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Evolving stress field at Yellowstone from 1988 to 2010 and relation with emplacement of sills

Elena Russo (1), Alessandro Tibaldi (1), Gregory P. Waite (2), Jamie Farrell (3), and Fred Massin (3)

(1) Department of Earth and Environmental Sciences, University of Milan-Bicocca, Milan, Italy, (2) Department of Geological and Mining Engineering and Science, Michigan Technological University, Houghton, USA, (3) Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah, USA

Yellowstone, in the western United States, is well known for intense seismic activity, abundant geothermal features and a violent volcanic history that includes a caldera-forming eruption 640 ka ago. Eruptions continued until as recently as 70 ka ago inside the caldera, while contemporary signs of volcanic activity include quasi-continuous deformation with intense hydrothermal activity, high seismicity and cycles of uplift and subsidence at rates of up to 70 mm/yr. Multiple volcano-tectonic phenomena involving magma intrusions below Yellowstone have been inferred from geophysical data over the past decades, yet none of these have come close to reaching the surface. One of the most important parameters for determining whether an intrusion will lead to an eruption is the stress state in the rock volume between the magma and the surface. Geodetic measurements document complex deformation patterns in crustal strain, whereas earthquakes result from spatial and temporal variations in the stress field.

Here we present seismological observations of the space-time evolution of fault kinematics and related state of stress within the caldera and adjacent Norris Geyser Basin, accompanying the 1988-2010 magmatic inflation and deflation phases. We use earthquake data to investigate these variations and their possible causes in more detail: earthquake relocations and a set of 369 well-constrained, double-couple, focal mechanism solutions were computed. Events were grouped according to location and time to investigate trends in faulting. Stress-field solutions for different areas and time periods were calculated from earthquake focal mechanism inversion. The dominant direction of extension throughout the 0.64 Ma Yellowstone caldera is nearly ENE, consistent with the perpendicular direction of alignment of volcanic vents within the caldera, but our study also reveals spatial and temporal variations. A well-resolved rotation of $\sigma 3$ was found, from NNE-SSW near the Hebgen Lake fault zone, to ENE-WSW near Norris Junction. In particular, the $\sigma 3$ direction changed throughout the years around Norris Geyser Basin, from being ENE-WSW to NNE-SSW, while the other $\sigma 3$ directions are mostly unchanged over time. The presence of “chocolate tablet” structures, with two sets of nearly perpendicular normal faults, were identified in many stages of the deformation history both in the Norris Geyser Basin area and inside the caldera, whereas strike-slip faulting events were also recognized. We finally propose structural models to explain the deformation patterns during both the inflation and deflation phases.