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# Data Repository

**DR Material 1:** Descriptions of samples for $^{36}$Cl surface-exposure dating, including information on shielding, erosion rates, analytical methods, and data reduction.

**DR Material 2:** $^{40}$Ar/$^{39}$Ar data details. This includes all of the raw analytical data for $^{40}$Ar/$^{39}$Ar dating experiments.

**DR Material 3:** $^{36}$Cl data details. This includes all input parameters.

**DR Material 4:** Monte Carlo simulation for estimating eruption volumes.

# Supplemental Material 1:
## Details on samples collected for $^{36}$Cl Cosmogenic Surface-Exposure Dating

### $^{36}$Cl Cosmogenic Surface-Exposure Dating

Eleven samples for $^{36}$Cl cosmogenic surface-exposure dating were collected from within our mapping area using a hammer and chisel. Five of these samples have been described in Downs et al. (2018) and Stelten et al. (2018) and we refer the reader to those publications for a description of those samples (R15MS004, R15TS189, R14TS097, R14AC099, and R15MS006).

Five samples were collected from three young-appearing basalt flows that are together referred to as the Five Fingers flows, located in the northeastern portion of the study area (see Figure 6 of the main text). One whole-rock sample from the basalt of Northern Fingers (R14TS019), one whole-rock sample from the basalt of Central Finger (R14MS030), two whole-rock samples from the basalt of Southern Fingers (R14TS009a and R15MS014), and one plagioclase separate from the basalt of Southern Fingers (R15DS107) were analyzed for $^{36}$Cl exposure ages. Sample R14TS019 is a whole-rock sample collected from the top 4 cm of a 2m by 2 m flat-topped, high standing region of the flow that is 4.3 km northeast of the source vent. Sample R14TS019 contains phenocrysts of plagioclase (<1–3%, ≤8 mm) and olivine (<1–2%, ≤2 mm). Sample R15MS030 was collected from the top 4 cm of a large, 3m by 3m, flat topped block (clinker) at the distal portion of the lava flow, ~9.5 km northeast of the source vent. The sample was collected >50 cm from the edge of the block and is composed of vesicular basalt with phenocrysts of plagioclase (2%, ≤10 mm) and olivine (<1–3%, ≤5 mm).

Three samples were collected from the basalt of Southern Fingers to test the reproducibility of the $^{36}$Cl dating method. R14TS009a is a sample of pāhoehoe collected from on top of a tumulus mound, ~3.6 km east-northeast of its source vent. The sample was trimmed such that only the upper 4 cm of the surface sample were used for $^{36}$Cl dating. R14TS009a is composed of vesicular basalt with phenocrysts of plagioclase (1–5%, ≤40 mm) and olivine (<1–3%, ≤30 mm). The basalt of Southern Fingers is easily distinguishable from the basalt of Northern Fingers by the presence of large feldspar (up to 40 mm) and olivine (up to 30 mm) grains. Sample R15MS014 is a sample of vesicular basalt with phenocrysts of plagioclase (1–5%, ≤40 mm) and olivine (<1–3%, ≤30 mm), collected from the top of a tumulus mound that stands 0.3 to 1 m above the surrounding flow, ~4.3 km northeast of its source vent. The sample was collected from the central, flat lying portion of the tumulus mound, and trimmed such that the upper 5 cm of the surface sample was analyzed for $^{36}$Cl dating. Sample R15DS107 consists of 0.5 cm to 2 cm long plagioclase phenocrysts collected from a flat portion of the basalt of Southern Fingers, ~11.8 km northeast of the source vent. The plagioclase phenocrysts collected were loose on the surface of the flow, but are petrographically identical to large plagioclase phenocrysts that are ubiquitous in the basalt of Southern Fingers and were likely eroded from the surface of the lava flow shortly after emplacement. These plagioclase phenocrysts are interpreted to be derived from the upper centimeter of the lava flow's surface.

Sample R17AC138 is an aphyric trachyte collected from a dense, flat, 4m by 4m block on the western rim of Um Rgaibah that stands 1 m above the its immediate surroundings. The sample was trimmed such that only the upper 4 cm of the surface sample were used for $^{36}$Cl dating. The peak of Um Rgaibah is ~24 m above and 226 m to the east of the sample location, yielding an angle of 6° to the horizon at an azimuth of 90° to 150°. No topographic shielding is observed in any other directions.

For all samples collected for this study, the dip of the sample surface collected was negligible (<5°). At all sample locations shielding was negligible, with the angle to the horizon being ≤6° in all directions (Gosse and Phillips, 2001). As such, no shielding correction was applied to samples from this study. Sample locations and elevations were measured by GPS using the WGS1984 UTM Zone 37N datum, and later confirmed using a 1 m-resolution digital elevation model (DEM). For all samples, erosion rates are estimated to be low (≤1 mm/kyr) based on the preservation of small scale (<1 cm), irregular surface features on each flow. Given the uncertainty in the erosion rate for each sample site, we conservatively assume an erosion rate of 1 ± 1 mm/kry (0.5 ± 0.5 mm/kyr for Um Rgaibah). See Supplemental Material 2 for all input parameters for $^{36}$Cl age calculations.

Chemical separation and analysis of samples via accelerator mass spectrometry took place at the Purdue Rare Isotope Measurement (PRIME) Laboratory at Purdue University in West Lafayette, Indiana. Samples were chemically dissolved, spiked with a $^{35}$Cl enriched tracer (*e.g.*, Desilets et al., 2006), and analyzed via accelerator mass spectrometry. Splits of each sample were analyzed for their major-element concentrations via wavelength dispersive x-ray fluorescence (XRF) and for their trace-element concentrations via inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS) at the U.S. Geological Survey in Denver, Colorado following Taggart (2002). All whole-rock samples contained vesicle fill

composed of secondary zeolites, carbonate, gypsum and anhydrite, clay, and wind-blown loess. These characteristics are ubiquitous for surface samples throughout northern Harrat Rahat. Prior to analysis for major- and trace-element concentrations, all samples were cleaned by (1) heating in DI water at 60°C for an hour to dissolve any gypsum and anhydrite, (2) heating in DI water at 90°C for an hour to dissolve any zeolites, (3) sonicating for 8 hours to disaggregate any foreign material, (4) placing the samples in concentrated $HNO_3$ to dissolve carbonate, and (5) sonicating in DI water for 8 hours to disaggregate any remaining foreign material. Trace-elements of particular importance for the calculation of $^{36}Cl$ cosmogenic surface-exposure ages are U and Th, which can indirectly produce thermal neutrons as a result of alpha decay, and B, Li, Sm, and Gd, which have large thermal neutron absorption cross-sections, and therefore reduce the production of $^{36}Cl$ from $^{35}Cl$. In some cases B and Li concentrations were below detection limits. Given that the detection limit for B and Li is 10 ppm, we assume the concentration of B and Li is 5 ± 5 ppm for all samples where these elements were below detection limit.
Cosmogenic surface-exposure ages were calculated using the online CRONUScalc $^{36}Cl$ Exposure Age Calculator v2.0 (Cosmic-Ray Produced Nuclide Systematics on Earth Project: http://www.physics.purdue.edu/primelab/CronusProject/cronus/) that utilizes a MATLAB-based code and is described in Marrero et al. (2016). Ages were calculated using the Lal/Stone time independent scaling model (Lal, 1991; Stone, 2000). We refer the reader to Marrero et al. (2016) for a detailed discussion of production rates for various production pathways, details of scaling models, and other parameters used in the calculation of $^{36}Cl$ cosmogenic surface-exposure ages.

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