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The geochemistry of continental hydrothermal systems

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Hydrothermal systems on the continents are of great significance because they are primary sources of economically important metals and geothermal energy, they are tourist attractions, they support bathing and health resorts, and they host extreme life forms. Research on hot springs and their deposits provide clues to early life on Earth and possibly on Mars and have led to major breakthroughs in biotechnology. Aqueous and gas-rich hydrothermal fluids also contribute to a range of volcanic hazards including the destabilization of volcanic edifices, acting as propellant in hydrothermal explosions, reducing effective stresses in lahars, emitting toxic and potentially lethal gases, and transporting toxic metals to watersheds. This review summarizes the state of knowledge on the chemistry of continental hydrothermal systems and highlights the myriad processes that operate under a wide range of temperatures, pressures, chemical compositions, and oxidation states. Suggested future studies include: 1) multidisciplinary studies that quantify the dynamic feedback between tectonic, magmatic, climatic, and hydrothermal processes at multiple temporal and spatial scales to establish cause and effect relationships, 2) laboratory experiments that quantify water-rock-gas reactions at various pressure, temperature, and redox conditions relevant to continental hydrothermal systems, 3) deep drilling to provide more in-situ data on the hydrothermal shells surrounding magma, 4) compare the chemical and isotopic composition of magmatic volatiles dissolved in silicate melt inclusions that constrain pre-eruptive dissolved volatile compositions in magma with the composition of these volatiles discharged from the surrounding hydrothermal system, 5) characterize the chemical composition of aqueous-rich supercritical fluids from deep wells, 6) characterize and quantify the processes that fractionate the stable isotopes of various solutes at hydrothermal conditions, 7) incorporate new analytical methods to make observations of small organic compounds in hydrothermal fluids and deposits, 8) combine experiments of organic compound transformation at hydrothermal conditions with improved thermodynamic calculations, 9) quantify the role of high-temperature microbial activity in geochemical cycles of elements across the periodic table, and 10) apply high-resolution imaging techniques to quantify how metals and metalloids are incorporated into hydrothermal deposits and altered rocks, and the role of microbial activity in water-rock reactions.