OPHIOLITES AS ANALOGS TO HABITATS ON MARS. M. Schulte and D. F. Blake, NASA Ames Research Center, Exobiology Branch, Mail Stop 239-4, Moffett Field, CA 94035-1000, USA (mschulte@mail.arc.nasa.gov and dblake@mail.arc.nasa.gov).

Introduction: Ophiolite sequences that are located in northern and central California provide easily accessible areas that serve as good analogs for martian crustal rocks. The rock types found in a typical ophiolite sequence compare well with those found in the Mars meteorites, and those expected from spectrophotometric analysis. We have begun investigating and characterizing these sites in order to understand better the processes that may be responsible for the groundwater chemistry, mineralogy and biology of similar environments on Mars.

One of the processes known to occur during water-rock reactions in mafic to ultramafic rocks at relatively low temperatures is serpentinization [1]. The general reaction for serpentinization of olivine is given by:

$$\text{olivine} + H_2O = \text{serpentine} + \text{brucite} + \text{magnetite} + H_2.$$

The serpentinization process results in an increase in volume, which results in increased cracking and increased fluid flow in the rocks. This exposes fresh fracture surfaces to further water-rock reaction, thus sustaining the process. In addition, serpentinization is a heat-generating process, which combined with fluid flow, leads to development of self-sustained hydrothermal cells.

The geophysical and geochemical processes in these terranes provide niches for unique communities of extremophiles and are the best terrestrial analogs for similar geochemical habitats on Mars.

Ophiolites in northern California: Ophiolites are sections of lower oceanic crust and upper mantle that have been thrust onto continental craton. The rock types range in composition from mafic (basalts) in the upper section to ultramafic (peridotites) near the base. The ophiolites found in northern California include the Trinity, Josephine, Coast Range and Point Sal, all of which are approximately 160 million years old [2]. Fluids from serpentinizing springs are generally alkaline with high pH and H_2 contents [3-7], indicating that the mafic rock compositions control the fluid composition through water-rock reactions during relatively low-grade hydrothermal processes. There are significant amounts of primary mineralogy remaining in the rocks, meaning that substantial alteration processes are still occurring in these terranes.

Mineralogy & petrology: We have analyzed the mineralogical composition of several rock samples collected from the Coast Range Ophiolite near Clear Lake, CA. The remnant primary mineralogy is fairly uniform in composition, with an olivine composition of Fo_{90}, and with pyroxene compositions of En_{90} for orthopyroxene and $En_{49}Wo_{48}Fs_{03}$ for the clinopyroxenes. Other primary phases include chromites and other spinels.

Examination of petrographic thin sections reveals that serpentinization reactions have occurred and are still occurring in these locations (Figure 1). The serpentine resulting from aqueous alteration of olivine and pyroxene resides in veins that are seen cross cutting the primary mineral grains. There are several generations of alteration products, comprised mostly of serpentines that are correspondingly magnesium rich, with magnetite, brucite and carbonates observed as accessory minerals. The formation of carbonates indicates the presence of CO_2 in the altering fluid.

Ophiolites as analogs for Mars: Taken as a whole, the sequence of rocks found in ophiolites is likely to represent a good analog for the rock types that will be encountered during missions to Mars. The Mars meteorites range from mafic to ultramafic (basalt- lherzolite-dunite) in composition, and this range closely parallels the sequence of pillow basalt-gabbro-peridotite found in complete ophiolite sections.

Because the potential mineralogy of Mars is similar to that in ophiolite sequences, the groundwater of Mars is likely to be basic (alkaline). The resulting water-rock reactions would be similar to those found in terrestrial ophiolite terranes; serpentinization reactions would produce similar assemblages of alteration minerals and self-sustaining hydrothermal cells could be established. The resulting hydration reactions may also serve as a sink for significant amounts of water. The outflows seen on the martian surface may contain alteration assemblages similar to those seen in modern terrestrial ophiolite spring systems and are likely to include not only hydrated minerals, but also evaporites resulting from the exposure of alkaline fluids to the dry martian atmosphere.

Ophiolites as biological habitats: Since photosynthesis does not appear to be present on the surface of Mars, any life on Mars will have to take advantage of the chemical energy available during water-rock reactions in the martian crust. One of the most primitive metabolic reactions among extremophiles is methanogenesis, in which carbon dioxide is reduced to methane. The general reaction is given by:

$$CO_2 + H_2 = CH_4 + H_2O.$$

Organisms living in ophiolite terranes could use the hydrogen that results from serpentinization reactions, along with ambient carbon dioxide to generate methane, thus using chemical energy as metabolic energy. In addition to methanogenesis, other chemotrophic metabolisms are possible in serpentinizing systems. For example, some organisms are known to use H_2 directly as an energy source and are likely candidates to inhabit these areas.

We collected samples from Complexion Spring (Figure 2) in the Coast Range Ophiolite in order to determine whether the geochemical processes in these environments are providing a niche for chemotrophic microorganisms, thus serving as geochemical habitats. DNA was extracted from sediment samples and the 16s rRNA gene was PCR amplified using Archaeal primers. Denaturing gradient gel electrophoresis (DGGE) was used to determine the community of Archaea thriving in these samples. Our results indicate that there were 8 different genera of Archaea in a single sample. We were able to sequence one of the eight. The sequence that was obtained was of an organism that is similar to *Halorubrum tibetense*, an alkalophilic Archaeon. This result suggests that these environments are likely hosts for communities of organisms that are adapted for the unique chemical environment provided by the alkaline spring.

Summary: The geology, geochemistry, water chemistry, and biology of ophiolite terranes provide a good model for crustal processes that may be occurring on Mars. The juxtaposition of liquid water and unstable minerals in these environments provides chemical energy sources that could be used by unique communities of microorganisms. Understanding how these communities function on Earth could prove invaluable in searching for habitable zones during future missions to Mars.

References: [1] McCollom T. M. and Seewald J. S. (2001) *GCA, 65*, 3769–3778. [2] Dickinson W. R. et al. (1996) *GSA Today, 6*, 1-10. [3] Coleman R. G. (1971) *Geol. Soc. Am. Bull., 82*, 897-918. [4] Neal C. and Stanger G. (1983) *EPSL, 66*, 315-320. [5] Neal C. and Stanger G. (1984) *Mineral. Mag., 48*, 237-241. [6] Peters E. K. (1993) *GCA, 57*, 1344–1345. [7] Kelley et al. (2001) *Nature, 412*, 145-149.

Figure 1. Olivine grain from Coast Range Ophiolite showing, with serpentinization alteration in veins. Field of view is approximately 2 mm across.

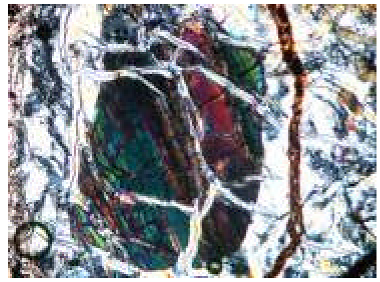

Figure 2. Sampling Complexion Spring in the Coast Range Ophiolite near Clear Lake, CA.