

Real-time Mud Gas Monitoring: A Technique to Obtain Information on the Composition and Distribution of Gases at Depth While Drilling

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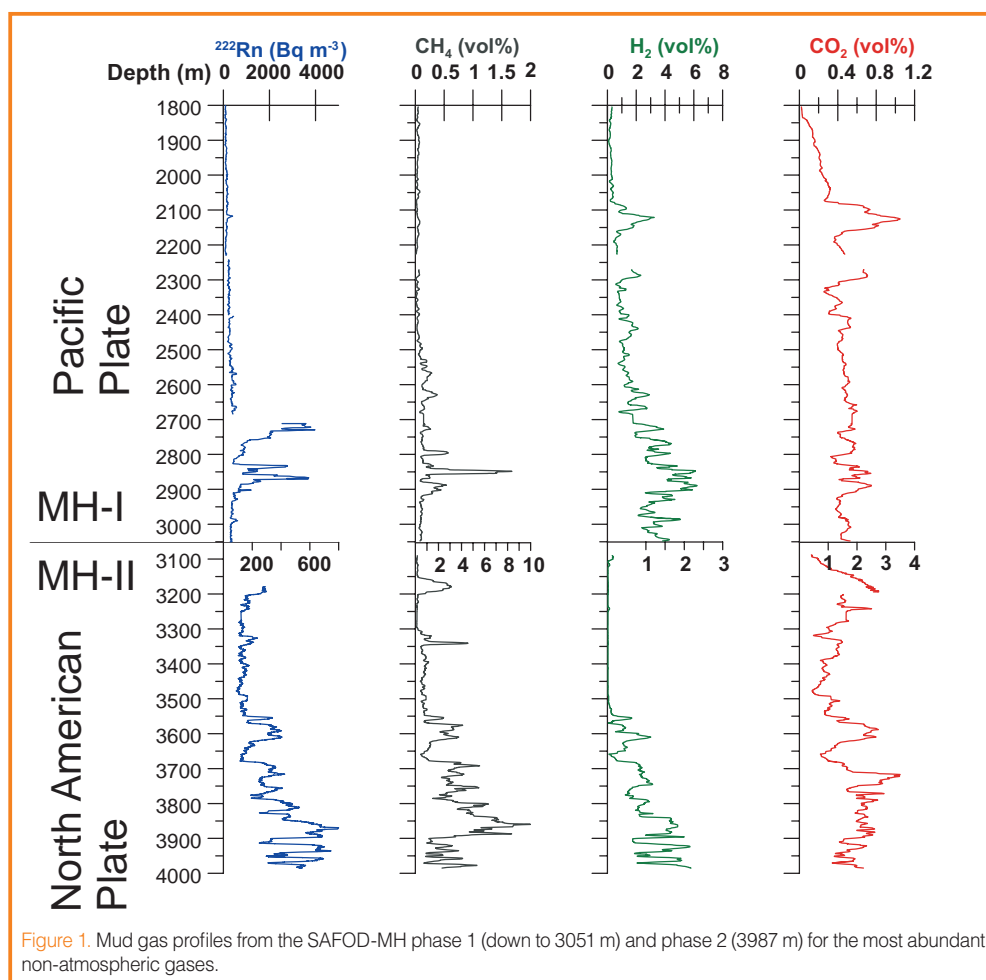
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Several techniques have been applied to obtain information on the composition of gases and fluids in drill holes, such as downhole fluid sampling, gas and fluid analysis during pumping tests, or *in vacuo* degassing of drill core samples. All these techniques can yield valuable information on the geochemistry of gases, but they are less useful for obtaining a continuous dataset on the distribution and composition of gases at depth. To reveal such data during drilling, we have developed a technique where gas is extracted from circulating drill mud with an agitator and continuously piped into a nearby laboratory trailer for on-line analysis. In addition, we routinely determine electrical conductivity, pH, and temperature continuously during the drilling operation within the mud pit at 10-min intervals.

Hydrocarbons, helium, radon, and carbon dioxide are the most suitable gases for the real-time detection of fluid-bearing horizons such as shear zone, open fractures, sections of enhanced permeability, and occurrences of permafrost methane hydrate. Gas analysis is carried out with a quadrupole mass spectrometer for N₂, O₂, Ar, CO₂, CH₄, He, H₂, and H₂S; a gas chromatograph (GC) equipped with a flame ionization detector (FID) for hydrocarbons (CH₄, C₂H₆, C₃H₈, n-C₄H₁₀, and i-C₄H₁₀), and a custom-built Lucas cell alpha-detector for ²²²Rn activity. When significant amounts of non-atmospheric gases are detected, off-line gas samples are automatically collected from the gas line for further investigations on isotopes (e.g. noble gases, carbon, and hydrogen) to reveal information on the origin and evolution of deep-seated fluids. The technique has been applied successfully on several International Continental Scientific Drilling Program (ICDP) projects, such as SAFOD (San Andreas Fault

Observatory at Depth), Mallik, and German Continental Deep Drilling Program KTB (Erzinger et al., 2004; Wiersberg et al., 2005; Zimmer and Erzinger, 1995).

As an example, we present results from the SAFOD Main Hole, drilled in 2004–2005 within the framework of ICDP. SAFOD wants to achieve a better understanding on the processes at active plate-bounding fault systems at the location of their origin. Knowledge about the role and origin of fluids and gases associated with the San Andreas Fault (SAF) zone is relatively poor. Besides the open question on how fluids are linked with fault zone processes in general, outstanding topics include the spatial distribution of fluids at depth, and, in particular, the contribution of mantle-derived fluids to the total fluid inventory of the SAF.



The pilot hole (PH) and the main hole (MH) were both drilled at a **short distance from each other**. In contrast to the vertical PH, which penetrates 768 m of Quaternary and Tertiary sediments into Cretaceous granite down to 2168 m final depth, the MH was deviated towards the SAF and re-enters sedimentary strata below 1930 m, where it remains down to the bottom of the hole (3987 m). Geophysical and geological observations identify the SAF in a depth interval of ~3100–3450 m.

In the lower, sedimentary part of the SAFOD-MH, drilled in 2004 (1900–3051 m) and 2005 (3051–3980 m), the most abundant non-atmospheric gases in drill mud were hydrogen (up to 6 vol %), methane (up to 10 vol %), and carbon dioxide (up to 4 vol %). The concentration of helium remained low (>20 ppmv), whereas radon activity reached values of up to 5000 Bq m⁻³. Two major sections could be identified where these gases were enriched in mud gas: from 2700–2900 m and from >3550 m to the bottom of the hole at 3987 m (Fig.1). A positive correlation between the numbers of beddings and fractures in these sections, identified by geophysical logging, and the radon activity implies that fluids enter the hole through open fissures. Furthermore, the radon activity indicates that the fluids are actively circulating. In both sections, radon also correlates positively with H₂, CO₂, and (in part) CH₄; however, the relative proportions of these gases are different in both sections. The upper and lower sections are enriched in ²²²Rn and H₂, and in CO₂ and CH₄, respectively.

Based on their distinct chemical compositions, we conclude that both sections represent individual hydrologic systems. Evidence for mixing is only slight. The gas concentrations found in the drill mud between 2900 m and 3550 m depths are low, especially for ²²²Rn. Only two sections, at 3150–3200 m and at 3340 m, show some higher gas concentrations. The spike at 3340 m, very close to the active part of SAF (3310 m), is almost exclusively composed of hydrocarbons. We assume that these are trapped in permeable sands embedded in less permeable strata, an interpretation supported by lithological data.

The air-corrected ³He/⁴He ratios of off-line mud gas samples are lower than the atmospheric ratio, but higher than the mean crustal values of ≤0.1 Ra; therefore, helium is a mixture of crustal helium with a small portion of mantle-derived helium. Down to a depth of 3051 m, air-corrected ³He/⁴He ratios of >0.45 Ra show that the contribution of mantle-derived helium is small (approx. 5%) on the Pacific plate, which composes the southwestern portion of the SAF. The ³He/⁴He ratios become significantly higher at depths below 3500 m on the North American plate, where ³He/⁴He ratios of 0.9 Ra were found, revealing a mantle contribution of 10%–12% for the total helium budget (Wiersberg and Erzinger, 2007).

Based on our observations, we conclude that the role of mantle-derived fluids in seismic processes at the SAF is small. The distinct helium isotopic compositions down to 3051 m and below 3500 m depths, with only little evidence for mixing between both hydrologic systems, again demonstrate that the SAF in some way acts as a barrier for fluid migration. Mantle-derived fluids migrate predominately through permeable country rock and leak to some extent into the SAF.

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