PERSPECTIVES

Drill, Baby, Drill – For Hydrogen

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Hydrogen is a powerful, portable fuel that is especially useful for transportation. It has an energy density that is greater than that of diesel or gasoline and can refuel a vehicle as fast as liquid hydrocarbons. Today, hydrogen is mostly made from water or natural gas, requiring significantly more energy than it provides when used as a fuel. For that reason, hydrogen is generally regarded as an energy storage media, not an energy source. That may be changing as evidence accumulates that hydrogen gas is coming out of the Earth (Arrouvel and Prinzhofer, 2021; Zgonnik, 2020; Ellis and Gelman, 2024) and that there are significant hydrogen deposits (white or natural hydrogen) that we can economically access with modern drilling techniques. This is very exciting because using natural hydrogen as a fuel could transform our economy at the same time it allows us to address global climate change by reducing carbon dioxide emissions. A concerted effort to figure this out is needed, and the geoscientific community should lead the effort. How do we do this?

First, we need to figure out where natural hydrogen deposits exist so that somebody or some company can find it, exploit it, and make lots of money. Natural hydrogen needs the equivalent of Marshall's 1848 discovery of gold in California or Drake's 1859 discovery of oil in Pennsylvania. We need a "hydrogen rush," beginning with somebody getting rich by finding and exploiting a hydrogen deposit. How do we help make this happen?

To set the stage for the "hydrogen rush," we need to better understand how hydrogen is generated in the Earth and migrates up to a trap where it accumulates: the hydrogen system. Advancing our understanding of the hydrogen system requires modifying the well-established petroleum system approach (Perrodon, 1992). The petroleum system concept is based on a sequence of processes in a sedimentary basin, starting with the genesis of oil or gas from source rocks, which then migrates upward or laterally to be trapped beneath some sealing layer or structure where it accumulates. Adaptation of the petroleum system approach to develop a hydrogen system approach (Saucier, 2025) focuses attention on sedimentary basins as the best places to look for economic hydrogen deposits.

Only sedimentary basins can have all three hydrogen system components: source, migration pathway, and trap. Migration of hydrogen is expected because this minuscule molecule is light and easily escapes from its source, but sources and traps are more problematic. What overlying lithologies can serve as seals to trap hydrogen and keep hungry microbes away? That key question is not addressed here beyond the observation that such traps can only be found in sedimentary basins, both onshore and offshore; this is where the search for geologic hydrogen must focus. Understanding hydrogen source rocks is the other big challenge, which we explore below.

Eight ways to make hydrogen were identified by Blay-Roger et al. (2024), but four are important: radiolysis, serpentinization, pyrolysis, and flux from the mantle (Fig. 1). Breakdown of water due to radioactivity (radiolysis) may be important in old, K-rich granites (Crowell, 2003). Water-rock interactions involve the reduction of water by oxidization of Fe^{2+}-bearing minerals, especially accompanying serpentinization (Jackson et al., 2024); this is the Schikorr reaction (Blay-Roger et al., 2024). Methane dissociates at high temperatures into H_2 and graphite as a result of pyrolysis. Horsfield et al. (2022) studied the ultradeep drill-hole Songke-2 well, which was drilled to 7018 m and into

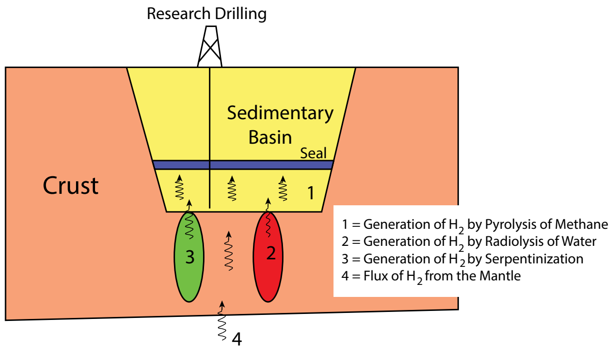

Fig. 1

Figure 1. Conceptual diagram for hydrogen formation, migration, and sedimentary basins.

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basement in the Songliao Basin of NE China, an established petroleum province. They found significant hydrogen in the crust under the sediments, beneath the stability field of methane. The helium isotope R/Ra ratio of 0.04–4.0 indicates that He (and perhaps H_2) was a mixture of crustal- and mantle-derived gases. Horsfield et al. (2022) concluded that hydrogen was created from breakdown of organic material. By analogy with 3He flux, hydrogen may also leak out of the mantle. These four processes dictate that we should look for economic hydrogen in sedimentary basins built above or around ancient evolved continental crust (radiolysis), that are methane-rich, deep, and hot (pyrolysis), that are underlain by olivine-rich rocks (serpentinization), and that are likely to have experienced a significant helium and hydrogen flux from the mantle. Figure 1 summarizes these four processes.

The inescapable conclusion is that we need to geophysically image and then drill deep into a sedimentary basin to better understand the hydrogen system and see how much hydrogen is there. But where to do this? Surprisingly, the Los Angeles basin, which lies beneath the United States' second largest city, may be best. This complex Neogene basin is one of the deepest onshore basins in the United States, filled with 30,000 ft (9144 m) of sediments (Fig. 2; Biddle, 1991). It is flanked on the east by ancient (Paleoproterozoic) rocks intruded by enriched Mesoproterozoic and Mesozoic plutons, providing opportunities for H_2 formation by radiolysis. The crust beneath the basin is thin (<10 km thick; Sawyer et al., 1987), suggesting that easily serpentinized olivine-rich oceanic crust may exist there, providing another source of hydrogen. Abundant faults provide many pathways for hydrogen generated in old continental crust, from serpentinization reactions, or escaping from the mantle to flow into the basin. Finally, the Los Angeles Basin is the richest basin in the world in terms of hydrocarbons per volume of sedimentary fill (Biddle, 1991). This, coupled with its great depth and high heat flow, means that there is excellent opportunity for hydrogen generation by pyrolysis.

Others may disagree that this is the best initial basin to explore for natural hydrogen, and other candidates such as the Permian Basin or Anadarko Basin, or a U.S. passive margin, should be considered. In any case, we need to identify one or more basin(s) to geophysically image and then choose one to drill into deeply and into basement, coring and sampling gasses all the way down. Let's get started, shall we?

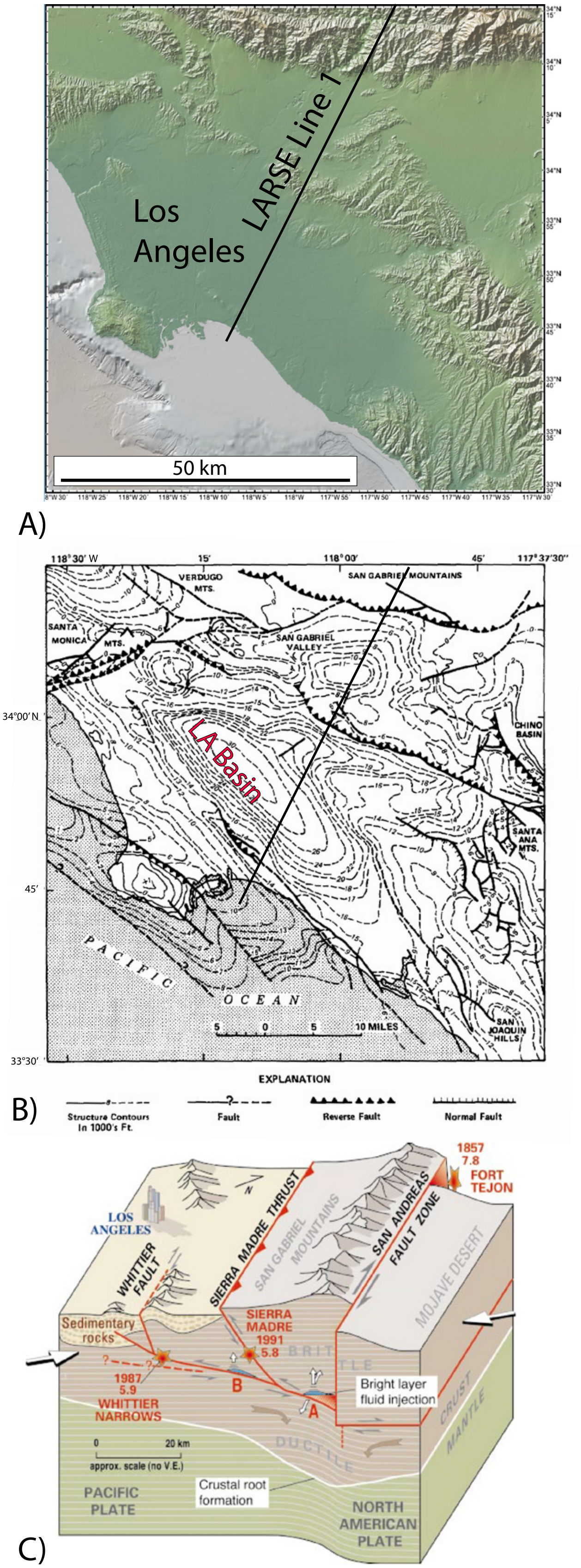

Figure 2. The Los Angeles basin hydrogen target. (A) Topography map from GeoMapApp, showing approximate trend of LARSE 1 line (Fuis et al., 2001). (B) Major structures and structural contours on top of basement, Los Angeles Basin (adapted from Biddle, 1991). The deepest penetration was drilled to 20,736 ft (6320 m). (C) Block diagram showing interpreted tectonics from seismic experiment of Fuis et al. (2001). Active faults are in orange; moderate and large earthquakes are orange stars with dates, magnitudes, and names. Gray half-arrows show relative fault motions. Small white arrows show block motions near bright reflective zones A and B (hydrogen pockets?). Large white arrows show convergence direction of Pacific and North American plates. Fluid injection (hydrogen?) is indicated by small lenticular blue areas in bright reflective zones A and B. V.E.—vertical exaggeration.

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