"Do "Super" eruption environments make for "super" hydrothermal explosions: Extreme hydrothermal explosions above the Yellowstone magma chamber"

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ABSTRACT

Hydrothermal explosions are violent and dramatic events resulting in the rapid ejection of boiling water, steam, mud, and rock fragments from source craters that range from a few meters up to more than 2 km in diameter; associated breccia can be emplaced as much as 3 to 4 km from the largest craters. Hydrothermal explosions occur where shallow interconnected reservoirs of steam- and liquid-saturated fluids with temperatures at or near the boiling curve underlie thermal fields. Sudden reduction in confining pressure causes fluids to flash to steam resulting in significant expansion, rock fragmentation, and debris ejection.

In Yellowstone, hydrothermal explosions are a potentially significant hazard for visitors and facilities and can damage or even destroy thermal features. The breccia deposits and associated craters formed from hydrothermal explosions are mapped as mostly Holocene units throughout Yellowstone National Park (YNP) and are spatially related to within the 0.64-Ma Yellowstone caldera and along the active Norris-Mammoth tectonic corridor.

In Yellowstone, at least 20 large (>100 m in diameter) hydrothermal explosion craters have been identified; the scale of the individual associated events dwarfs similar features in geothermal areas elsewhere in the world. Large hydrothermal explosions in Yellowstone have occurred over the past 16 ka averaging to ~1 every 700 yr; similar events are likely in the future. Our studies of large hydrothermal explosion events indicate: (1) none are directly associated with eruptive volcanic or shallow intrusive events; (2) several historical explosions have been triggered by seismic events; (3) lithic clasts and comingled matrix material that form hydrothermal explosion deposits are extensively altered, indicating that explosions occur in areas subjected to intense hydrothermal processes; (4) many lithic clasts contained in explosion breccia deposits preserve evidence of repeated fracturing and vein-filling; and (5) areal dimensions of many large hydrothermal explosion craters in Yellowstone are similar to those of its active geyser basins and thermal areas. For Yellowstone, our knowledge of hydrothermal craters and ejecta is generally limited to after the Yellowstone Plateau emerged from beneath a late Pleistocene icecap that was roughly a kilometer thick. Large hydrothermal explosions may have occurred earlier as indicated by multiple episodes of cementation and brecciation commonly observed in hydrothermal ejecta clasts.

Critical components for large, explosive hydrothermal systems include a water-saturated system at or near boiling temperatures and an interconnected system of well-developed joints and fractures along which hydrothermal fluids flow. Active deformation of the Yellowstone caldera, active faulting and moderate local seismicity, high heat flow, rapid changes in climate, and regional stresses are factors that have strong influences on the type of hydrothermal system developed. Ascending hydrothermal fluids flow along fractures that have developed in response to active caldera deformation and along edges of low-permeability rhyolitic lava flows. Alteration of the area affected, self-sealing leading to development of a caprock for the hydrothermal system, and dissolution of silica-rich rocks are additional factors that may constrain the distribution and development of hydrothermal fields. A partial low permeability layer that acts as a cap to the hydrothermal system may produce some over-pressurization, thought to be small in most systems. Any abrupt drop in pressure initiates steam flashing and is rapidly transmitted through interconnected fractures that result in a series of multiple large-scale explosions contributing to the excavation of a larger explosion crater. Similarities between the size and dimensions of large hydrothermal explosion craters and thermal fields in Yellowstone may indicate that catastrophic events which result in large hydrothermal explosions are an end phase in geyser basin evolution.

The Mary Bay hydrothermal explosion crater complex is the largest such complex in Yellowstone, and possibly in the world, with a diameter of 2.8 km in length and 2.4 km in width. It is nested in Mary Bay in the northern basin of Yellowstone Lake, an area of high heat flow and active deformation within the Yellowstone caldera. A sequence exposed in wave-cut cliffs between Storm Point and Mary Bay gives insight into the geologic history of the Mary Bay hydrothermal explosion event. The Mary Bay explosion breccia deposits overlie sand above varved lake sediments and are separated locally into an upper and lower unit. The sand unit contains numerous small normal faults and is coextensive with the Mary Bay breccia in its northern extent. This sand may represent deposits of an earthquake-generated wave. Seismicity associated with the earthquake may have triggered the hydrothermal explosion responsible for development of the Mary Bay crater complex. Large hydrothermal explosions are rare events on a human time scale; however, the potential for additional future events of the sort in Yellowstone National Park is not insignificant. Based on the occurrence of large hydrothermal explosion events over the past 16,000 yr, an explosion large enough to create a 100-m-wide crater might be expected every 200 yr.