Petrography and geochemistry of serpentinites from Sand Dollar Beach and Jade Cove, Big Sur area, Monterey County, California

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INTRODUCTION

Outcrops at the two field areas (Sand Dollar Beach and Jade Cove) contain blocks of massive serpentinite, ranging from pebble to boulder size, in a matrix of fine-grained serpentinite. Serpentinite blocks from the two field areas preserve relict textures from the protolith, but exhibit contrasting assemblages, degrees of overprinting of original minerals and chemical composition. This study is an attempt to characterize and explain these mineralogical and chemical differences in terms of the protolith and metamorphic histories of these serpentinites.

METHODS AND APPROACH

In the field, nine samples were taken from the massive serpentinite blocks that appeared to preserve mineral textures from the protolith. These samples were analyzed in thin-section. To the extent that these blocks represent remnants from an original ultramafic body, they provide the most information about the protolith. Some phase identification was accomplished using the Energy Dispersive System (EDS) on scanning electron microscope (SEM) at the Analytical Electron Microscopy Facility at University of California Riverside. Whole rock major and minor element data were obtained using X-ray fluorescence analysis (XRF) performed by Act Labs in Ontario, Canada.

OBSERVATIONS

Sand Dollar Beach (SDB). This field area contains a meta-greywacke unit and a serpentinite unit which are separated by a <1m gouge zone. The serpentinite of SDB contains pebble to boulder size blocks of serpentinite. Individual blocks are separated by a thin, generally < 3cm wide, foliated matrix of friable, fine-grained serpentinite. The outcrops at SDB contain 10m to 150m wide shear zones with well-developed S-C fabric separated by less sheared areas. Serpentinite blocks within the shear zone are generally lenticular, oriented within the shear zone and bounded by an anastamosing serpentine cleavage of the matrix. There are very few viens SDB on the outcrop scale. Thin sections, however, show several generations of serpentine veins that are cut by veins composed of calcite and clays.

Petrographically, the serpentinite blocks preserve at least three generations of mineral growth. The SDB blocks contain many relict orthopyroxenes, with enstatite and clinopyroxene components, that are partially altered to light-gray clays, which give the rock a spotted appearance in hand sample. There are two generations of clinopyroxene preserved in the SDB samples. Large, relict clinopyroxene with exsolution lamellae are rimmed by smaller neoblastic crystals, with idioblastic to hypidioblastic form (see figure 1 and figure 2). Mineral analysis using EDS shows the relict clinopyroxene to be an augite with significant omphacite/jadeite, hedenbergite and chromium diopside components (see figure 2). The neoblastic pyroxenes have a composition close to end-member diopside (see figure 1). The diopsides also occur as reaction rims around pseudomorphs of chlorite and/or serpentine after orthopyroxene (see figure 3).

A third generation of mineral growth is represented by the presence of serpentine and related minerals. The most abundant mineral in SDB samples is serpentine with a mesh texture after olivine. Relict olivine was only observed in one sample collected from SDB (see King 1999, this volume). Oxides occur both as neoblastic minerals and as relicts from the protolith. Analysis using the EDS shows the oxide phase is usually magnetite, occurring alone or rimming chromite or a Cu or Ni sulfide, which is then rimmed by chlorite. Clinopyroxenes occurring near calcite and clay veins are partially to completely covered by clays and calcite and tend to show breakdown of diopside to amphibole.

Geochemically, samples from SDB have a Ca content that is higher than expected for a pure serpentinite (see figure 4). This correlates with the significant amount of relict clinopyroxene in the samples (up to 20% modal abundance). Relict clinopyroxenes contain Ca, Mg, Al and Na, along with small amounts of Cr and Fe. Neoblastic diopsides contain only Mg, Ca and trace amounts of Fe (see figure 3). Al remains fairly constant (between 2.08 and 3.21 weight percent $Al2O3$) in all samples. Aluminum occurs in relict clinopyroxene as well as chlorite, but not in the neoblastic diopside, therefore samples with the highest ratio of Ca to Al contain the most neoblastic diopside (see figure 1).

Jade Cove (JDC). Outcrops at JDC consist of a serpentinite unit and a sheared meta-greywacke unit. The contacts between the serpentinite units and greywacke units at JDC, when exposed mostly appear to be contacts, with well-developed gouge zones. Outcrops of talc occur at or near some of the serpentinite/greywacke contacts. The serpentinite at JDC consists of angular, pebble to boulder size blocks of massive, black serpentinite within a matrix of friable, fine-grained serpentinite. Blocks contain many serpentinite-filled fractures. The JDC serpentinite contains abundant veins of calcite, quartz and serpentine in outcrop scale, ranging in width from μm to tens of cm. Small veins of calcite form web patterns in the outcrop.

In thin-section, serpentinite blocks from JDC are mostly fine-grained serpentine and chlorite. Large pseudomorphs (0.1mm to 6mm measured along the longest dimension) of serpentine and/or chlorite after orthopyroxene account for as much as 20 modal% of the samples from JDC. Energy Dispersisve System analysis of a pseudomorph after orthopyroxenes show the presence of slivers (~20-30μm long, <5 μm wide) of relict clinopyroxene. Reaction relationships observed include the breakdown of brucite to chlorite and chlorite and serpentine forming after orthopyroxene. In some samples from JDC, talc is replacing pseudomorphs of chlorite and serpentine after orthopyroxene. Oxides contain some chromite components rimmed by magnetite, which is rimmed by chlorite. Neoblastic oxides also occur.

Geochemically, all of the samples from JDC contain less CaO than samples from SDB (see figure 4) and are closer is composition to pure serpentine minerals. $Al203$ content is fairly constant in all samples, this means that JDC is depleted in Ca compared to SDB. This correlates with the general absence of clinopyroxene in JDC. Also JDC is enriched in Fe compared to SDB. Also, chlorite from JDC has more Al than chlorite from SDB (see figure 5).

DISCUSSION

The field, petrographic and geochemical data place constraints on the protolith and metamorphic history of these two field areas. In addition, the observations discussed provide possible explanations for the compositional and textural differences between SDB and JDC.

Sand Dollar Beach (SDB). The protolith of the serpentinites is indicated by the composition of the relict clinopyroxenes. Cr bearing pyroxenes would occur only in mantle rocks. The high Al omphacite/jadeite component of the relict clinopyroxenes discourages the possibility that the protolith could be a mafic cumulate The protolith for the serpentinite at SDB is most likely a mantle peridotite.

A diopside lacking Cr is not typical of clinopyroxene from mantle peridotites; therefore the formation of diopside from relict clinopyroxene at SDB most likely represents an early, high temperature metamorphism. This interpretation is indicated by the reaction textures. Either the metamorphism of the rocks at SDB must have been a high temperature episode, or there were multiple metamorphic events, high-grade event in which the diopside formed and a low-grade event during which serpentinization occurred.

The occurrence of serpentine and associated reactions, including the formation of amphibole from diopside, represents a low-grade overprint of the first two generations of mineral growth. The reactions that produce serpentine and associated minerals require the presence of an aqueous phase. The fact that relict pyroxenes (and olivine) are preserved at SDB and not at JDC suggests that SDB was a less fluid-rich environment during serpentinization than JDC.

One sample collected from SDB contains a Ca-rich, clinopyroxene-bearing core surrounded by an outer rim of serpentine and oxides. The outer portion of this samples has the lowest Ca content of any sample, while the core is very Ca-rich (see figure 4). Diopside occurring near the reaction front is breaking down to a fibrous amphibole phase. The texture and compositional variation in this rock provides evidence for the removal of Ca from rocks at SDB. Calcite veins in samples from SDB represent the presence of a Ca-rich fluid in the rock and could be a mechanism for removing Ca.

Jade Cove (JDC). While rocks from JDC do not preserve relict clinopyroxenes, they do contains large pseudomorphs of serpentine and/or chlorite after pyroxene, which are similar in size and form to relict pyroxenes at SDB and contain relict slivers of clinopyroxenes. JDC samples also contain some relict chromite and the mineral assemblage serpentine + brucite + magnetite which likely formed after olivine and/or enstatite. Because primary mineral assemblages are not preserved in JDC rocks, the protolith is difficult to constrain. However, the textural similarities between JDC and SDB suggest that the protoliths may have been similar.

The presence of diopside at only SDB could imply either that SDB underwent a high-grade metamorphism that JDC did not experience, or the removal of Ca from JDC by fluids erased any evidence of this reaction. Diopside appears to be breaking down to an amphibole phase prior to removal near the reaction front in the sample from SDB, yet the serpentinite out portion does not contain any amphibole. The fact that diopsides and other clinopyroxenes near the reaction front and near to veins tend to be covered by calcite suggests that Ca from the clinopyroxenes could be mobile in the presence of fluid. The observation that chlorite from JDC contains more Al could be interpreted to mean that Al was not leaving the rock with Ca, but was being taken up by the chlorite as the relict was clinopyroxene broken down to diopside.

The abundance of large veins in the JDC serpentinite serves as further evidence of fluid flow. Reactions producing talc and chlorite, both phases containing more Si than serpentine, and the occurrence of large outcrops of talc at JDC suggests that this area was effected by an Si-rich fluid during metamorphism. The abundance of calcite veins in JDC outcrop probably represents a process that transported Ca away from the rock as the clinopyroxenes were reacted out.

CONCLUSION

I propose that the differences between the serpentinite in two field areas could be due to either 1) a different protolith composition for the serpentinite of each beach, 2) different pressure and temperature conditions during metamorphism, 3) differences in the fluid/rock interaction during serpentinization, or 4) some combination of these. The first two hypotheses are impossible to evaluate in this study due to the low-grade overprint, which obscures relict textures. However, given all the observations that suggest JDC was an extremely fluid rich environment compared to SDB, the simplest explanation is that the two serpentinites were originally the same, or very similar and the differences that are observed in outcrop today represent a difference in the fluid/rock interaction at the two locations. Accepting the interpretation that JDC was a more fluid rich environment during low grade metamorphism than SDB, it follows that, all other conditions being equal, brittle deformation would be more likely to dominate at JDC than SDB because of an increase in pore pressure.

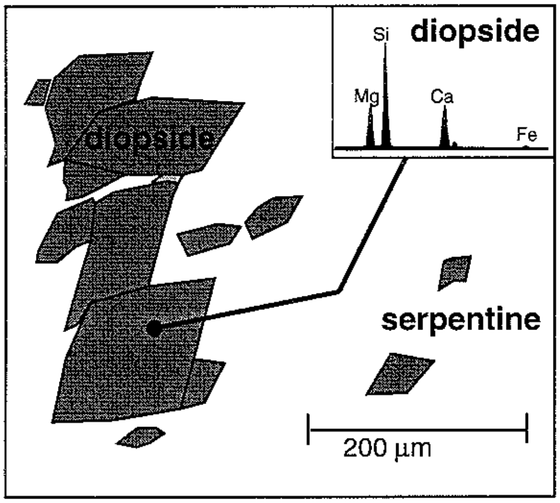

Fig 1. This figure, sketched from a BSE image,shows the texture of the idioblastic diopsides, surrounded by undifferentiated, fine-grain serpentine.

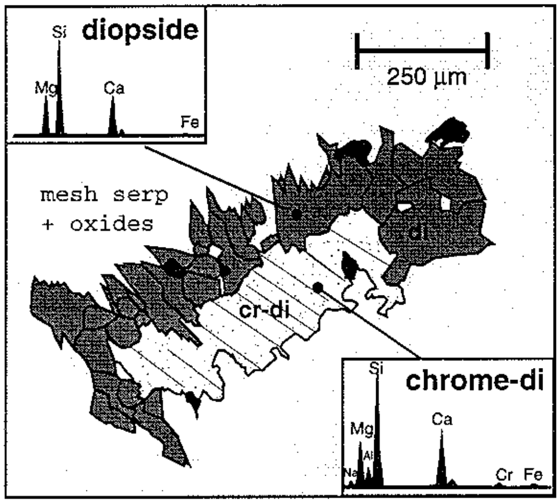

Fig 3. Sketch from Sand Dollar Beach thin section showing relict cpx rimmed by diopside. Mineral composition data were obtained from EDS. Peaks for Na and Al occur to the left of Mg and Si respectively.

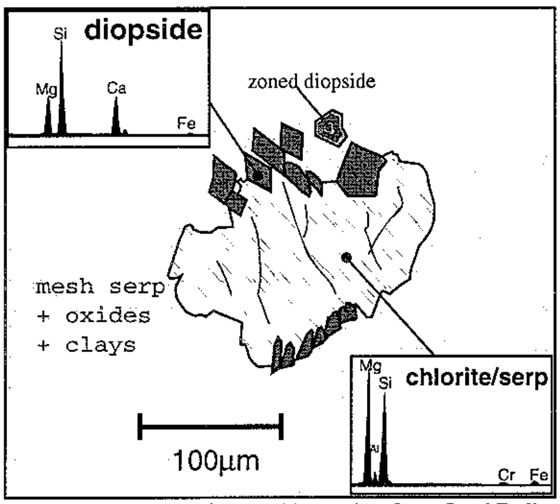

Fig 4. This sketch from a thin section from Sand Dollar Beach shows a pseudomorphof chlorite/ serpentine after pyroxene with a rection rim of diopside. Mineral composition data are obtained from EDS. Peak Al occurs between Mg and Si.

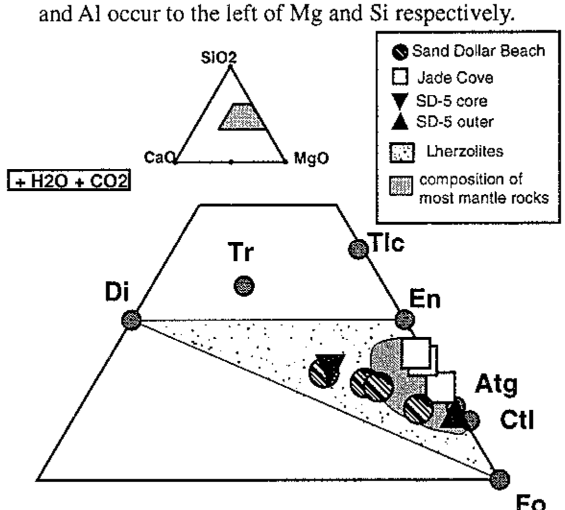

Fig. 4. . Plot of ultramafic CMS-HS system projected from CO2 and H2O onto the plane of CaO-MgO-SiO2. Redrawn after Bucher and Frey, 1994 with my sample superimposed. Di=diopside, Tr=tremolite Tlc=talc, En=enstatite, Atg=antigorite, Ctl=chrysotile, Fo=forsterite.

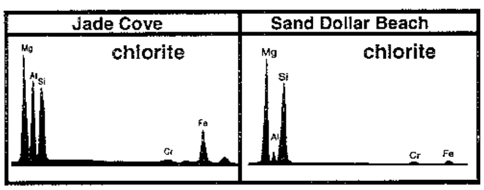

Fig 5. This shows a comparison of EDS spectra of chlorites from Jade Cove and Sand Dollar Beach. Chlorite from Jade Cove contains more Al.

Reference: Bucher, Kurt and Frey, Martin(1994)
Petrogenesis of Metamorphic Rocks,
6th edition, Springer Verlag, Berlin

AUTHOR INDEX