"Gold" hydrogen in natural fluid inclusions

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Fluid inclusions in minerals are natural storage vessels of fluids. The most common fluids that are preserved in inclusions are mixtures of water, carbon-dioxide and salts. In reduced geological environments gases such as methane (and other thermogenic alkanes, also known as "abiotic"), nitrogen, and hydrogen may be included. The present study gives some new results on the occurrence of hydrogen in natural fluid inclusions in specific geological settings.

Hydrogen is a highly volatile gas component that is not assumed to retain within the crust and mantle for a long period, but is continuously outgassed. Several natural seeps of hydrogen-rich fluids are already considered for exploration (so-called "gold" hydrogen). This hydrogen may be captured within fluid inclusions in environments with sufficient concentrations. Both seeps and fluid inclusions are aspects of the existence of a hydrogen-rich fluid that may circulate in rock. The latter may also provide information on hydrogen-rich flows in the geological past, because inclusions may preserve paleo fluid properties.

There are only few studies that mention the existence of hydrogen within fluid inclusions, that provide abundant speculative models of the origin of hydrogen within rock, usually with a lack of sufficient and relevant data. For example, both serpentinization and de-serpentinization were considered as formation processes of hydrogen. Redox conditions in rock are the main factors that define the composition of a fluid phase in deep rock, that only occupy a minor volume fraction of the system. This fluid is buffered by the coexistence of solid phases within the rock. Highly reduced conditions are common within mantle rock. Methane is closely related to the occurrence of hydrogen as both represent these reduced conditions. Similar conditions exist in Si-undersaturation igneous environments (e.g. nepheline syenite). An alternative source of hydrogen is radiolysis, but this is not sufficiently supported by fluid inclusion studies.

Hydrogen-rich fluid inclusions are analysed in three different geological settings: 1. In Upper Cretaceous strongly serpentinized mantle rock (Troodos, Cyprus); 2. In Neogene pegmatites closely related to serpentinite host-rock from metamorphosed ophiolitic-sedimentary tectonic units (Elba, Italy) (Bakker & Schilli, 2016); 3. In Mesoproterozoic metasediments of the Mt Painter Inlier, Arkaroola (Australia) (Bakker & Elburg, 2006)

Inclusions in pyroxene in strongly serpentinized areas in Troodos contain mixtures of CH_4, H_2 and H_2O (Fig. 1). Similar fluids are observed in chromite in mantle rock that is hardly affected by serpentinization (McElduff, 1989).

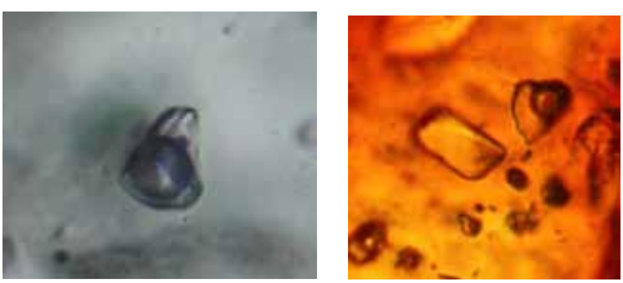

Figure 1. Fluid inclusions (ca. 10 μm) in pyroxene (left) and chromite (right).
The vapour phase is highly enriched in H_2.

Fluid inclusions in pegmatites from Elba represent a complex interaction between magmatic and metamorphic fluids. Multiple pulses of low salinity H_2O-rich magmatic and reduced metamorphic fluid stages are recorded. Magmatic fluids are characterized by the presence of minor amounts of CO_2 and H_3BO_3, whereas the metamorphic fluids contain CH_4 and H_2 (minor N_2, H_2S, and C_2H_6) that may origin from the input of more reduced fluids from serpentinites, that may completely replace the magmatic fluid. H_2-rich fluid inclusions were observed in andalusite, quartz, plagioclase, and tourmaline.


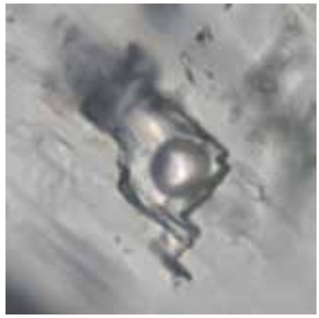

Figure 2. Fluid inclusions (ca. 20 µm) in quartz (left) and plagioclase (right) (Bakker & Schilli, 2016). The vapour phase is a mixture of mainly H_2 and CH_4.

A massive hydrothermal event in Arkaroola is demonstrated by an epithermal hematite-quartz assemblage, bladed calcite, and fluorite (Fig. 3). Fluid inclusions in fluorite contain a mixture of H_2O and H_2. The hydrogen occurs preferentially within the purple fluorite, which also includes some uranium mineralizations (radiation damage centres). These mineralizations are also proposed to be responsible for defining the colour of fluorite from green to purple that grew contemporaneously with the late hydrothermal quartz–hematite mineralization. The origin of hydrogen in fluid inclusions in fluorite is suggested to be radiolysis.

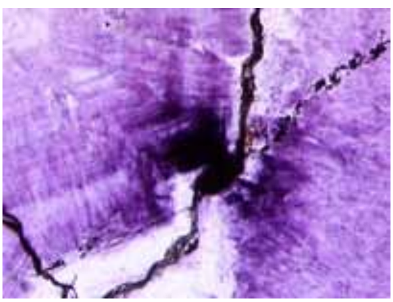
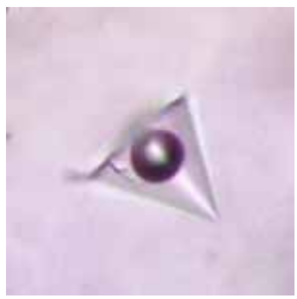

Figure 3. Purple fluorite with radiation damage centres (left), and H_2-rich fluid inclusions, ca. 10 µm (right) (Bakker & Elburg, 2006). Left image has a length of 200 µm.

Diffusion of hydrogen is a common aspect to explain the absence of hydrogen in most rock, even in environments where hydrogen is assumed to be a major fluid component. The examples illustrate that hydrogen may be preserved within fluid inclusions, similar to most fluid components.

Bakker RJ, Elburg MA (2006): A magmatic-hydrothermal transition in Arkaroola (northern Flinders Ranges, South Australia): from diopside-titanite pegmatites to hematite-quartz growth. - Contrib Mineral Petrol 152, 541

Bakker RJ, Schilli SE (2016): Formation conditions of leucogranite dykes and aplite-pegmatite dykes in the eastern Mt. Capanne plutonic complex (Elba, Italy): fluid inclusion studies in quartz, tourmaline, andalusite and plagioclase. - Mineral Petrol 110, 43

McElduff, B (1989): Inclusions in chromite from Troodos (Cyprus) and their petrological significance. - Ph.D. Thesis, Montanuniversität Leoben, Austria