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Emplacement of the basalt of Mammoth Crater

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The basalt of Mammoth Crater (bmc) covers ~250 km^2 in northern California, USA, including about two-thirds of Lava Beds National Monument, where it hosts most of the park's iconic lava-tube caves. The eruption took place ~35,000 years ago from several vents on the north flank of Medicine Lake volcano, a large shield-shaped composite volcano (Donnelly-Nolan, 2010 geologic map, https://pubs.usgs.gov/sim/2927/) located in the southern Cascades rear-arc. Although most of the erupted volume is basalt (<52 wt.% SiO_2), the unit is compositionally zoned and early vent-related lava has SiO_2 contents as high as 55.9 wt.%. Lava was distributed via lava tubes across a broad E-W area on the lower north flank of the volcano forming a radial pattern reminiscent of the tentacles of an octopus. The vents, aligned N-S to NW-SE, are located at elevations as high as 1600 m (5,300 ft), and fed distal parts of the flow field at elevations <1250 m (4100 ft). The most primitive samples (SiO_2 as low as 48.4 wt.%, MgO as high as 9.61 wt.%) were mostly transported by lava tubes to distal locations. K_2O contents of the primitive samples are as low as 0.15 wt.%, an order of magnitude lower than the ~1.5 wt.% contents of the high-silica samples. Despite the compositional range of the lavas, most samples contain few visible crystals, thus limiting the ability to map the emplacement sequence in the field. Paleomagnetic sampling of 25 sites yielded a single common direction of magnetization indicating that only decades were likely needed to emplace the full flow field. A similar study of the ~12,500-yr-old basalt of Giant Crater (Donnelly-Nolan et al., JGR, 1991) on the south flank of the volcano revealed a less common remanent magnetic direction showing a small angular variation (Champion and Donnelly-Nolan, JGR, 1994) indicating as little as a decade for emplacement of that 200-km^2 lava field. In the Giant Crater case, higher silica lavas also built the vent area and lower-silica lava with high MgO contents was transported to distal areas by lava tube, but the lavas displayed petrographic variation and were emplaced one lobe atop another in a graben allowing for direct stratigraphic control of the compositional variation through time.

The recent discovery of a major lava-tube cave at the south margin of Lava Beds National Monument has led to new chemical sampling in that cave and in other caves, as well as collection and analysis of new samples at the primary vent where late stage magma withdrawal created the 100-m-deep Mammoth Crater. Seventy chemical analyses allow characterization of the compositions present along each of the major lava tube systems. Together with a few stratigraphic relations derived from fieldwork and from air photo analysis, we propose an eruptive sequence. Initially, a small shield built at the location of Mammoth Crater and adjacent vents to the north. Surface flows extended to the NW and west and a lava tube formed on the east side of the shield and carried lava eastward through what is now the enlarged channel of Hidden Valley. Lava thence flowed through the new cave, and east as far as ~20 km from vent, but never having SiO_2 contents lower than 51 wt.%. The distal flow field produced by this lava tube is overlain by much more primitive lava from the tube system that

runs through the Visitor Center area, east through Craig Cave, and then NE ~25 km from the vent. A sample recently collected from a solid outcrop on the NE wall of Mammoth Crater has the low-SiO_2, high-MgO composition of the distal NE lavas. Farther to the north, vents opened at and near Modoc Crater and fed lava tubes northward, with one set on the west side of the earlier Schonchin Flow, and another including Skull Cave around the east side. Compositional data indicate that the samples from these lava tubes have higher TiO_2 contents than those from the southern tube and from the Visitor Center-Craig Cave tube. Air photos indicate that lava associated with the Skull Cave tube is younger than lava from the Visitor Center tube. Another compositionally distinctive lobe was fed to the west from Mammoth Crater through Upper Ice Cave. This high-FeO, high-TiO_2 lobe is partially buried by younger lava flows, but can be traced ~20 km to the NW. The much higher FeO content (~1.3-1.5 wt.%) relative to the other erupted lavas (~0.9-1.1 wt.%) suggests a higher density, possibly indicating that this lobe might be the last-erupted from the subjacent magma reservoir.