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Probing the Source of Explosive Volcanic Eruptions (Sergey Soloviev Medal Lecture)

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What if we knew where magma is located under a volcano and its current state? Such information would transform volcanology.

For extreme events, we typically know where the vulnerabilities are: people, lifelines, and critical infrastructure, but seldom do we know the "source term" beforehand. For restless calderas such as Campi Flegrei, Italy and Yellowstone, USA, the threat is silicic magma within the caldera itself. Great effort has gone into finding such bodies through surface measurements. "Discovery" is declared when consensus is achieved.

But there is a difference between consensus and knowledge. By following certain conventions in finding magma bodies (aseismic volume, seismic attenuation, Mogi source location, water and CO_2 content of melt inclusions) and depicting them in accepted ways (oblate spheroids or lenses with an impossible solid/liquid boundary discontinuity), we perpetuate myths that mislead even ourselves. The consensus view of the Long Valley Caldera, USA, magma reservoir has evolved over 40 years from a 10^4 km^3 balloon to two tiny pockets of magma, in part because drilling revealed a temperature of 100°C at 3 km depth over the "balloon".

Oil and gas exploration is free of fanciful reservoirs because there is ground truth. Geophysics and geology define a possible reservoir and a well is drilled. If oil is not there, the model needs revision.

The situation is worse for conditions of magma storage. The heretofore-unknowable roof zone of magma chambers has been invoked for separating melt from crystals and/or for accumulating vapor and evolved magma leading to eruption. Anything is possible when there are no data.

The accidental (but technically remarkable) drilling discovery of rhyolite magma at 2,100 m depth under Krafla Caldera, Iceland by Landsvirkjun Co. and the Iceland Deep Drilling Project opens the door to properly detect magma and to understand how magma evolves, energizes hydrothermal systems, and erupts. A new project before the International Continental Scientific Drilling Program (ICDP) would continuously core through the margin of the magma body, accompanied by state-of-the-art geophysics, geochemical analyses and 3-D mass/heat transport modeling. Coring of molten rock has been conducted with success in lava lakes. Gradients in phase assemblage and composition will provide definitive tests of models of mass/heat transfer and magma evolution. By knowing "the answer", techniques for finding magma will likewise be tested, making Krafla an international magma laboratory. In fact, Krafla may resemble the state of neighboring Askja Caldera system prior its 1875 eruption, with hidden rhyolite being brewed in a basalt-fired caldera crucible. Additionally, the observed high permeability and sustained power output from the magma body's margin implies self-sustained thermal fracturing, i.e. an "Enhanced Geothermal System" an order of magnitude more powerful than conventional geothermal.

The cost should be balanced against the higher cost of ignorance. For tsunamis, Sergey Soloviev showed there is no substitute for direct measurements at depth, despite technical and economic obstacles. He also led the way in Russian – American cooperation on natural hazards, thereby mitigating the risk of the ultimate hazard, of humans to each other.