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Tracing the magmatic/hydrothermal transition in regional low-strain zones: The role of magma dynamics in strain localization at pluton roof, implications for intrusion-related gold deposits

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ABSTRACT

Structural controls are critical during magmatic-to-hydrothermal transition in the formation of intrusion-related gold deposits. They may explain why only some parts of intrusions are mineralized and why only very few intrusions host large deposits. Moreover, most of these gold deposits postdate peak regional metamorphism and were formed in zones of relatively low strain. Indeed, the efficiency of structural gold traps is highest along favourably oriented intrusion/host-rock contacts where mechanical instability maintains high permeability in the cracked thermal aureole. This may be reinforced by melt injections from an underlying root zone. We present a structural analysis of the deformation features of a granite-pluton roof; large-scale dykes and a network of gold veins are intensively developed in this roof, recording a succession of mechanical instabilities. Our gravity survey underlines the presence of a pluton feeder zone located just beneath the mineralized network. It is argued that interferences between regional stress and melt injection in the feeder zone favoured the development of the network by strain located close to the granite roof. This stresses the role of mechanical instabilities triggered by the combined effects of regional stress and melt dynamics in determining the location and size of this type of gold deposit.

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1. Introduction

Mechanical instabilities at the roof of a magmatic intrusion (the term 'roof' describes the apical envelope before erosion of an intrusion) appear to be a major structural prerequisite for localizing the magmatic-to-hydrothermal transition. Roof instabilities favour morphological features like cupolas, apexes and dyke swarms, which appear to be critical when mineralization is formed, as in the case of reduced intrusion-related gold deposits (e.g. Goldfarb et al., 2005; Hart, 2007). This class of gold deposit has only been recognized as a separate feature from the orogenic gold deposit class since 1999 and, as such, is in a juvenile state of understanding (Hart, 2007). Reduced intrusion-related gold deposits (RIRGD) include various deposit styles, such as skarns, disseminations, replacements, breccias, stockworks or, more commonly, intrusion-hosted sheeted arrays of thin quartz veins. Such veins with a low-sulphide Au–Bi–Te–W signature may develop within, beyond, or above the thermal aureole of the pluton. The intrusions have moderately low primary oxidation states, making them into reduced, ilmenite-series (Ishihara, 1981) granitoids. In such mineralized systems, the emplacement-to-cooling cycle of reduced felsic intrusions is assumed to be coeval and genetically related to gold deposition. RIRGD are therefore systems where the magmatic-to-hydrothermal transition is demonstrated by fluid-inclusion studies (Baker and Lang, 2001); they are generally centred on small plutons, plutonic apexes or dyke swarms, around which a cracked thermal aureole was developed (Baker and Lang, 2001; Stephens et al., 2004). Such intrusions are weakly deformed as they postdate regional ductile shearing and peak metamorphism.

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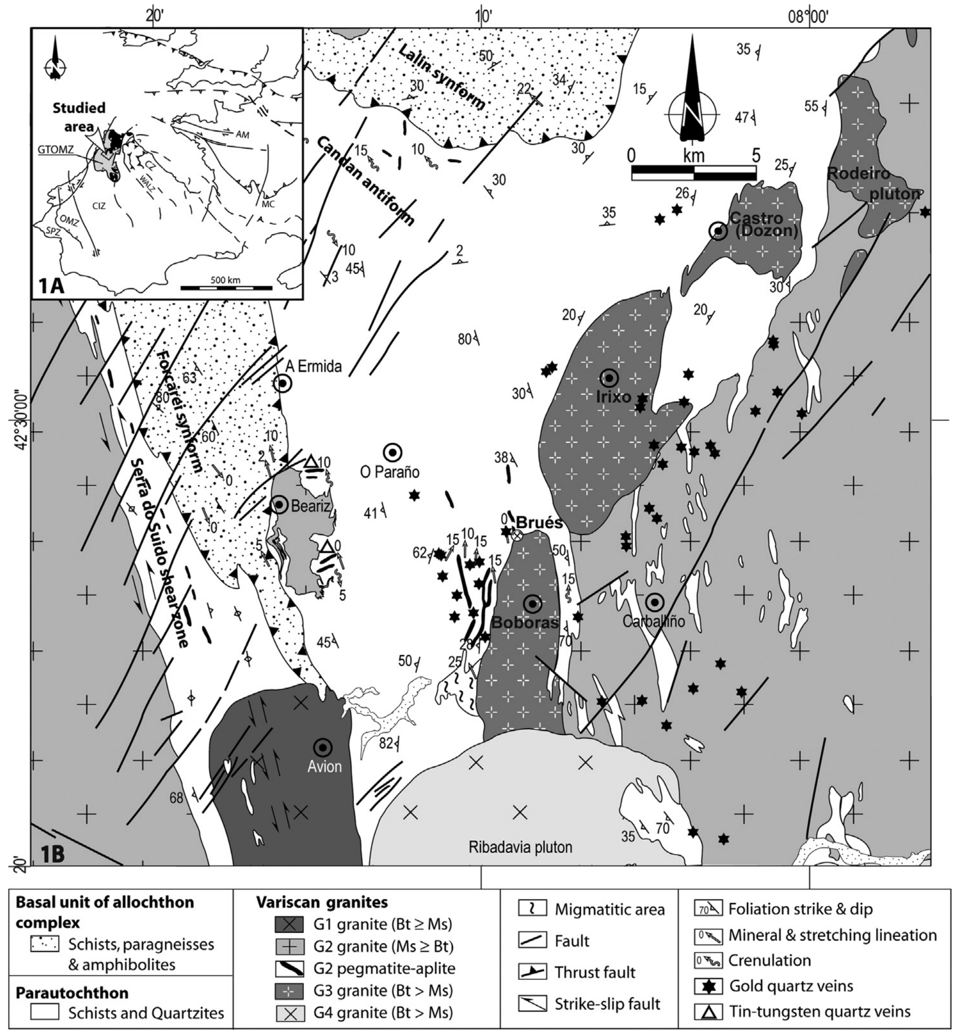

Fig. 1. The study area in the western part of the Variscan belt before opening of the Bay of Biscay. (A) Location in Western Europe; abbreviations: AM, Armorican Massif, MC, Massif Central, CZ, Cantabrian Zone, WALZ, West-Asturian-Leonese Zone, GTOMZ, Galicia-Trás-os-Montes Zone, CIZ, Centro Iberian Zone, OMZ, Ossa-Morena Zone, SPZ, South Portuguese Zone; (B) Geological sketch map of the Schistose Domain in Galicia Trás-os-Montes Zone.
Modified from Barrera Morate et al., 1989; from González Cuadra et al., 2006; Sizaret et al., 2009 for the Beariz granite.

However, despite favourable conditions, to our knowledge no structural studies (including gravimetry) exist that are dedicated to such deposits, accounting for intrusion dynamics as structural controls of such magmatic-hydrothermal mineralized systems.

The magmatic-to-hydrothermal transition is a key process in ore-forming systems related to igneous activity (see review in Halter and Webster, 2004). While this transition is well known from mineralogical and geochemical investigations, it remains difficult to assess via structural and textural analyses. This assertion is particularly valid for plutonic- and hydrothermal-related systems, as plutons emplaced close to high-strain regional shear zones (e.g. the footwall of detachments planes in metamorphic core complexes) may preserve magmatic and submagmatic textural gauges, but on-going high solid-state strain and rapid exhumation make it difficult accurately to establish a possible genetic link between magma injection and the subsequent hydrothermal system (e.g. Menant et al., 2013). In contrast, although magmatic and submagmatic textural gauges are subtle features due to low strain, plutons and their related ore-bearing systems emplaced far from major shear zones are good candidates for showing the magmatic-to-hydrothermal transition from a structural and textural point of view.

A weakly deformed magmatic system also provides an opportunity for evaluating the contribution of magma dynamics to the textural framework and plumbing system of a magmatic-to-hydrothermal transition.

In this paper we present a detailed structural and microstructural analysis of the roof of the Late Variscan Boborás granite and its associated gold mineralization, the Brués deposit in north-western Spain. The Boborás granite, dated at 318 ± 5 Ma (Gloaguen, 2006) is part of a roughly 30 km-long NNE-SSW alignment of four plutons, displaying a strong spatial association with gold mineralization located in and around the plutons (Fig. 1). Gold-bearing quartz veins in the granite, dykes or pegmatites, exhibit the typical low-sulphide Au–Bi–Te–W signature of RIRGD and contain locally magmatic brines. The Brués deposit on the north-western edge of the Boborás pluton is the most important deposit of the area (Asensio Pérez et al., 2000; Gloaguen et al., 2003; Gloaguen, 2006, Fig. 2). It is composed of a high density of near-parallel granite dykes and sills crosscutting micaschists at the roof of the pluton. Steeply-dipping dykes hosting gold-bearing quartz veins, trend N060°E close to the pluton and turn gradually to N100°E farther west. Veins from this deposit result from at least four successive deformation events with fluid infill. The deposition of gold

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