Dynamics of Yellowstone's Hydrothermal System

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Yellowstone's hydrothermal features are spectacular, globally unique, and unexpectedly diverse. Their existence alone led in part to the establishment of Yellowstone as the first national park in the world. The hydrothermal system comprises the largest concentration of geysers and hydrothermal explosion craters on Earth, with more than 10,000 thermal features, including fumaroles, mud pots, frying pans, and varicolored thermal pools. Hot fluids discharged at the surface deposit silica sinter, travertine, native sulfur, and other minerals. The springs host biota from all three domains of life (Bacteria, Archaea, and Eukarya), which use diverse sources of energy for metabolism. Hydrothermal activity is modulated and perturbed by processes that operate over time scales ranging from seconds (e.g., earthquakes), to days (e.g., air pressure and temperature variations), to seasonal (e.g., precipitation, snow melt, lake level), to decadal, centennial, millennial (e.g., caldera inflation and deflation, ice sheet advance and retreat), and even longer (volcanic cycles).

In the recent paper "Dynamics of the Yellowstone Hydrothermal System" published in the journal *Reviews of Geophysics* (Volume 52(3):375-411*), U.S. Geological Survey scientists Shaul Hurwitz and Jacob Lowenstern review the substantial advances that have emerged in the past quarter of a century in understanding the processes operating in Yellowstone's dynamic hydrothermal system. This follows a similar review "Geochemistry and the Dynamics of the Yellowstone Hydrothermal System" published in the journal *Annual Review of Earth and Planetary Sciences* (Volume 17:13-53) written by retired U.S. Geological Survey scientist Robert Fournier in 1989. The collective body of work during the past 25 years documents large changes at many different temporal and spatial scales, and the coupling between physical, chemical, and biological processes.

Hurwitz and Lowenstern demonstrate that the most recent advances stem from the development of modern technologies, densification of monitoring networks, accumulation of large data sets, discovery of hydrothermal vents in Yellowstone Lake, evidence relating thermophile microorganisms to the geochemical cycle, and additional research intensity due to establishment of the Yellowstone Center for Resources in 1993 and the Yellowstone Volcano Observatory in 2001. This progress has built upon more than 140 years of research since the 1870 Washburn expedition, the 1871 Hayden expedition, and the establishment of Yellowstone National Park in 1872.

In addition to reviewing the significant research accomplishments, the recent paper also highlights some unresolved questions and suggests future research directions. Answering the most fundamental question "what does the future hold for Yellowstone?" will largely depend on the ability to resolve spatial and temporal patterns of heat and mass discharge; characterize and quantify the spatial and temporal correlations between tectonic, magmatic, and climatic processes; and link instrumental signals to source processes. Hopefully, addressing some of these issues will improve current estimates of the various hazards posed by hydrothermal activity, provide a framework for understanding life in extreme environments, and guide the protection and preservation of the unique and diverse thermal features in Yellowstone.

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