Helium studies in the Mojave Desert, California: Quantifying mantle and crustal additions to the regional groundwater system

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We report helium concentrations and isotope results measured on deep groundwaters from the western Mojave River Basin (MRB), 130 km east of Los Angeles. The aquifer is composed of Quaternary alluvial fan and basin fill deposits (interbedded gravel, sand, silt, and clay) that overlie a crystalline complex of pre-Tertiary igneous and metamorphic rocks. Samples were collected along two groundwater flowpaths that originate in the San Gabriel Mountains and discharge to the Mojave River ~30 km to the northeast. The basin is adjacent (~10 km) to the NW-SE trending San Andreas Fault (SAF) system. The primary objective of this study is to quantify the crustal and mantle helium contributions to the regional groundwater system.

A total of 25 groundwaters, sampled previously for chemistry and isotope systematics (including C-14 activity), have measured helium concentrations which increase along flowpaths from 9.9×10^{-8} to 1.0×10^{-4} cm^3STPg^{-1} H_2O. Concomitantly, $^3He/^4He$ ratios decrease from 0.84 R_A to 0.11 R_A (R_A equals the $^3He/^4He$ ratio in air = 1.4×10^{-6}). In no samples did we measure $^3He/^4He$ ratios equivalent to crustal production values (~$0.02R_A$).

Measured helium concentrations were resolved into components associated with solubility equilibration, air entrainment, in-situ production within the aquifer and an extraneous flux. Young groundwaters close to recharge areas were dominated by the first 2 components – older groundwaters by the latter 2. The $^3He/^4He$ ratio of the extraneous component is ~$0.11R_A$ indicating addition of mantle-derived He to a (deep) crustal flux. If the mantle component is characterized by $8R_A$ then addition of 1-2% is sufficient to account for the observed ratios. Therefore, this study confirms findings of Kennedy et al. (Science, 1997) of the presence of mantle-derived fluids proximal to the SAF. By comparing ^4He and C-14 ages and assuming a range of porosities between 10-25%, the calculated crustal flux of helium varies between 3×10^{-6} and 3×10^{-7} $cm^3STPcm^{-2}yr^{-1}$. This range is comparable to values published for other regions of the western USA (e.g. Carrizo aquifer, Texas and San Juan Basin, New Mexico).

Weathering through Earth history: controls and consequences

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Chemical erosion of the continents is the predominant source of solutes to the ocean. The chemistry of the ocean is expected to have varied in response to changes in chemical erosion over Earth history, but by how much is poorly known. Most proxies of chemical erosion rates (e.g., changes in the radiogenic isotope composition of the oceans as recorded in limestones) are ambiguous because they respond both to changes in the magnitude and isotopic composition of the riverine inputs. Use of multiple proxies holds the promise of unravelling these influences.

One of the most hotly debated topics is the extent to which chemical weathering provides stability to long-term climate through feedback in the carbon cycle. The fundamental issue is what controls chemical erosion rates on global scales, yet much of the debate has focused on controls on individual watersheds. Tectonic uplift (shedding of the soil mantle) is clearly a limiting factor for a number of watersheds, whereas a climate limitation, especially a temperature dependence for chemical erosion, has been more elusive. Using Ge as a proxy indicator for transport vs. weathering limitation (after Stallard and Edmond), one finds that the world as a whole is strongly weathering limited. Thus, those factors that control weathering (climate, rock composition) are limiting the rate of chemical erosion today. During periods of tectonic stasis, transport limitation could have dominated.

Limits on the range of global chemical erosion rates over geologic time are likely tied to the water cycle. Extreme continental aridity might have caused erosion rates to fall near zero in the Neoproterozoic, Late Permian/Early Triassic, and Paleoproterozoic (ca. 2.0 Ga), as indicated by extreme enrichments and rapid swings in carbon isotope composition. Maximum rates of chemical erosion would have been realized when the water cycle was accelerated and rivers were saturated with $CaCO_3$. Under the most favorable conditions, chemical erosion rates could have been 50 times today’s.