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Soil Hydrogen Gas Anomalies and Their Geological Sources in the Sanshui Basin, South China

DR. CHENGSHENG CHEN[1], LIYA FENG[1,2], XUAN YANG[1,2], DR. YUNPENG WANG[1], YUN LI[1], SHIWEN DENG[1,2], QIANG WANG[1] AND ZHENG ZHOU[3]

[1]State Key Laboratory of Deep Earth Processes and Resources, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, China

[2]University of Chinese Academy of Sciences, China

[3]Lancaster Environmental Centre, Lancaster University, UK

Soil hydrogen (H_2) anomalies in sedimentary basins hold significant implications for potential energy resources and geodynamic processes. The Sanshui Basin in South China exhibits widespread H_2 anomalies along active faults. Whether the H_2 is derived from mantle degassing, water-rock interactions, or shallow processes remain enigmatic. We collected 7 soil gas samples from high H_2 flux zones in the central basin and its margin along main faults. Gas compositions and isotopes ($\delta^{13}C_{CO2}$, $\delta^{2}H_{H2}$, $^{3}He/^{4}He$, $^{20}Ne/^{21}Ne/^{22}Ne$) were analyzed to trace H_2 sources and migration mechanisms.

All samples show N_2 and O_2 concentrations close to air, confirming they represent authentic soil gases (Fig. 1a). However, measured $^{3}He/^{4}He$ ratios (0.54-0.92Ra) are below atmospheric value (1.0Ra), with >99% of helium being crustal-derived with negligible mantle contributions. Measured ^{4}He and ^{20}Ne significantly exceed atmospheric levels (Fig. 1b). After correction for air and air-saturated water (ASW) contributions, $(^{4}He/^{20}Ne)_{ASW}$ values are larger than 0.26. Mass-dependent Ne isotope fractionation ($^{20}Ne/^{22}Ne$ vs. $^{21}Ne/^{22}Ne$) demonstrate that noble gases underwent degassing fractionation from groundwater (Fig. 1c). H_2 concentrations show a positive correlation with $^{4}He/^{20}Ne$ and a negative correlation with $^{3}He/^{4}He$ values, suggesting that radiogenic ^{4}He within the basin has been enriched and possibly is released alongside H_2. $\delta^{2}H_{H2}$ values in samples (−799.5‰~−672.2‰) fall with the range diagnostic of serpentinization, implying potential hydrogen production during basalt alteration in the basin. On the $CO_2/^{3}He$ vs. $\delta^{13}C_{CO2}$ correlation, some data points fall within the mantle-organic sediment mixing field and suggest CO_2 dissolution and calcite precipitation occurred at 50–150°C (Fig. 1d). However, mantle-derived ^{3}He flux is too low to indicate mantle H_2 contribution. The mantle-like CO_2 signature is derived from Cenozoic basalts interbedded with sedimentary rocks. $H_2/^{3}He$ values remain within the crustal domain even after atmospheric correction, confirming a dominantly crustal H_2 source.

We suggest that soil H_2 anomalies in the Sanshui Basin originate predominantly from low-temperature alteration of Cenozoic basalts interacting with groundwater along fault zones, rather than from mantle degassing. Groundwater serves as a critical medium transporting both H_2 and fractionated noble gases to the surface. The absence of mantle H_2 signatures may reflect either limited mantle degassing or H_2 consumption during upward migration.

