HOT AND COLD SPRING DEPOSITS AS A SOURCE OF PALAEO-FLUID SAMPLES ON MARS.

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Introduction: Fluid inclusions are micron-scale volumes of fluid entrapped during the precipitation of minerals. Fluids are entrapped during primary mineral growth, and during healing of later fractures. The water in fluid inclusions in minerals precipitated in the upper crust of Mars contains a record of the ambient environment during precipitation. This includes data on fluid temperature and ion chemistry, which can constrain the likelihood of life in that environment. More significantly, the fluid chemistry could include a biomolecular signature of life.

Mineral precipitation in the upper crust on earth (down to depths of a few km) occurs at the surface and in pore spaces and fracture systems. Precipitation in the subsurface is enhanced by the circulation of fluids carrying dissolved ions, which also function as nutrients for life. Surface precipitation may also be biologically mediated. As precipitation occurs, micron-scale volumes of fluid are trapped as inclusions in the minerals. Thus mineral precipitates are both associated with life and contain entrapped water, and we can use the water as a source of information about the life. If life existed in the environment of mineral precipitation, all the requirements for detecting it can be met [1].

A number of environments have been suggested as possible places for life on Mars, including evaporitic, lacustrine, chemosynthetic, speleothem and hydrothermal deposits. This is a terrestrial analogue study investigating the preservation of surface fluids from modern day hot and cold spring deposits, which could have preserved molecular biomarkers. Spring deposits have been suggested as particularly valuable targets for astrobiological exploration, based on their association with flourishing biotas on earth [2, 3, 4]

Samples of study and results: Travertines, which are composed of carbonate and sometimes silica minerals, are developed in hot springs, rivers, waterfalls coastal marshes and lakes. They develop is response to degassing of calcium carbonate-bearing waters and are frequently associated with a rich bacterial flora. The bacteria can directly precipitate calcium carbonate by removal of dissolved carbon dioxide during photosynthesis. They also can provide a framework for the nucleation of calcium carbonate crystals.

Travertines were sampled from active hot springs at Bagno Vignone in Italy and Tehuacan in Mexico that occur in associated with recent volcanic centres. These travertines, which are composed of fine-grained, magnesium-rich calcite crystals, contain layers of endolithic cyanobacteria close to the surface of the rock [5]. A recent travertine occurring in association with a cold spring in Gordale, England was also sampled. This travertine is composed of fine-grained, magnesium-rich calcite crystals interlayered with the remains of cyanobacterial colonies [6] (Fig. 1).

Fluid inclusions are micron-scale vacuoles filled with the waters present during the growth of the host mineral. The travertine samples from Bagno Vignone, Tehuacan and Gordale all contain fluid inclusions, which entrapped fluids present during the original growth of the carbonate mineral. These inclusions are small in size with the majority less than 5 microns in diameter. At room temperature all these fluid inclusions are one-phase, aqueous liquid-filled, indicating that they were entrapped at temperatures lower than 40 to 50^{o}C. The temperature at which ice melts in aqueous-filled fluid inclusions can be used to estimate the salt content of the fluids entrapped within the inclusions. Upon freezing these inclusions, ice melts at temperatures between –1.8 and 0^{o}C indicating that these inclusions contain salinities of between 0 and 3 wt.% NaCl. Figure 2 shows that the majority of the inclusions within the travertine samples contain salinities of less than 1 wt.% NaCl.

Discussion: The majority of the fluid inclusions contain aqueous liquid which contain very low salinities with most values close to that of pure water. This suggests that the fluid inclusions entrapped meteoric water present during the formation of the travertines. The salinity of marine waters are approximately 3.5 wt.% NaCl and brines in geological sedimentary basins typically have values greater than this. The low temperature of entrapment is also compatible with the inclusions preserving surface water present during the growth of the carbonate minerals forming the travertines.

Rocks composed of carbonate minerals often recrystallize with time. Any fluid inclusions trapped within these recrystallized minerals would trap fluids present during recystallization rather than the original formation of the carbonate rock. It is therefore important to address whether the carbonate minerals forming these travertines have recrystallized. Recrystallization of carbonate rocks typically involves an increase in grain size and the production of randomly orientated crystal fabrics. All the travertine samples in this study possess elongate crystal fabrics orientated perpendicular to laminae which indicates that the carbonate minerals are primary precipitates. This shows that minerals, which form in environments containing algal growths, contain fluid inclusions that trap waters present during the growth of the mineral.

Implications: Terrestrial studies have shown that surface waters are preserved in fluid inclusions in rocks over 3.2 Ga indicating the long-term preservation of fluid inclusions [7]. Studies of terrestrial petroleum systems show that organic compounds are preserved unaltered in fluid inclusions [e.g. 8, 9]. Fluid inclusions are preserved long-term within minerals that have not undergone excess heating or recrystallization. The very high temperatures generated within impact craters on Mars would destroy inclusions, but fluid inclusions within rocks outside the craters would survive. Recrystallization of minerals requires free surface waters, which means that minerals on the Martian surface are unlikely to recrystallize during dry periods.

As has already been shown fluid inclusions preserve waters present within environments that may contain organic growth. Water within fluid inclusions may preserve evidence of any bacteria or algae growth present in the vicinity of mineral growth. Bacteria and algae produce a wide range of organic compounds that are dissolved in water, a number of which have long term stabilities. Analytical sensitivities are high enough to record the small quantities of organic compounds preserved in typical fluid inclusions. Waters present within fluid inclusions can be released by either heating or crushing the mineral host, although strong heating will decompose complex organic molecules. The thermally created gases or the liberated liquids can then be analysed for molecular biomarkers by either mass spectrometry and/or gas chromatography, or a range of other molecular sensing techniques [e.g. 10, 11]. These analyses only require very small quantities of material and could be performed in a remote manner. Regardless of the lack of water on the present day Martian surface, molecular biomarkers as evidence for past life on Mars may be preserved in fluid inclusions in precipitates formed at the surface at a time when water was present. This gives us the potential to search for a signature of life in fluid inclusions in samples of surface precipitates on Mars.

Conclusions: This study of fluid inclusions in terrestrial hot and cold spring deposits shows that this type of deposit will be a valuable target for astrobiological sampling on Mars because: (i) they preserve palaeofluids samples, (ii) in at least some cases they are not altered by recrystallization, (iii) the fluids were entrapped at low temperature, so complex organic molecules should survive in them, and (iv) the association of spring deposits with flourishing biotas suggests that entrapped fluids should be rich in biomolecules.

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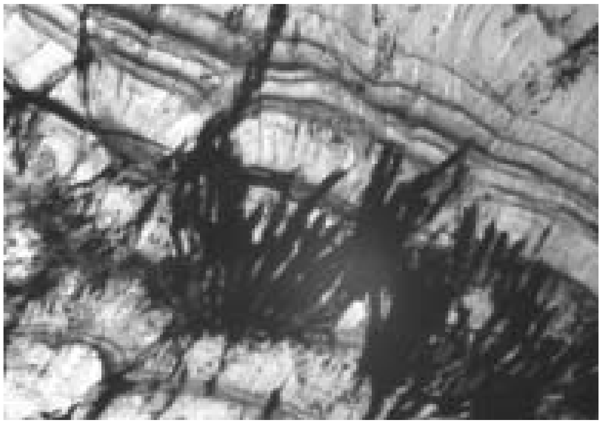

Figure 1. Microphotograph of cyanobacterial colonies preserved within layers of elongate calcite from a spring travertine at Gordale (width of view: 1mm).

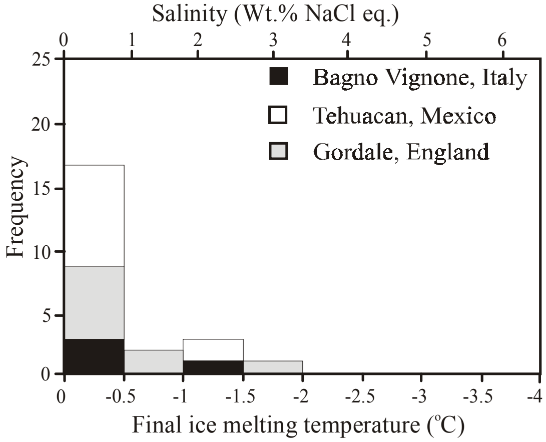

Figure 2. Final ice melting temperatures and salinities of primary inclusions within travertines from Bagno Vignone, Tehuacan and Gordale.