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Actinolitic rinds on low-T mafic blueschist blocks in the Franciscan shale-matrix mélange near San Simeon: Implications for metasomatism and tectonic history

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ABSTRACT

In the mélange terrane of the Franciscan accretionary prism, Mg-rich actinolite/tremolite "rinds" have long been known to be present on many high-T, garnet ± epidote-bearing, mafic blueschist and eclogite blocks, but they were thought to be absent on low-T lawsonite + chlorite blueschist blocks. By analogy with rinds on high-T blocks, these rinds on low-T blocks must have been produced by metasomatic reaction with ultramafic rock. The rinds on high-T blocks have led to the speculation that the high-T Franciscan blueschists were uplifted to the surface in serpentinite diapirs, while other processes exhumed the volumetrically more numerous low-T blocks. This paper reports the discovery of actinolitic rinds on the margins of nine low-T, lawsonite ± epidote Franciscan blueschists that are, or were, clearly encased in the shale-matrix mélange exposed in seacliffs and wavecut benches near San Simeon, California. Petrographic and geochemical analyses show these Mg-rich rinds are similar to those found on high-T garnet-bearing blocks.

The bulk composition indicates the protolith of the blueschist blocks was mafic oceanic crust. The high $Fe^{3+}/\sum Fe$ contents indicate it was probably the uppermost hydrated volcanic part of the crust. The block/ultramafic rock association was created by faulting during subduction initiation as fragments from the top of the subducting ocean crust were imbricated with mantle materials at the base of the ophiolitic leading edge of the North American plate. The chemistry of a block margin altered to actinolitic rind indicates Si, Na, Pb, Cu, and Sr were lost from the blocks while K, Rb, Cs, and Ba were added. Most pieces of actinolitic rind are Mg- and Ni-rich because they are metasomatized ultramafic material that was enriched in Si, K, Rb, Cs, and Ba. These metasomatic changes indicate the fluids that hydrated the mantle and altered the mafic blocks ascended from subducting and/or underplated sediments. Both high-T and low-T blueschists that have actinolitic rinds were uplifted to near the surface after they sank or were plucked from the base of the overriding plate by subduction-generated mélange that upwelled from depths of > 15 km.

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1. Introduction

Patches of Mg-rich actinolite/tremolite rinds are present along the margins of most, and perhaps all, high-T, coarsely-crystalline garnet ± epidote-bearing mafic blueschist, eclogite and amphibolite blocks in the Franciscan mélange terrane of California (Central Belt of Bailey et al., 1964; Coleman and Lanphere, 1971; Moore, 1984). Where blocks have elliptical shapes, patches of "wrap-around" rind can be found on opposite sides, and at the rounded ends. This suggests these rinds are remnants of once concentric selvages around large rounded boudins (Coleman, 1980). Actinolitic rinds typically also contain chlorite with minor white mica or talc, and rutile and/or titanite (Moore, 1984; Sorensen, 1988; Catlos and Sorensen, 2003; Wakabayashi and Dumitru, 2007). Some of the amphiboles are tremolite and the chlorite is Mg-rich. Similar assemblages have been described for Ca-enriched, SiO_2-undersaturated rocks usually termed "rodingites" (Coleman and Lanphere, 1971; Leach and Rodgers, 1978; Evans et al., 1979; Koller and Richter, 1980), which have been interpreted to form at the contact between mafic and ultramafic rocks during serpentinization (Frost, 1975; Dubińska and Wiewiora, 1999; Puschnig, 2002; Dubińska et al., 2004; Trumbull et al., 2009; Bulle et al., 2010). Such metasomatic reactions result in the formation of a "blackwall" or reaction front between the block and serpentinite, in this case a rind.

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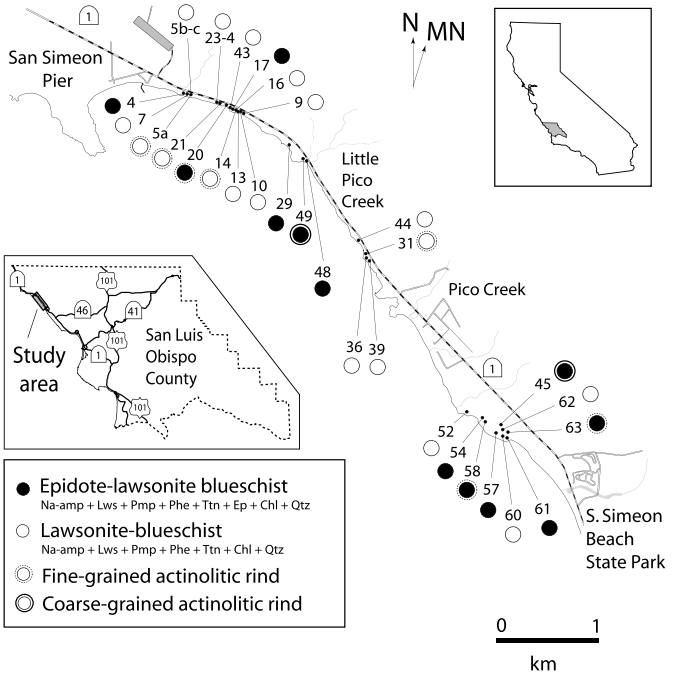

Fig. 1. Map showing the location of blueschist blocks (abbreviated numbers) with associated actinolitic rinds. Mineral assemblages in blueschist blocks are from Ukar and Cloos (in press). Chl = Chlorite; Ep = epidote; Lws = lawsonite; Na-amp = sodic amphibole; Phe = phengite; Pmp = pumpellyite; Ttn = titanite; Qtz = quartz.

Intact actinolitic rinds have been described around mafic blocks encased in serpentine-matrix mélanges from New Zealand (Coleman, 1966), California and New Caledonia (Coleman, 1967), several sites in the Caribbean region (e.g. Giaramita and Sorensen, 1994; Tsujimori et al., 2006), Greece (e.g., Bulle et al., 2010), and the Alps (e.g., Federico et al., 2007). In nearly all Franciscan occurrences, such as at Tiburon Peninsula (Catlos and Sorensen, 2003) or Jenner Beach (Krogh et al., 1994), block–matrix contact relationships are covered, so a current or recent association with serpentinite is inferred.

Before this study, Mg-rich actinolitic rinds had never been reported on the low-T, finely-crystalline mafic blueschists that vastly outnumber the high-T blueschists in the Franciscan mélange terrane. The association of actinolitic rinds with high-T Franciscan blueschists led several authors to propose that high-T blocks were uplifted to shallow depths in serpentinite diapirs (Ernst, 1965; Coleman and Lanphere, 1971; Coleman, 1980), whereas low-T blueschists may have been uplifted through other processes such as (1) imbricate thrusting (e.g., Coleman and Lanphere, 1971; Maxwell, 1974), (2) extensional faulting caused by gravitational collapse (Platt 1975, 1986), (3) synsubduction upward flow of mélange in the subduction channel (Cloos, 1982), or (4) gravity-driven extensional thinning that followed a shallowing of the plate dip (Ukar, 2012).

Along the 6 km-long seacliff exposure of the Franciscan mélange near San Simeon (Hsu, 1969; Cowan, 1978), close examination revealed remnants of actinolitic rinds on the margins of nine of the 34 (~ 25%) lawsonite ± epidote-bearing, low-T blueschist blocks that are or were clearly encased in shale-matrix mélange (Fig. 1). This area of remarkable block–matrix exposure is especially notable for there are only two minor exposures of serpentinite. One is an elongate mass, near the creek south of San Simeon Pier (Fig. 1), which is probably a fragment of the nearby ophiolite fragment that is offset along a splay off the San Simeon fault. The other mass is an elliptical block about 1 m across encased in the shale-matrix that was recently exposed by erosion in a small creek and discovered by John Wakabayashi (personal communication).

In this paper we present petrological, mineralogical, and geochemical data that confirms the similarities between the high-T and low-T actinolite/tremolite rinds on mafic blueschists, which indicates metasomatic exchange with ultramafic rock. This is the first reported association of actinolitic rinds with low-T Franciscan blueschists, which suggests that similar processes may have been responsible for the exhumation of both high-T and low-T blueschist blocks. We infer the rinds formed after subducted oceanic crust was dynamically deformed and imbricated with mantle material in a metamorphic aureole beneath the Coast Range Ophiolite, the leading edge of the North America plate (Platt, 1975; Cloos, 1985). Following serpentinization, fragments of the blueschist aureole became entrained and uplifted towards the surface in shale-matrix mélange that upwelled from depths of 15 + km. This paper focuses on the chemical analysis of three actinolitic contact zones that reveals a high mobility for Si, Na, Pb, Cu and an addition of K, Rb, Cs, and Ba during rind-forming alteration at temperatures less than 350 °C to perhaps 200 °C.

2. Lithology of the mélange near San Simeon

The seacliff and wave-cut bench exposures of shale-matrix mélange south of San Simeon are part of the Franciscan Complex known as the Nacimiento Block (Ernst, 1980; Page, 1981). The Franciscan Complex is an accretionary prism formed during late Jurassic to present by subduction of the Farallon plate beneath North America (Hamilton, 1969; Ernst, 1970). Most of the Franciscan mélange in the Nacimiento Block is lithologically and structurally similar to the mélange that forms the bulk of the Central Belt north of San Francisco (Cloos, 1986). Due to dextral strike-slip motion along the San Andreas and related faults, this region has been transported northward from the latitude of southern California (Atwater, 1970, 1989).

The inclusions that are immersed in a shale-matrix consist mostly of sandstone (graywacke, ~ 75%), greenstone (general term used for altered metamafic rocks that contain abundant chlorite, but in which some primary igneous textures and structures are preserved – see Turner and Verhoogen, 1960; ~ 20%), chert (~ 5%), and a small volume (~ 0.5%) of mafic blueschists and metasedimentary graphite-schists. The volumetric ratio of inclusions to shale-matrix is approximately one (Cloos, 1982). Most blocks that are clearly surrounded by matrix are less than ~ 10 m across (Hsu, 1969; Cloos, 1986). Blocks of all rock types have developed pinch-and-swell or boudinage structures and typically have a roughly ellipsoidal shape with their long axis subparallel to the scaly cleavage of the matrix. The high-mobility of the shale-matrix mélange near the surface is evident from mélange intrusions into the Cambria Slab trench slope basin deposits (Becker and Cloos, 1985).

2.1. San Simeon blueschist blocks

Most studies of Franciscan blueschists have focused on coarsely crystalline, typically garnet ± epidote-bearing, high-T blocks from the Central Belt north of San Francisco, and the Diablo Range (e.g., Coleman et al., 1965; Hermes, 1973; Moore, 1984; Oh and Liou, 1990). In contrast, mafic blueschists near San Simeon are very finely-crystalline, low-T schistose lawsonite blocks (Type III of Coleman and Lee, 1963) that are volumetrically much more abundant than the relatively well studied (Type IV) high-T blueschists. Petrologic study of the mafic blueschists at San Simeon reveals they are of two kinds: lawsonite-Na-amphibole, and epidote-lawsonite-Na-amphibole (Fig. 1; Table 1; Ukar and Cloos, in press). They also contain smaller and highly variable amounts of chlorite, phengite, pumpellyite, quartz and titanite. The diagnostic difference between the two kinds of blueschists at San Simeon is the presence or absence of epidote. All but one lack garnet (one block