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Field and petrological study of metasomatism and high-pressure carbonation from lawsonite eclogite-facies terrains, Alpine Corsica

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ABSTRACT

This study presents new field and petrological data on carbonated metasomatic rocks from the lawsonite-eclogite units of Alpine Corsica. These rocks form along major, slab-scale lithological boundaries of the subducted Alpine Tethys plate. Our results indicate that a large variety of rocks ranging from metamafic/ultramafic to metafelsic can react with carbon-bearing fluids, leading to carbon sequestration at high-pressure conditions. The process of carbonation includes both replacement of silicates by high-pressure carbonate, and carbonate veining. The field, microstructural and mineralogical data strongly suggest that the metasomatism was mediated by the infiltration of external fluids of mixed origin, including both mafic/ultramafic and metasedimentary sources. Our results support the following three-step evolution: (i) Release of aqueous fluids by lawsonite and/or antigorite breakdown at depth; (ii) Fluid channelization along the base of the metasedimentary pile of the subducted lithospheric plate and related reactive fluid flow leading to carbonate mineral dissolution; (iii) Further interactions of the resulting carbon-bearing fluids with slab-forming rocks at depths of ca. 70 km and carbonation of pre-existing silicate-rich lithologies. This study highlights the importance of carbonate-bearing fluids evolving along down-T, down-P paths, such as along slab-parallel lithological boundaries, for the sequestration of carbon in subduction zones, and suggests that similar processes may also operate in collisional settings.

1. Introduction

Subduction zones control an important part of the carbon cycle by regulating the exchanges between shallow and deep carbon reservoirs (e.g., Hammouda, 2003; Hayes and Waldbauer, 2006; Dasgupta and Hirschmann, 2010; Dasgupta, 2013; Evans, 2012; Poli, 2015). The amount of carbon that enters subduction zones is currently estimated to range from 40 to 66 Mt C/yr (Kelemen and Manning, 2015). This carbon is dominantly hosted in carbonate minerals present in both sediments and altered oceanic crust and mantle rocks (Plank and Langmuir, 1998; Alt and Teagle, 1999; Jarrard, 2003; Plank, 2014).

The study of the petrological evolution of subducting carbonate-bearing rocks is therefore crucial for the understanding of the global carbon cycle (Kerrick and Connolly, 1998, 2001; Molina and Poli, 2000; Gorman et al., 2006). Subducted carbonate may experience different mechanisms of recycling, which are in most cases enhanced by open-system conditions and infiltration of external fluids. These mechanisms include processes related to the reactivity between carbonates and silicates (e.g. decarbonation reactions; Kerrick and Connolly, 1998, 2001; Gorman et al., 2006), processes related to carbonate solubility in aqueous fluids (e.g. carbonate dissolution; Frezzotti et al., 2011; Ague and Nicolescu, 2014), processes of carbonate reduction (to either solid or fluid reduced phases; Malvoisin et al., 2011; Galvez et al., 2013; Vitale Brovarone et al., 2017), and melting (Schneider and Eggler, 1986; Hammouda, 2003; Poli, 2015). Several works have focused on the mechanism that can release carbon from subducting slabs and transfer it to shallower reservoirs, most notably the mantle wedge and volcanic arcs above subduction zones. Decarbonation reactions releasing CO_2 are expected to be particularly efficient at forearc conditions (Kerrick and Connolly, 1998, 2001; Gorman et al., 2006), whereas carbonate dissolution has been identified as a major process for carbon release occurring at forearc and possibly subarc depths (Frezzotti et al., 2011; Ague and Nicolescu, 2014). Accounting for the ensemble of these processes, Kelemen and Manning (2015) estimate deep carbon fluxes from the subducting slab into the shallow mantle of 4 to 60 Mt C/yr. Accordingly, the authors suggest that potentially most subducted carbon (40 to 66 Mt C/yr) is released from the slab into deep fluids.

Conversely, much less is known regarding the reactivity of carbon-bearing fluids, generated by decarbonation/dissolution processes, with silicate rocks in the subducting slab. Equivalent processes are known at low-pressure conditions in both oceanic and on-land settings, where they can sequestrate significant amounts of carbon, including

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atmospheric CO_2 (e.g. Kelemen and Matter, 2008). In HP metamorphic settings, recent studies on the exhumed eclogite-facies units of Alpine Corsica and the Western Alps report that, during flow, carbon-bearing fluids can be extremely reactive with mafic and ultramafic rocks and lead to high-pressure (HP) rock carbonation (Piccoli et al., 2016; Scambelluri et al., 2016). HP rock carbonation is a newly discovered process of carbon sequestration that can contribute to counterbalance carbon fluxes due to mobilization processes (both decarbonation and dissolution), with potential large-scale implications for the global carbon cycle (Piccoli et al., 2016). The identification of HP carbonation in exhumed metamorphic terranes, however, may be challenging owing to the absence of diagnostic mineral assemblages and the effect of deformation and late metamorphic overprinting.

In this contribution, we present a detailed field and petrological dataset for several occurrences of carbonated metasomatic rocks in the lawsonite eclogite-facies terrains of Alpine Corsica (France). The aim of this work is threefold. Firstly to provide an exhaustive picture of the nature and diversity of these carbonated metasomatic products and their protolith rocks. Secondly, elucidate general petrological and geochemical features characterizing carbonate metasomatic processes at HP conditions in subduction zones. Lastly, discuss the fluid composition and sources. A conceptual model of large-scale reactive fluid flow is then proposed based on the field, petrological, and geochemical observations in order to better assess the impact of this process on the carbon inventory in subduction zone reservoirs.

2. Geological setting

2.1. Geology of Alpine Corsica and the San Petrone unit

Alpine Corsica occupies the northeastern part of the island of Corsica (France) and is a segment of the Alpine orogenic system (Jolivet

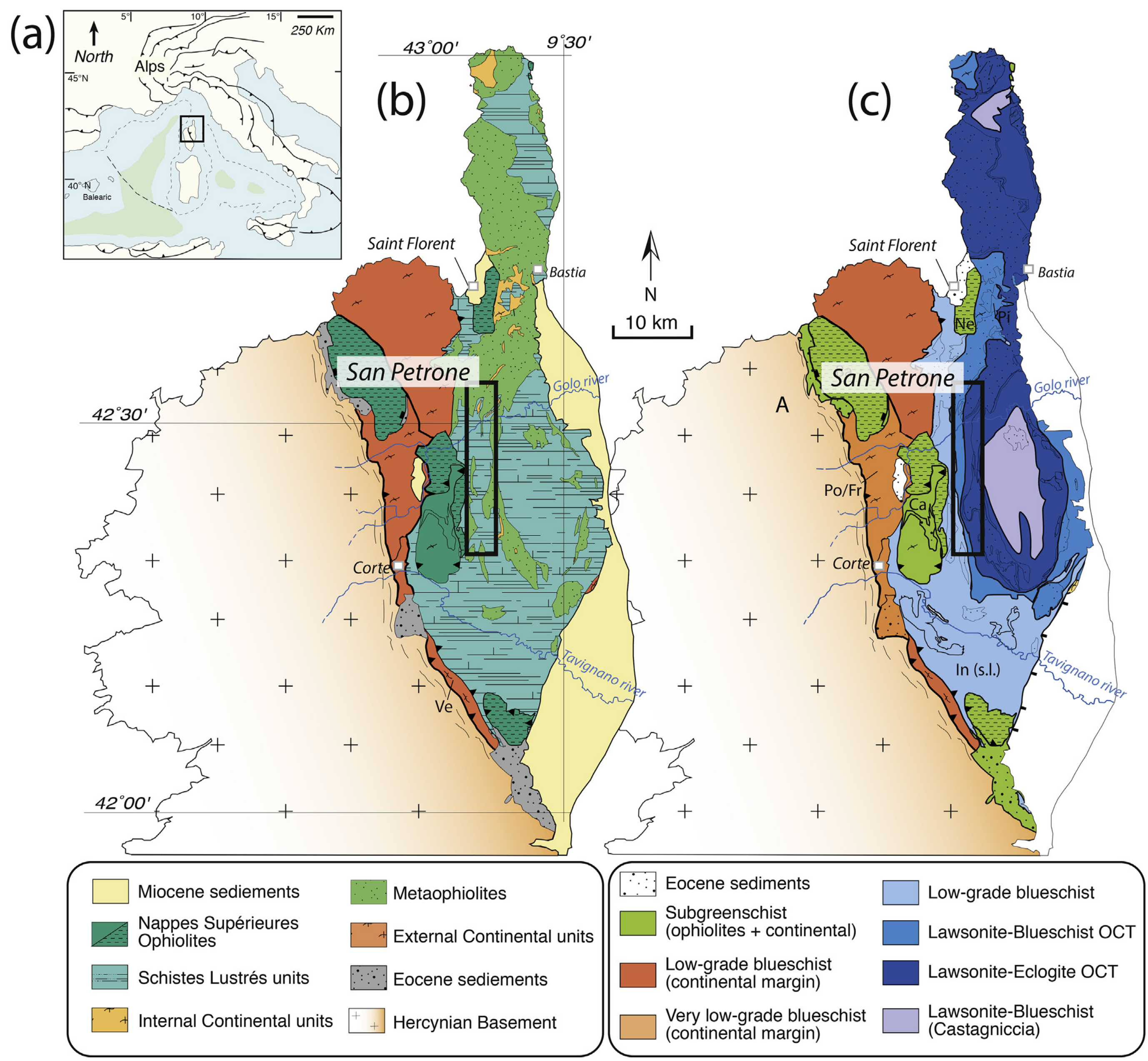

Fig. 1. Geological setting of the study area. **a)** Simplified regional setting of Alpine Corsica (France) in the Western Mediterranean region. Modified after Molli and Malavieille (2011). **b-c)** Simplified tectono-stratigraphic and metamorphism maps of Alpine Corsica. The black box indicates the location of the San Petrone unit, belonging to the lawsonite-eclogite terrains. Modified after Vitale Brovarone et al. (2014a).