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MODE OF FORMATION OF GOLD-BEARING MINERALIZATION ON TOP OF THE BOBORÁS GRANITE (GALICIA, SPAIN) – THE COMBINED ROLE OF MECHANICAL INSTABILITIES, STRAIN LOCALIZATION AND VEIN FORMATION

E. Gloaguen[a], A. Chauvet[b], Y. Branquet[a], V. Bouchot[c] and J.L. Vigneresse[d]

[a] *Institut des Sciences de la Terre d'Orléans – UMR CNRS 6113, Université d'Orléans, BP 6759, 45067 Orléans Cedex 2, France. eric.gloaguen@univ-orleans.fr;*
[b] *Laboratoire de Dynamique de la Lithosphère – ISTEEM - UMR CNRS 5573, Université Montpellier 2, CC. 60, 34095 Montpellier cedex 5, France.*
[c] *BRGM, Mineral Resources Division, Avenue Claude Guillemin, BP 6009, F-45060 Orléans Cedex 02, France.*
[d] *UMR G2R, Université de Nancy*

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1. Introduction and geological setting

The Galician Hercynian segment constitutes the core of the Ibero-Armorican orogenic arc, characterized by few tectonic units that record three main phases of deformation (D1 to D3). Four generations of granite, syn- to post-D3 intruded the major tectonic units. From older to younger, we find: i) syn-kinematic biotite-rich granodiorite (G1); ii) syn-kinematic two micas granites (G2) ; iii) biotite-dominant granites (G3) and iii) late-kinematic biotite-rich granodiorite (G4). Numerous sills, dykes and vein systems are widespread within the metasediments of the para-autochton unit. Gold-bearing quartz veins were spatially associated with G3 granites likely the Boborás intrusion, concerned by this work. The Boborás granite (G3) outcrops as a small NS-elongated elliptical intrusion. Granite is homogeneous and exhibits an equigranular texture composed of quartz, oligoclase, microcline, biotite dominant and muscovite.

2. Structures around and within the Boborás G3 pluton

2.1 Field structures

At map scale, the structure of the country rocks is dominated by a nearly constant, N-S trending, S2 cleavage and S3 crenulation cleavage within surrounding micaschists of the para-autochtonous unit. The general dip is about 40° to the west. A sparse N-S near horizontal mineral or stretching lineation is observed within micaschists associated with N-S boudinage of thin black quartzite level and asymmetric quartz or quartz-feldspar exudates. All the criteria are indicator of top-to-the north motion.

2.2 Dykes, sills and veins network

Numerous dykes, sill and veins are encountered within the study area, mainly around the granite bodies. Sill and dykes are composed by aplite, pegmatite and granite whereas veins are filled by quartz. Aplite-pegmatite sills and dykes are particularly well-developed northwest of the G3 Boborás pluton. Pegmatite sills are linked to the emplacement of the neighbouring G2 Carballiño granite whereas high-angle and north-dipping aplite-pegmatite and granite dykes connected with granitic sills are associated with the Boborás G3 granite.
Pegmatite and granite dykes are frequently underlined by centimetre to meter-scale quartz veins that are divided into tension gashes and shear veins following

their dip, aspect and attitude. Tension gashes are sub-vertical and frequently arranged in “en echelon” geometry, consistent with a north-verging normal motion. Inversely, quartz shear veins systematically present a steep northward dip associated with north-verging shearing motions. Magmatic dykes and quartz veins occur following three directions but systematically dip towards the north (except near-vertical quartz-rich tension-gashes). They trend N060°E to N065°E close to the granite and turn gradually towards a N090°E to N100°E orientation far east of the granite.

3. Microscopic characters

3.1. Magmatic features

Microstructural observations performed on magmatic features (granite, dykes and sills) show very little evidences of magmatic flow criteria. Sub solidus deformation is characterized by the occurrence of numerous fractured plagioclases (Bouchez et al. 1992) with fractures filled by magmatic quartz. Few asymmetric fractures define northward normal faulting. The presence of quartz within plagioclase microfractures is interpreted as a witness of melt relocation during the late stage of granite crystallisation (Hibbard 1987; Bouchez et al. 1992). Within all magmatic features, quartz is present under the form of large grains without any effects of plastic deformation. The most typical textures are chessboard pattern, representing evidences for the existence of deformation developed at high-temperature (more than 630°C, Kruhl 1996; Stipp et al. 2002). Very weak effects of later dynamic recrystallisation are observed. Quartz lattice preferred orientations indicate dominant prism ⟨c⟩ and prism ⟨a⟩ slip, with some contributions from rhomb ⟨a⟩ slip. Both traduce high temperature conditions of deformation. Basal ⟨a⟩ gliding is not suspected, confirming the weakness of late, post-solidus deformation within all magmatic rocks of the studied area.

3.2. Quartz tension gashes and shear veins

Three stages of quartz are recognized and identified (Q1, Q2 (a and b) and Q3) within the veins. Q2a is defined as the Q2 quartz that precedes arsenopyrite whereas Q2b is the one that occurs in fractures of the arsenopyrite. Q1 quartz is the first and major filling. They are elongate comb quartz with grain long-axis parallel or oblique to vein boundary. Quartz grains appear very deformed and exhibit spectacular effects of an intense dynamic recrystallisation. Extinction is strongly undulose and a high-angle conjugate set of shear bands is systematically observed. The most common Q2a appearances are very elongate grains characterized by the absence of any kind of dynamic recrystallisation. Final to the formation of arsenopyrite, few little size Q3 (un-deformed) quartz grains have crystallized within arsenopyrite micro-fractures.

Universal stage measurements are performed on quartz shear veins for both Q1 and elongate Q2 quartz. Q1 quartz ⟨c⟩ axis diagram exhibits well-defined maxima close to the vein direction whereas others, less defined, are localized at intermediate location, in position for rhombohedric activation. The diagram of long axis grain distribution shows a well-defined preferred orientation with grain long axis maxima also parallel to the vein direction. The good correlation between the maxima of the two diagrams (⟨c⟩ axis and quartz long axis) confirms that Q1 quartz are comb quartz, from which the long axis is indicator of the opening direction. The other maxima are certainly due to the ⟨c⟩ axis related to sub-grains formed by dynamic recrystallisation. To summarize, grains located close to the stereonet diagram are those corresponding to the comb quartz (fibre) whereas other are linked to the latter effects of post-solidus deformation.

The diagram of Q2 quartz ⟨c⟩ axes displays a drastically different distribution. Few grains have their ⟨c⟩ axis close to the diagram rim whereas the others are in intermediate position. The long-axes of Q2 quartz grain are strictly parallel to those of Q1. The aspect of the diagrams indicates that the deformation effects are more developed for Q2 quartz although several grains, likely the most elongate and less affected by recrystallisation processes, are additional witnesses of the direction of vein aperture.

4. Model of formation of hydrothermal vein system on granite roof

The study of the Boborás pluton and its neighbouring dyke and vein systems underline the existence of a mechanical instability that is supposed to be at the origin of the formation of all the structures herein described. All the structures are coeval with a north-verging plastic flow associated with an E-W and horizontal direction of shortening. The near horizontal granite-micaschist contact on the NW of the Boborás granite (rheological contrast) and the presence of the granite feeder zone (revealed by the gravimetric study) appears to be the cause of the mechanical instability that will be at the origin of the formation of vein and dyke systems. The micro structures meet in dykes, dykes root areas and granite roof record deformation patterns evolving from sub-magmatic stages developed at high temperature (broken feldspars, migration of residual melt into lower-pressure sites), followed by high temperature solid state deformation (chessboard pattern, ⟨c⟩ axis patterns, myrmekites) and finishing by fairly developed low temperature solid state structures (late aplite-pegmatite dykes emplacement crosscutting crystallised granite roof, feldspars twins and kink-bands, biotite-muscovite kink bands). This model implies a long lived continuum of deformation with normal north-verging motion during since late stages of granite emplacement until final high-angle normal faults. The earliest structures like normal faults and/or granitic dyke in host rock creates rheological heterogeneities which progressively localised the successive deformation. The originality consists in the fact that deformation is localized within the last structure emplaced. This begins with the main granite (deformed under sub-magmatic stages), the late aplite-pegmatite sills and dykes (also affected by sub-magmatic deformation) and achieved by the formation of syntectonic quartz veins.

5. Conclusion

The micro tectonic study herein proposed confirms the polyphase character of the veins filling and granite emplacement, with a continuum of fluids flow using the same pathways, and re-opening and re-using of magmatic dyke and quartz vein. These study suggest that at least a part of the vein filling occur during North-verging veins movement, providing locally elongate quartz fibres. The morphologies and deformation of some syn-kinematic magmatic dykes and quartz vein systems reflect change in temperature and transition from ductile to brittle deformation conditions (undulose deformation, sub-grain recrystallisation, oriented syn-deformation crystallisation to quartz fracture filling and brecciated quartz generation). This study represents a case study of integrated micro and macro tectonics analysis that allows to better understand the transition from magmatic to hydrothermal systems and to propose a well-illustrated geological model for the tectono-magmatic evolution of an hercynian segment that takes into account for magmatic, tectonic, fabrics and internal texture constraints. All these data are integrated within a general model that underlines the significant role of mechanical instability, rheological control and continuous process of deformation in order to develop both magmatic and hydrothermal vein systems.

References

Bouchez J-L, Delas C, Gleizes G, Nédélec A, Cuney M (1992) Submagmatic microfractures in granites. Geology 20: 35-38.

Hibbard MJ (1987) Deformation of incompletely crystallized magma systems: granitic gneisses and their tectonic implications. Journal of Geology 95: 543-561.

Kruhl JH (1996) Prism- and basal-plane parallel subgrain boundaries in quartz: a microstructural geothermobarometer. Journal of Metamorphic Geology 14: 581-589.

Stipp M, Stünitz H, Heilbronner R, Schmid SM (2002) The eastern Tonale fault zone: a "natural laboratory" for crystal plastic deformation of quartz over a temperature range from 250 to 700°C. Journal of Structural Geology 24: 1861-1884.