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Fluid flow and polymetallic sulfide mineralization in the Kettara shear zone (Jebilet Massif, Variscan Belt, Morocco)

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ABSTRACT

The Kettara shear zone is a regional wrench shear zone within the Jebilet massif of Western Morocco, part of the Variscan orogenic belt. This massif is characterized by bimodal magmatism, largely intrusive, and by a number of polymetallic massive sulfide deposits. A syntectonic mafic-ultramafic intrusion and an adjacent, deformed pyrrhotite-rich massive sulfide deposit are located within a 'compressional jog' of the shear zone. Hydrothermal alteration in both the intrusion and the wall rocks adjacent to the deposit is characterized by syntectonic replacement processes leading to formation of chlorite-schists and quartz ± calcite veins. Fluid inclusions in mineralized (pyrrhotite-bearing) quartz veins from the wall rocks adjacent to the deposit and in veins associated with chlorite-schists within the intrusion indicate a prevalence of H_2O-CO_2-CH_4-N_2 and H_2O-salt fluid systems. In the mineralized veins the fluid shows reducing conditions, with gas dominated by CH_4 and N_2 and salinities around 7.5 wt% NaCl, whereas in the chlorite shear zones fluid is CO_2 dominated and salinities are higher than 23 wt% NaCl. Hydrogen and oxygen isotopic compositions of chlorite and quartz are similar and demonstrate involvement of metamorphic water in both the deposit and the intrusion.

The data are consistent with a regional metamorphic fluid flow through the Kettara shear zone. The migrating metamorphic fluids were reduced in the organic matter-rich host rocks leading to deposition of sulfides in the mineralized veins. There are two possible hypotheses for the origin of these mineralized veins: either they were formed during deformation and remobilization of a syn-sedimentary massive sulfide deposit, or they were formed synchronously with the sulfide deposit during development of the Kettara shear zone.

1. Introduction

Crustal shear zones form narrow zones of low strength and high permeability within the upper crust, and may serve as fluid pathways, capable of focusing ore-forming processes (Oliver, 1996; Cox et al., 2001; Chernicoff et al., 2002). The association of many hydrothermal mineral deposits with shear zones and crustal discontinuities is widely documented in the literature (e.g., Groves et al., 1998; Sillitoe, 2000). Examples of mineralization that display a spatial relationship with fault and shear zones include orogenic gold deposits (e.g., Sibson et al., 1988; Cox et al., 1991; Bouchot et al., 2000). Polymetallic sulfide mineralization associated with shear zones has been described at a range of structural levels (Glen, 1987; Nicol et al., 1997; Gaouzi et al., 2001; Piessens et al., 2002; Bellot, 2004) and emphasizes the importance of this type of mineralization in collisional belts. Hydrothermal fluid flow associated with syntectonic intrusions may be concentrated along shear zones and, when combined with a precipitation mechanism operating in a restricted space (e.g., Hedenquist and Lowenstern, 1994), may lead to ore deposition. This work focuses on a shear zone hosting a mafic-ultramafic intrusion and a massive sulfide deposit in the Variscan belt of Morocco, and considers the relationship between deformation, fluid flow and sulfide mineralization.

The central unit of the Jebilet massif, in the Marrakech region of Western Morocco, is a block of Carboniferous sedimentary rocks

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deformed during the Variscan orogeny. The block is located along the southern branch of the West Meseta shear zone (Piqué et al., 1980; Lagarde and Michard, 1986). This block and its southern extension (the Guemassa massif) host a bimodal intrusive magmatic suite (Bordonaro, 1983; Essaifi et al., 2014) and significant massive sulfide mineralization (Huvelin, 1972; Bernard et al., 1988). The origin of the massive sulfide deposits is the subject of continuing debate. They have been variously considered as deformed syngenetic VMS or SEDEX bodies (Belkabir et al., 2008; Marcoux et al., 2008; Moreno et al., 2008; Lotfi et al., 2008) or as later syntectonic bodies (Essaifi and Hibti, 2008).

The Kettara deposit is a pyrrhotite-rich, near-vertical massive sulfide lens located near the mafic-ultramafic Kettara intrusion. Both are located within a shear zone interconnected with a regionally anastomosing network of sub-vertical shear zones (Essaifi et al., 2001; Essaifi and Hibti, 2008). The deposit has previously been interpreted as a mineralized dyke filling a sub-vertical fracture (Agard et al., 1952), or as a deformed pre-tectonic, synsedimentary deposit (Huvelin, 1970).

The Kettara deposit was the first massive sulfide deposit to be discovered and mined in central Jebilet. The gossan was exploited for limonite and ochre from 1938 to 1963. The extracted quantities are 150 000 t grading 45–52% Fe and 50 000 t grading 50–58% Fe, respectively (Essaifi, 2011 and references therein). Below the gossan a cementation zone with mineralization composed of native copper, pyrite, chalcocite (Cu2S), covellite (CuS), with traces of gold and silver (Souaré, 1988) is present. Pyrite was extracted from this zone between 1955 and 1966, and used in the manufacture of sulfuric acid with recuperation of Cu contained in chalcocite and covellite. Its total reserves have been estimated as 180 000 t grading 38% sulfur. Below the cementation zone, the primary mineralization is pyrrhotite-rich (up to 95%) and forms an elongate subvertical lens 500 m deep, 40–70 m thick and 1500 m long (Huvelin and Permingeat, 1980; Bernard et al., 1988). The ore reserves are estimated as 30 Mt of pyrrhotite grading 0.7% Cu; with 8 Mt extracted between 1964 and 1982, and used in the manufacture of sulfuric acid. Difficulties related to pyrrhotite storage (fast oxidation), poor sulfur content (25%), and to the volume of mine wastes resulted in the closure of the operation in 1982.

This paper presents new structural, chemical and fluid inclusion evidence of regional fluid migration along the Kettara shear zone, leading to synkinematic hydrothermal alteration around the polymetallic sulfide mineralization, and discusses the significance of this fluid migration on the genesis of the Kettara massive sulfide deposit.

2. Geological framework

2.1. The Moroccan Meseta

The Variscan orogenic belt of Morocco is subdivided into the eastern and western Meseta domains (Fig. 1A, B), which were folded and metamorphosed respectively during late Devonian and late Carboniferous (mainly early Westphalian) Variscan tectonic events (Hollard, 1978; Hoepffner et al., 2005; Michard et al., 2010). The Jebilet massif, together with the Rehamna and the central Paleozoic massifs to the north, and the high Atlas Paleozoic block to the south, form the Western Meseta. A late Devonian-early Carboniferous foreland sedimentary basin was developed in the western Meseta and was bounded by relatively rigid blocks to the north (Sehoul block) and west (Coastal block) and by the Anti-Atlas and West African craton to the south (Piqué and Michard, 1989; Hoepffner et al., 2006; Burkhard et al., 2006). Basin closure during the late Carboniferous was accompanied by strongly heterogeneous ductile deformation. Narrow, highly deformed regional shear zones of low to medium metamorphic grade contrast with wide moderately deformed areas with very low-grade metamorphism (Piqué et al., 1980; Lagarde and Michard, 1986; Piqué and Michard, 1989). The narrow deformed zones and are commonly spatially associated with syn-to late-kinematic granitic intrusions (Lagarde et al., 1990). Among these shear zones, the western boundary of the Devonian-Carboniferous basin is a major lithospheric structure, the West Meseta Shear Zone (WMSZ), which extends from Rabat in the north to the High Atlas in the south (Piqué et al., 1980; Lagarde and Michard, 1986). Most geodynamic models relate formation of the Moroccan Meseta to a westward continuous compression of the Variscan foreland in which the Rheic suture is hidden at the eastern boundary of the eastern Meseta (Kharbouch et al., 1985; Boulin et al., 1988; Roddaz et al., 2002, 2006; Essaifi et al., 2014). Recent structural and geochronological work in the Rehanma Massif by Chopin et al. (2014) indicates a more complex (polyphase) history beginning with southward thrusting, followed by N-S directed bulk crustal shortening, in turn followed by E-W crustal shortening, all occurring from late Carboniferous to Lower Permian times.

2.2. The Jebilet massif

The Jebilet massif, just north of Marrakech provides an E-W section through the western Meseta domain. It is composed of three structural units (Fig. 1C):

i) The western Jebilet unit is a weakly deformed block composed of unmetamorphosed Cambro-Ordovician limestones, shales and sandstones with north-south trending kilometer-scale folds. It is part of the Coastal block, which was emergent since Devonian times (Piqué et al., 1980).

(ii) The central Jebilet unit consists of a schistose low-grade metamorphosed (anchizone and epizone) block of marine Visean shales (the Sarhlef schists) deposited in an anoxic platform setting (Beauchamp, 1984). This unit is also characterized by the occurrence of massive sulfide deposits together with numerous magmatic mafic and felsic intrusions which form a bimodal magmatic association (Bordonaro, 1983; Essaifi et al., 2014). The boundary between the central and western Jebilet is a NNE–SSW dextral thrust-wrench shear zone (Le Corre and Bouloton, 1987; Mayol and Muller, 1985), and this is the southern extension of the West Meseta Shear Zone (WMSZ, Fig. 1B, C).

(iii) The eastern Jebilet unit is a weakly metamorphosed to unmetamorphosed block separated from the central unit by a sinistral shear zone with a NNW-SSE trend, the Marrakech Shear Zone (Lagarde and Choukroune, 1982). It is composed of Upper Visean syntectonic 'flysch' (Kharrouba flysch) including olistostromes and inliers of Ordovician to Devonian sedimentary rocks. Such Carboniferous syntectonic deposits also characterize the eastern part of central Morocco and were deposited in a compressional retro-foreland basin (Bouabdelli and Piqué, 1996; Ben Abbou et al., 2001; Roddaz et al., 2002).

Two syntectonic calc-alkaline granite plutons intruded by leucogranite sheets are spatially associated with the Marrakech shear zone (Lagarde and Choukroune, 1982). Westphalian-Permian continental conglomerates (Huvelin, 1977) rest unconformably upon the Variscan folded sequence in western and eastern Jebilet (Fig. 1C).