Supplementary Information

The rebirth and evolution of Bezymianny volcano, Kamchatka after the 1956 sector collapse

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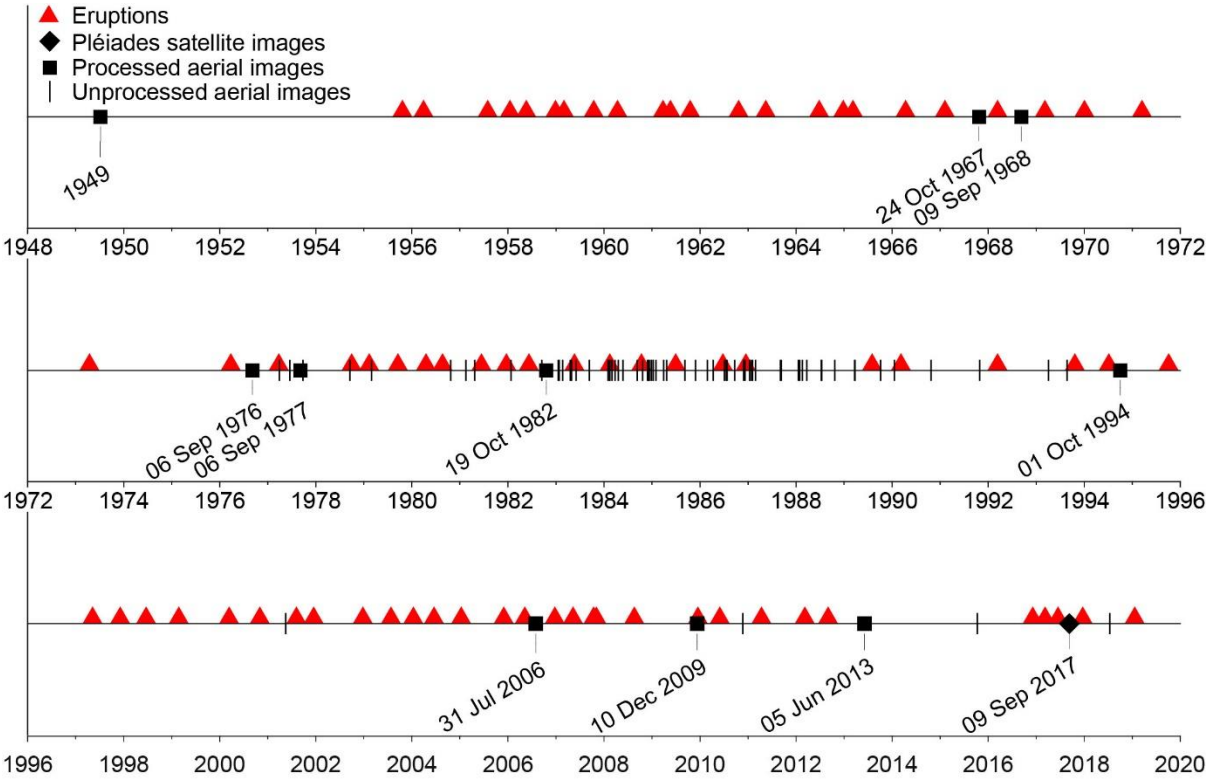
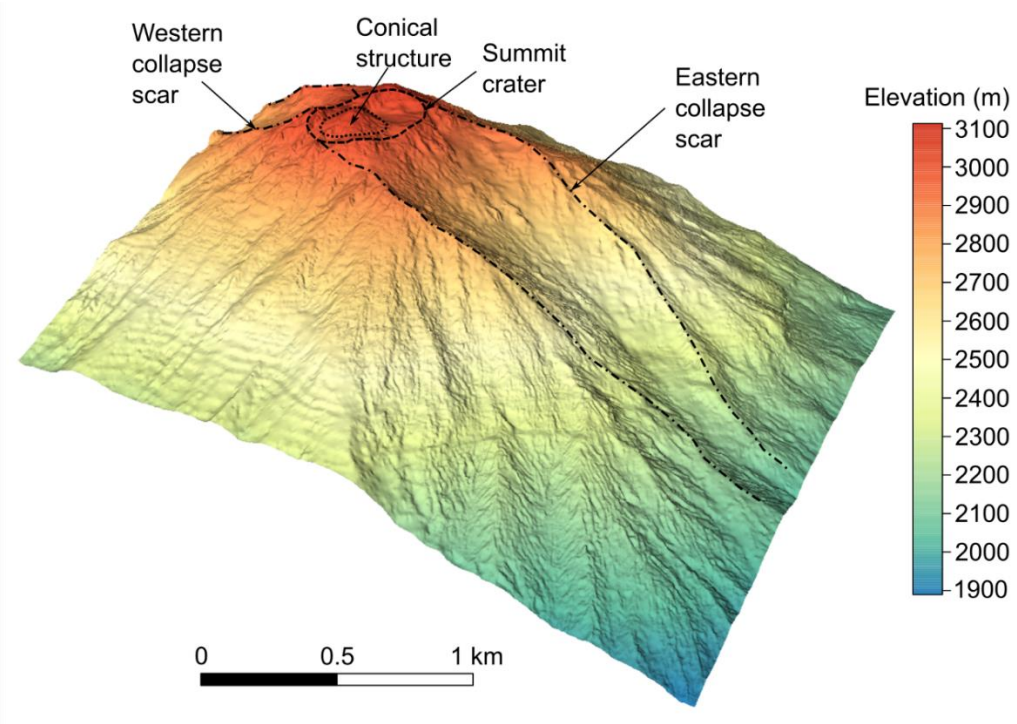
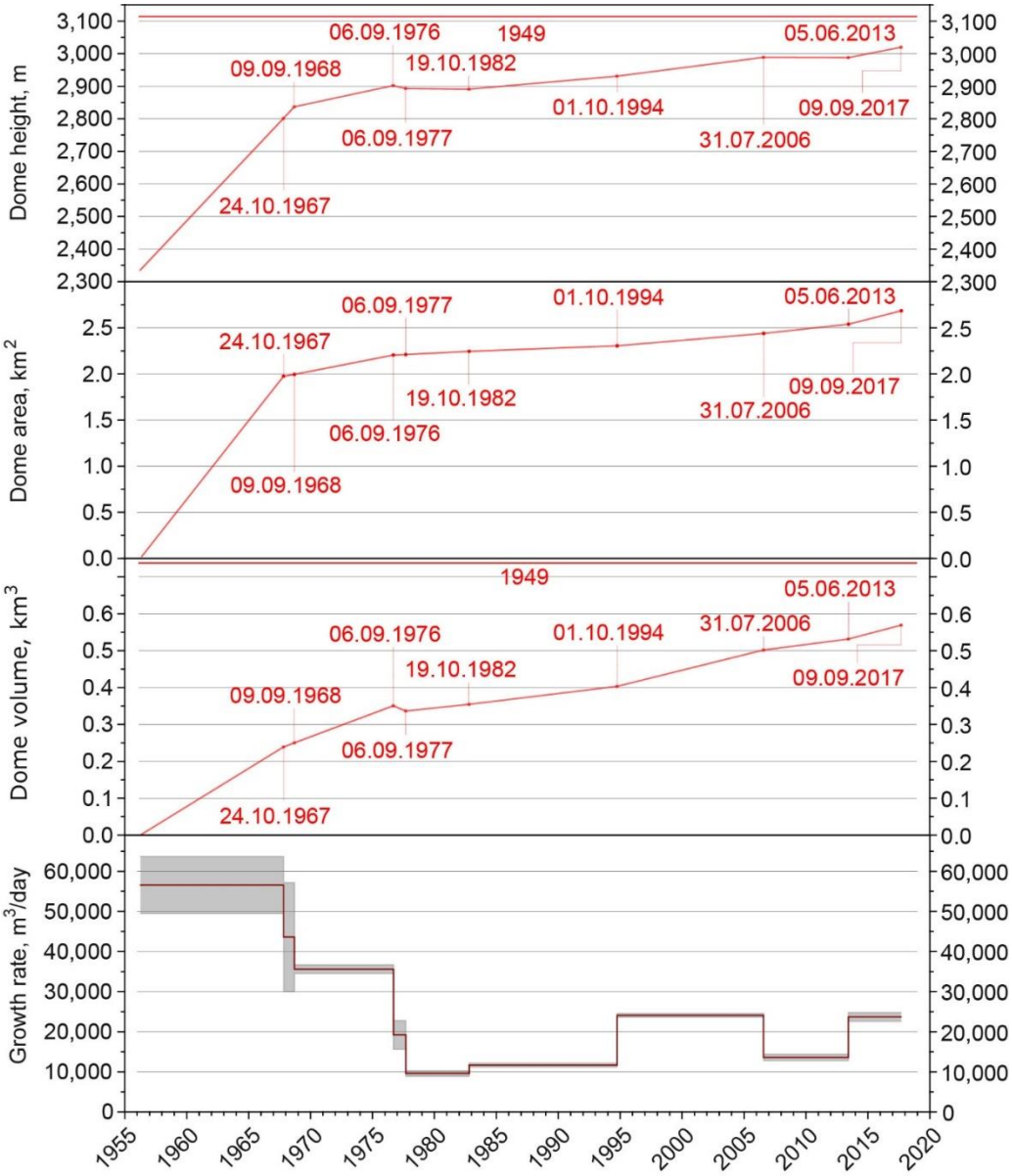
Supplementary Figures



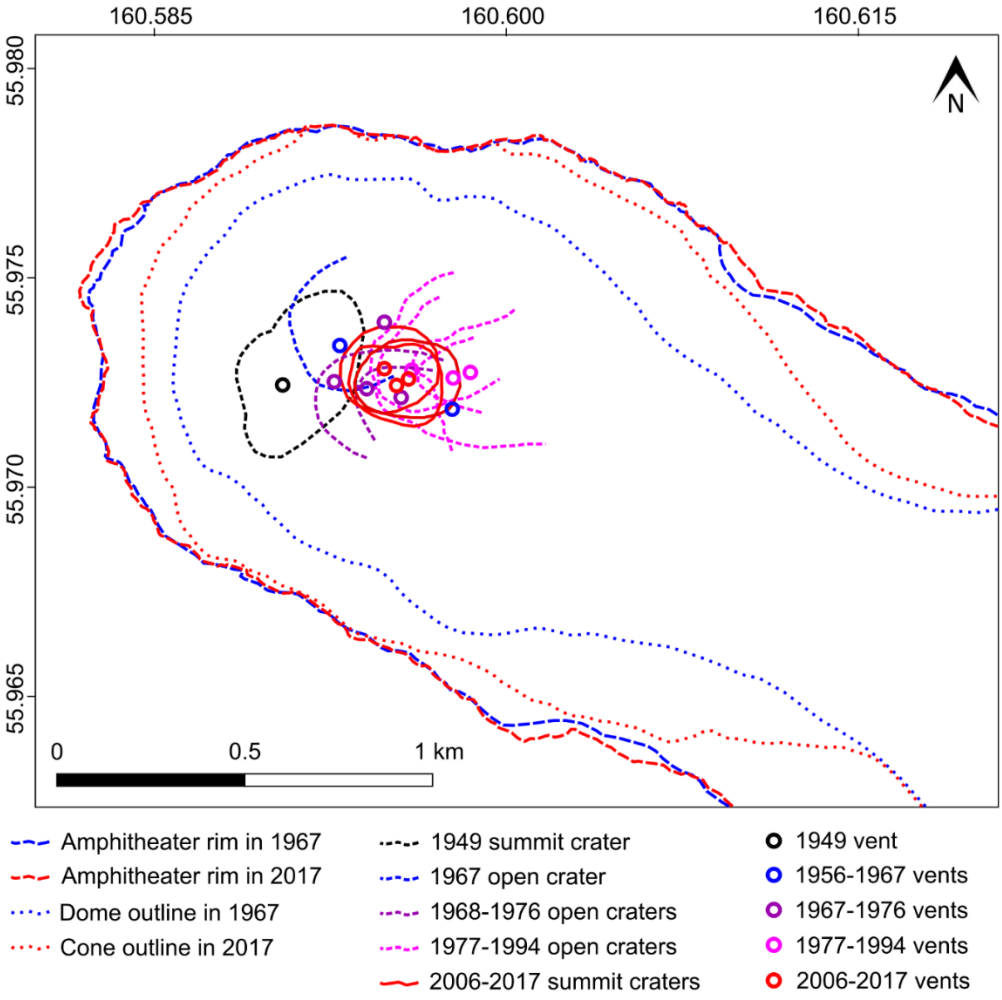
Supplementary Fig. 1 Bezymianny eruptions timeline shown by red triangle symbology (Kamchatka Volcanic Eruption Response Team (KVERT) data, accessed online on 22 July 2019: http://www.kscnet.ru/ivs/kvert/volc.php?name=Bezymianny&lang=en) and availability of photogrammetric data shown by black lines and square symbology.



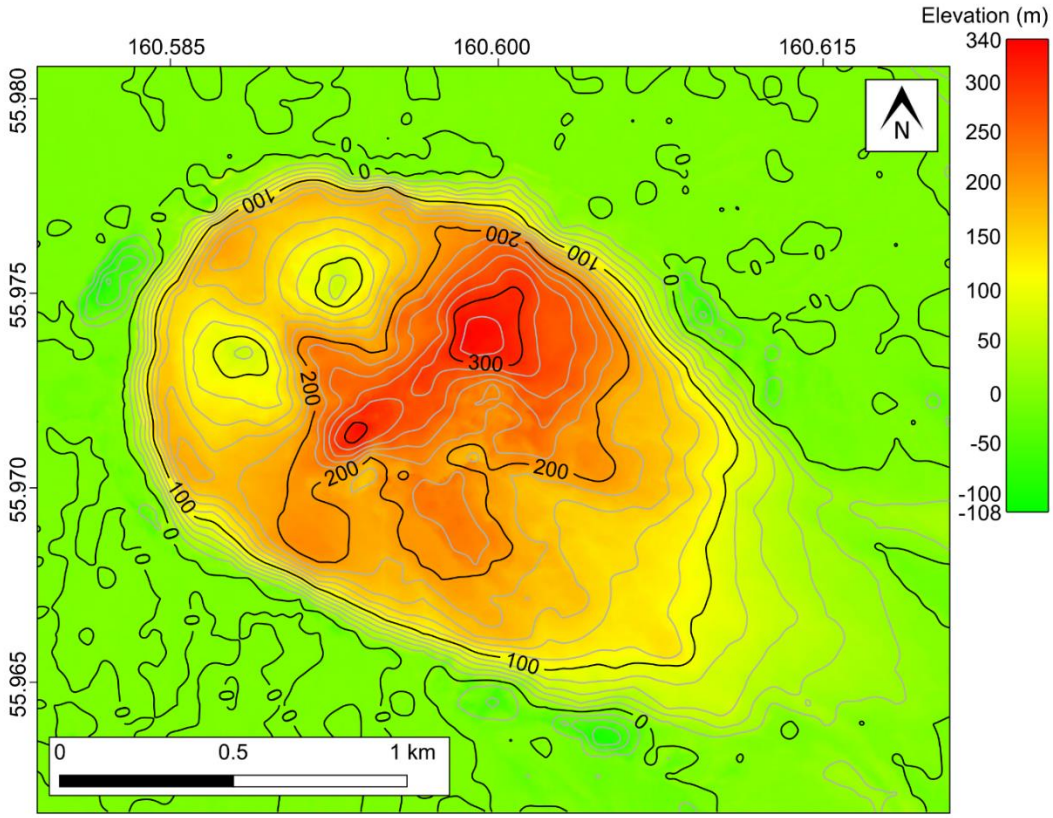
Supplementary Fig. 2 Oblique (from SSE) hillshade visualizations of the 1949 DEM of Bezymianny volcano. The DEM was generated by photogrammetric processing of aerial images. In 1949 Bezymianny was a 3,113 m high (WGS84) stratocone. It was bisected by two collapse scars directed toward west and east from the summit. The eastern scar was 630 m in width and 1,900 m in axial length; its depth was up to 50 m. The western scar was 380 m in width and 1,050 m in axial length; its depth was up to 70 m. The summit accommodated an explosion crater 500×400 m in size. Inside the crater, asymmetrically, closer to its southern rim, a cinder-cone-like structure 100 m in height emplaced with a small crater, 35 m in diameter, on top.



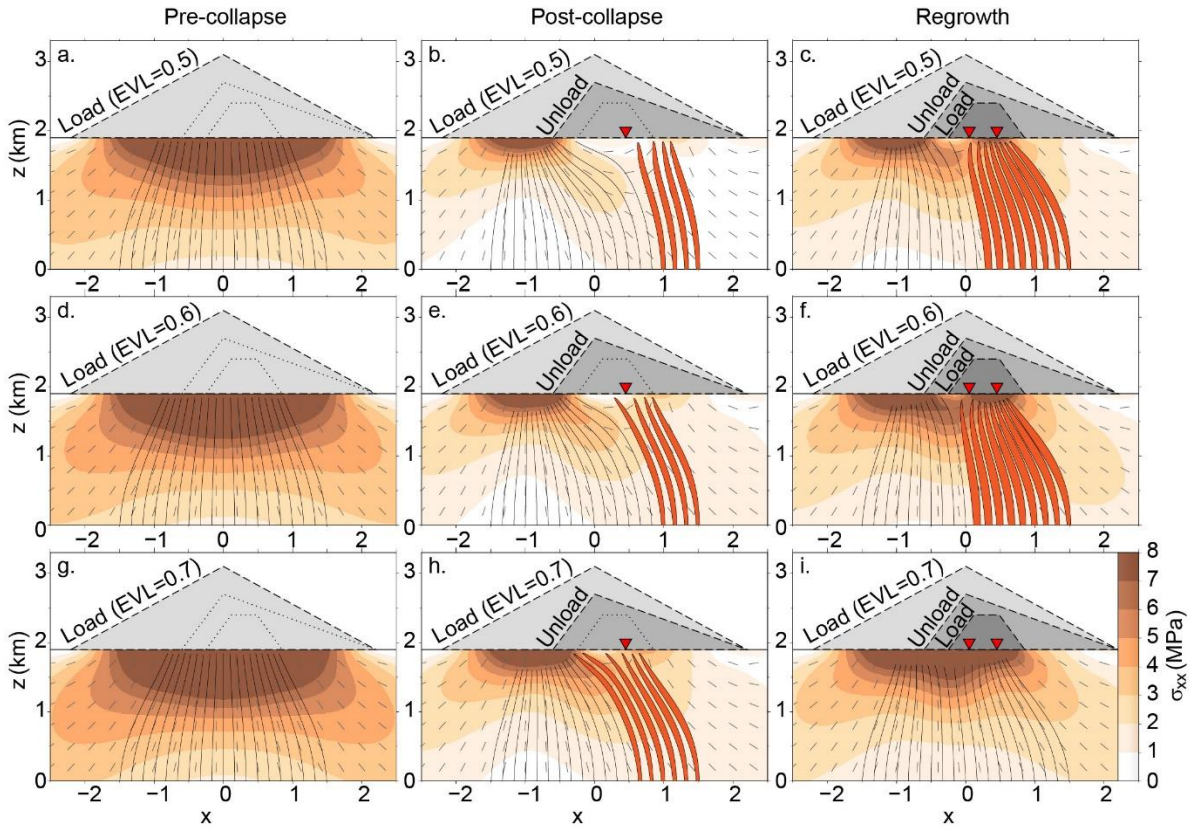
Supplementary Fig. 3 Temporal evolution of the height, area, volume, and growth rate of the Bezymianny dome. Gray transparent bars indicate ranges of the eruption rates uncertainties of 2.1-31.2 % related to inaccuracies in photogrammetric processing and DEMs alignment.



Supplementary Fig. 4 Bezymianny amphitheater and dome outlines, and craters and vents location changes over the 1949-2017 period.



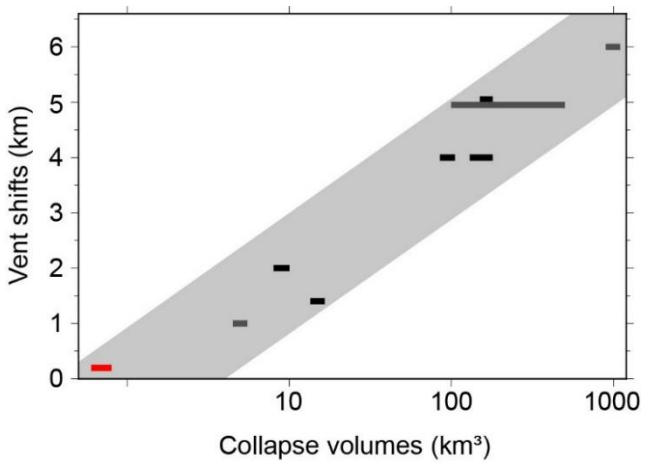
Supplementary Fig. 5 Height difference map of Bezymianny over the 1967-2017 period. The main areas of eruptive material accumulation are observed in the central and north-eastern sectors of the dome. Isopachs are drawn with a 20 m interval.



Supplementary Fig. 6 Magma paths ways change and stress distribution. **a,d,g,** Pre-collapse stresses simulation. **b,e,h,** Post-collapse stresses simulation. **c,f,i,** Regrowth stresses simulation. The color contours and the gray dashes represent the magnitude of horizontal stress and the direction of maximum compression induced by the topography, respectively. Dashed and dotted lines represent the simple geometrical shapes chosen for the force distributions that simulate the effect of topography (dashed lines represent the distribution which is actually considered in that figure panel, while the dotted lines represent the topographic feature that will develop at a later stage). Solid black lines represent the paths of magmatic intrusions that are converging towards the rim of the collapse amphitheater. We highlight in red the trajectories and shapes of magmatic intrusions which are expected to feed vents within the collapse scarp. The red reversed triangles represent vent locations within the collapse scarp (c.f. Fig 6b, 1956-1967 profile): the first vent that opened within the collapse embayment is the one further towards the east (and its location is plotted in the panels relative to the post-collapse scenarios) later vents opened at locations between the 1957-1967 vents (therefore their location is plotted in the panels relative to the dome-growth scenarios).

The Stress scenario with EVL=0.6 seems to explain better the location of the first vent and the focusing of vents at the dome location, after the first dome growth. Smaller EVL would cause larger deflections, however, if intrusions would start even at shallower levels also EVL=0.5 may give a good fit with the vent locations. EVL=0.7 seems to be already too large, the loading dominates over unloading, and the first dome growth seems to compensate already for the collapse.

Another interesting observation is that looking at stress contours – which represents the horizontal stress induced by topography – for the post-collapse scenarios, we always get a region with lower horizontal compression, exactly beneath the location where the dome will develop. This region tends to move towards the left with the establishment of the first dome topography (regrowth scenarios).



Supplementary Fig. 7 Vent shifts vs. collapse volumes, modified from[1]. The vent shifts between the center of pre-collapse volcanism and the location of post-collapse volcanism is plotted as a function of the collapsed volumes. All shifts occurred towards the collapsed flank. Black segments refer to volcanoes with no evidence of shallow reservoirs, grey segments refer to volcanoes where shallow reservoirs exist, and the red segment refers to Bezymianny 1956 collapse.

Supplementary Tables

Date of survey (dd.mm.yyyy)	TRMSE X (m)	TRMSE Y (m)	TRMSE Z (m)	TRMSE volume error (%)	ARMSE volume error (%)	Extrusion rate error (%)
24.10.1967	1.9	1.2	1.6	1.4	-	12.5
09.09.1968	1.9	1.7	1.5	1.2	-	31.2
06.09.1976	1.3	1.3	0.5	0.3	-	3.1
06.09.1977	0.7	0.8	0.4	0.3	-	18.8
19.10.1982	0.4	0.6	0.5	0.3	-	7.3
01.10.1994	1	1.7	0.8	0.5	-	4.3
31.07.2006	1.3	1.9	0.6	0.3	-	2.1
05.06.2013	0.9	0.7	0.6	0.3	-	5.9
09.09.2017	0.2	0.2	0.2	0.1	0.6	4.6

Supplementary Tab. 1 Errors of the Bezymianny dome parameters estimation.

Dates	Type	Features (positive)	Features (negative)	Vents migration amplitude (m)
1956	Sector collapse	-	Amphitheater	500
1956-1967	Endogenous dome growth	Endogenous lava domes	Explosion craters	400
1967-1976	Exogenous (extrusive) dome growth	Shear lobes	Explosion open craters, crease structure	210
1977-2006	Exogenous (extrusive-effusive) dome growth	Shear lobes, lava flows, lava plugs, pyroclastic deposits	Explosion open craters, summit craters, collapse scars (avalanche chutes)	150
2006-present	Stratocone formation	Lava flows, lava plugs, pyroclastic deposits	Summit crater, collapse scars (avalanche chutes)	80

Supplementary Tab. 2 Main stages of the Bezymianny regrowth.

References

1. Maccaferri, F., Richter, N. & Walter, T. R. The effect of giant lateral collapses on magma pathways and the location of volcanism. Nat. Commun. 8, 1097 https://doi.org/10.1038/s41467-017-01256-2 (2017).