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Characterization of natural hydrogen seeps through advanced surface geochemistry

Turner, A.; Hunt, A.G., Ellis, G.S.

Interest in natural hydrogen (H2) has rapidly increased in recent years due to its potential as an alternative low-carbon source of energy. However, identifying locations and mechanisms of natural hydrogen generation and accumulation in the subsurface remains a challenge. Searching for and studying surface seeps is an important first step in natural hydrogen exploration, one which many groups have begun to work on. The primary method which has been used to identify and characterize seeps in recent work has been the concentration of hydrogen in soil gases at the surface. While this strategy has had success, issues such as varying temporal and environmental conditions limit interpretation of data. A central question is whether hydrogen measured in soil gas is produced locally by biological processes or in the subsurface by geologic mechanisms. This is difficult to definitively answer with surface soil gas hydrogen concentration measurements alone. To better characterize sources of hydrogen seeps, other techniques must be used in conjunction with hydrogen concentration measurements. Examining the concentrations of additional gases, such as methane and other hydrocarbons, carbon dioxide, nitrogen, and noble gases can help to place a particular hydrogen observation within a framework of potential gas sources. Hydrogen produced by different mechanisms has different characteristic associated gases, which we are beginning to characterize and catalogue in soil gases. Bulk isotopic compositions of hydrogen, as well as the other associated gases mentioned above, can provide another layer of information. Some isotopic signatures are suggestive of biological origin (e.g., potentially highly depleted methane or hydrogen isotopic compositions), and indirect evidence for differing generation mechanisms may be inferred from formation or re-equilibration temperatures. As gases move towards the surface, they may interact with other species encountered along migration pathways, and their isotopic compositions might be altered. Isotopic compositions of different molecules can be assessed together through apparent fractionation factors, providing information on the relationship between different gas species. For example, hydrogen-bearing species such as methane or water are known to interact with hydrogen, and equilibration or partial equilibration of the isotopic composition of hydrogen

with these species is possible and could overprint a signal of the pathway that gases take from subsurface to surface in the isotopic compositions of the gases themselves. Finally, clumped isotopes of hydrogen, methane, carbon dioxide, and potentially other novel techniques may provide yet another dimension to understand the formation and migration of gases from the subsurface to the surface. We will discuss the utility and potential for measurements of isotopic compositions and concentrations of hydrogen and associated species in soil and subsurface (e.g., dissolved in groundwater) gases to contribute to our understanding of natural hydrogen surface seeps and their potential connection to subsurface sources.