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Syn-collapse eclogite metamorphism and exhumation of deep crust in a migmatite dome: The P–T–t record of the youngest Variscan eclogite (Montagne Noire, French Massif Central)

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ABSTRACT

In many orogens, high-pressure (HP) metamorphic rocks such as eclogite occur as lenses in quartzofeldspathic gneiss that equilibrated at much lower pressures. The pressure–temperature–time (P–T–t) history of eclogite relative to host gneiss provides information about mechanisms and timescales of exhumation of orogenic crust. The Montagne Noire of the southern Massif Central, France, is an eclogite-bearing gneiss (migmatite) dome located at the orogen-foreland transition of the Variscan belt. Results of our study show that it contains the youngest eclogite in the orogen, similar in age to migmatite and granite that crystallized under low-pressure conditions. P–T conditions for an exceptionally unaltered eclogite from the central Montagne Noire were estimated using a pseudosection supplemented by garnet–clinopyroxene and Zr-in-rutile thermometry. Results indicate peak $P \sim 1.4$ GPa and $T \sim 725\,°C$ for Mg-rich garnet rim (50 mol% pyrope) + omphacite (36 mol% jadeite) + rutile + quartz. U–Pb geochronology (LA-ICP-MS) of 16 zoned zircon grains yielded ∼360 Ma (4 cores) and ∼315 Ma (12 rims and cores). Rare earth element abundances determined by LA-ICP-MS for dated zircon are consistent with crystallization of ∼315 Ma zircon under garnet-stable, plagioclase-unstable conditions that we interpret to indicate high pressure; in contrast, the ∼360 Ma zircon core corresponds to crystallization under lower pressure plagioclase-stable conditions. Based on garnet zoning and inclusion suites, rutile textures and Zr zoning, P–T results, and zircon petrochronology, we interpret the ∼315 Ma date as the age of eclogite-facies metamorphism that only slightly preceded dome formation and crystallization at 315–300 Ma. This age relation indicates that eclogite formation at high pressure and migmatite dome emplacement at low pressure were closely spaced in time. We propose that collapse-driven material transfer from the hot orogen to the cool foreland resulted in thickening of the orogen edge, leading to eclogite facies metamorphism of the deep crust. Soon after, the low-viscosity partially molten crust flowed from the plateau toward the foreland, incorporating and exhuming eclogite. The P–T–t history of the Montagne Noire eclogite shows that some dome material ascended from >40 km depth to shallow crustal levels, likely in a single decompression event, and that migmatite domes are therefore very efficient at exhuming the deep crust.

1. Introduction

Partially molten crust flows laterally in the deep crust in response to pressure gradients, such as occur at the transition from a thick orogenic plateau to its adjacent foreland (Fig. 1). This hot crust may ascend to shallow crustal levels in response to instabilities such as upper crustal extension, forming domal structures comprised of migmatite (the crystallized partially molten crust) and crustally derived granite (e.g., Teyssier and Whitney, 2002; Rey et al., 2011) (Fig. 1). This mechanism can transport high-pressure (HP) rocks from great depth (>30–40 km) to very shallow levels (<2–10 km) (Whitney et al., 2004). Different rock types experience different degrees of equilibration during decompression, resulting in the common occurrence of HP bodies (eclogite or HP granulite) within host gneiss/migmatite that records significantly lower pressures (e.g., Stipska et al., 2008). Unresolved questions are when, where, and how eclogite metamorphism occurred, and how eclogite pressure–temperature–time (P–T–t) history relates to that of the host rock.

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In the case of HP rocks exhumed as part of a collisional orogenic event, HP metamorphism may have occurred by pre-collision oceanic subduction, syn-collision continental subduction, or at depth in thickened orogenic crust. In the case of high-pressure bodies in migmatite domes, HP metamorphism may significantly pre-date migmatization and the dome-forming event (e.g., if two events occurred during different orogenies or during very different temporal stages of the same orogeny), or HP metamorphism may be more closely related in time with migmatization and doming. In the latter case, mineral compositions, zoning, textures, and age data may provide information about the orogenic events that produced both HP rocks and the host migmatite.

In this paper, we consider the exhumation of meter- to kilometer-scale eclogite inclusions in a migmatite dome: the eclogite-bearing Montagne Noire dome, French Massif Central (Figs. 2, 3). We document the petrology (including pressure–temperature conditions) of the least-altered eclogite collected as part of this study, present U–Pb geochronology and trace element abundances for zircon in eclogite, and discuss the new P–T–time (t) results in the context of dome dynamics and orogenic evolution. We show that the Montagne Noire eclogite is the youngest in the Variscan belt, postdating the contractional history of the orogen, requiring an explanation for crustal thickening at the orogen-foreland boundary zone during collapse of the orogenic crust, followed rapidly by ascent of eclogite in partially molten crust >40 km upward to the shallow crust.

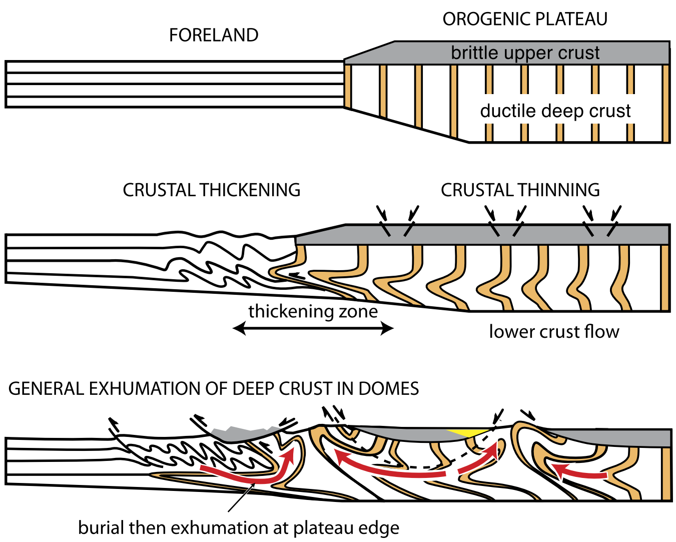

Fig. 1. Conceptual model of the flow of partially molten crust laterally (in a deep crustal channel) and vertically (to form migmatite domes) at the transition between the thick crust of an orogenic plateau (including a ductile layer in the deep crust) and the thinner, cooler foreland during extension (figure based on 2D numerical models and modified from Rey et al., 2010).

2. Montagne Noire geologic setting and metamorphic petrology

Located at the southern edge of the French Massif Central (Figs. 2, 3a), the Montagne Noire dome occupies the transition between the Variscan orogen to the north and the foreland to the south (e.g., Faure, 1995, 2009). To the north of the Montagne Noire, the eastern Massif Central crust (east of the Sillon Houiller, Fig. 2) can be described in terms of an upper unit derived from oceanic assemblages (with numerous eclogite pods), a middle unit dominated by metasedimentary rocks (especially micaschist, such as the schist units of the Cévennes region), and a lower unit consisting of quartzofeldspathic migmatite and peraluminous granitoids exposed in domes (Vanderhaeghe et al., 1999). This region of the Variscan orogen was accreted during the Carboniferous, with contraction starting around 340–335 Ma and lasting until ∼325 Ma based on ages of synorogenic flysch deposits in the orogen foreland. According to Faure et al. (2009), the core of the southern Massif Central orogen underwent extension during 320–295 Ma (e.g., review by Lardeaux, 2014), while the outer zone represented by the Montagne Noire and the Pyrenees remained in contraction (Faure et al., 2009). Recent structural and geochronological work on the core of the Montagne Noire indicates dome emplacement, internal deformation, and melt crystallization between ∼315 and 300 Ma (Roger et al., 2015).

The Montagne Noire consists of three units (Fig. 3b). The northern unit is a SW-directed thrust imbricate involving low-grade lower Paleozoic metasedimentary strata. The central unit (Axial Zone) consists of a granite–migmatite dome, mainly comprised of migmatitic orthogneiss (augen gneiss), paragneiss, and

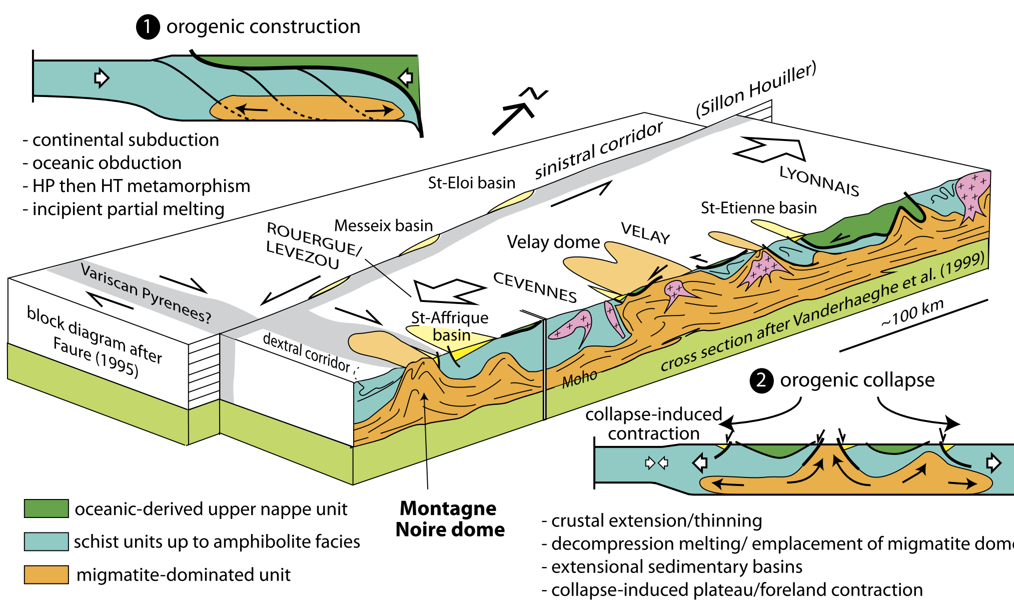

Fig. 2. Schematic block diagram (after Faure, 1995) and cross-section (after Vanderhaeghe et al., 1999) of the main late Carboniferous units in the French Massif Central. Inset sections represent two stages of orogenic development: crustal accretion and plateau development followed by orogenic collapse, emplacement of migmatite domes, and deposition of extensional sedimentary basins.