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Natural hydrogen genesis and pyritization

CORINNE ARROUVEL[1] AND ALAIN PRINZHOFER[2]

[1]UFSCar

[2]GEO4U

Presenting Author: corinne@ufscar.br

While most of the known reactions are usually associated with minerals reacting with water under oxidizing conditions (e.g. serpentinization) and radiolysis, the role of pyritization has been underestimated. We aim to explain the H_2 genesis in a sulfur environment and to list proxies helping to localize hydrogen in Earth's crust (formation and accumulation). The used thermodynamic simulations enable to predict the direction of a range of possible metamorphic reactions regarding Gibbs free energies as a function of depth in the crust, temperatures up to 1500ºC, pressure up to 10kbar and including the relative partial pressures of H_2 and H_2S gases. We show that iron-based oxide precursors under hydrogen sulfide lead to H_2 formation and pyrite FeS_2 in the upper part of the continental crust (down to 12km using the thermal gradient of 30ºC at Qr=1). As the crust can be considered as a semi-open system for gas mobility (lowing H_2 partial pressure by leaking), its genesis should occur at deeper levels. The slow cooling of continental crust through time in cratonic areas is also compatible with the enhancement of exothermic pyritization reactions. The pyritization induces a reduction of ferric into ferrous iron, completing the iron redox cycle to the inverse oxidation process represented by the serpentinization[1]. Pyritization and serpentinization are complementary reactions and can co-exist (e.g. pyritization in acidic black smokers and serpentinization in basic white smokers). Active sites (e.g black smokers, geothermals) with iron sulfides are therefore propitious areas for H_2 formation. To localize the kitchen of H_2 formation and its accumulation, direct and indirect methods are available such as studying magnetic anomalies, thermal gradient anomalies, gravimetry, fluids and minerals analysis, natural radioactive emissions. To estimate the cost for its exploration, monitoring the H_2 fluxes and localising its possible accumulation via geological analysis of the field is necessary. Some case studies will be discussed in terms of potential investment for using natural H_2 as a clean energy for fuel cells and other industrial applications.

Reference:

[1] Arrouvel & Prinzhofer (2021) International Journal of Hydrogen Energy 46, 18780-18794

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