V52C MC: 305 Friday 1330h

Conduit Processes During Explosive Basaltic Eruptions III *(joint with P, S, T)*

Presiding: **J Taddeucci,** INGV-CT**; R Seyfried,** GEOMAR

V52C-01 1330h

Infrared Imaging of Strombolian Eruptions

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A forward looking infrared radiometer (FLIR) was used experimentally to capture time series imagery of strombolian eruptions during May and June of 2001 at Stromboli and Etna volcanoes. Though an image is captured only every second or two, eruption sequences covering over 13 hours of imagery over 2 weeks were acquired. Four distinct types of bursts were captured. The first 3 types were observed at Stromboli, and a fourth unique signature was observed at SE crater on Mount Etna. At Stromboli, the three types are; 1) Spatter followed by gas emissions, 2) Gas emissions followed by spatter bursts, and 3) Simultaneous ejections of gas and spatter. Each shows a unique morphology in the time series imagery. The spatter bursts have varying amounts of gas which follow, the gas being much cooler (on the order of 100 degrees Cor more) than the spatter. The volumes of gas estimated using the 2D imagery vary widely, as yet no pattern to this behavior has been discovered. The spatter is not always a single burst, several small sustained (on the order of several seconds) spatter events were observed. The primarily gas bursts showed higher gas volumes and higher gas temperatures than the primarily spatter ejections. Spatter usually, but not always, follows these emissions, and is less voluminous than in the previous ejection type. In the third type, both spatter and gas are ejected simultaneously, the gas emission usually lasting longer than the spatter event. Determination of relative temperatures of the two components is problematic since they overlay one another in the imagery. No relative temperature determinations are made as yet to ejection temperature of spatter in these types due to the relatively small size of the lava bombs in relation to the pixel size in the imagery. However, temperatures over 700 degrees C have been recovered. At Etna a fourth type of burst, mostly gas with a mushroom-shaped structure, followed by a few high ejection angle bombs was observed. These bursts were accompanied by strong signals in infrasound data, and visible pressure waves in the gases over the vent. It is proposed that a unique geometry of the vent is responsible for the constriction of the spatter, the shape of the cloud, and the amplification of the pressure wave and infrasound signal.

V52C-02 1345h

Geologic Constraints on Conduit Formation at Explosive Basaltic Volcanoes

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Models of explosive basaltic processes often are sensitive to shallow (<2 km) conduit dimensions. Geologic data constrain how these conduits can evolve. Xenoliths in the 1975 Tolbachik, Kamchatka, violent strombolian basalt eruption are derived from Quaternary volcanic (0-1 km deep) and Tertiary sedimentary (1-4 km) rocks. Xenolith abundances in the lower half of fall deposits from the Cone 1 eruption stage are 0.001-0.01 vol%. This period sustained 6-10-km high eruption columns and lacked lavas. Xenolith abundances increase to 0.01-1.0 vol% in the upper half of the deposits, which correlates with lava effusion and columns 2-6-km high. The 3×10^5 m^3 total xenolith volume represents a cylindrical conduit 15±2 m in diameter and 1.7±0.2 km deep. Eruption of Cone 1 ended with 12 hr of hydromagmatic falls containing 3×10^6 m^3 (70 vol%) xenoliths. The conduit must have widened from 15±2 to 48±4 m to produce this xenolith volume. The subsequent Cone 2-3 eruption stage produced abundant lavas and eruption columns <4-km high. Xenolith abundances are 0.01-0.1 vol%, indicating progressive widening of the conduit to 6±1 m extending to 2.8±0.4 km depth. Simultaneous eruptions of tephra and lava suggest an annulus of degassed magma developed on conduit walls, enhancing xenolith entrainment; little entrainment occurred early at Cone 1 with an apparent droplet flow regime.

Alkali basalt plugs and dikes representing 1±0.5 km paleodepths are exposed in the 4 Ma San Rafael volcanic field, Utah. Dike-plug complexes represent typical dimensions for basaltic volcanic eruptions and are interpreted as subvolcanic conduit systems. Mapped conduits range from 2-m wide buds along dikes with little wall-rock disruption, to 10-60-m wide cylindrical plugs having <5-m wide conduit margins with abundant xenoliths. These margins may represent typical wall-rock plucking and conduit widening during annular flow (i.e., late Cone 1 and Cone 2-3). Several larger conduits, however, have a 1-6 m xenolith-poor annulus with a 10-40 m inner core of extensive wall-rock breccia and pervasive low-temperature hydrothermal alteration. Xenoliths in the inner breccia often are derived from deeper stratigraphic units. These brecciated conduits appear analogous to late-stage hydromagmatic events at Cone 1. Models of explosive basaltic cinder cone eruptions should consider that subvolcanic conduit diameters to <2 km depth may progressively widen to order of 10-60 m.

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V52C-03 1400h

Periodic behaviour in lava dome eruptions

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Lava dome eruptions commonly display fairly regular alternations between periods of high activity and periods of low or no activity. The time scales for these alternations is typically months to several years. Here we develop a generic model of magma discharge through a conduit from an open-system magma chamber with continuous replenishment. The model takes account of the principal controls on flow, namely the replenishment rate, magma chamber size, elastic or viscoelastic deformation of the chamber walls and conduit, conduit resistance, and variations of magma viscosity. Critical to the model is the idea that there can be two stable states of flow related to the kinetics of crystallization induced by degassing of magma. In one state magma ascends too fast for crystallization to be substantial and viscosity remains low. In the other state magma ascends slowly, extensive crystallization occurs and the magma develops a very high viscosity. Period behaviour is the consequence of alternations between these states. The analysis indicates a rich diversity of behaviours. Depending on conditions magma discharge rate can be periodic with the period strongly dependent on magma chamber size and conduit width. Many features of eruptions, such as alternations between periodic behaviours and continuous steady discharge, sharp changes in discharge rate, and transitions between effusive and explosive activity, can be explained in terms of the non-linear dynamics of conduit flows from open-system magma chambers. The activity of Mount St Helens in 1980-86 provides an outstanding natural experiment to evaluate the model. There were two stages of periodic dome growth with brief periods of high magma discharge (2-7 days) alternating with much longer periods (tens of days) of no growth. There was also a period of steady discharge of 286 days between the two stages of periodic behaviour. The Mount St Helens activity can be simulated by the model using some of the observations of governing parameters. Some of outputs of the model such as conduit diameter, magma viscosity and chamber size agree with estimates based on independent methods. We also consider periodic behaviour related to variations of magma viscosity caused by magma chamber convection.

V52C-04 1415h

Destruction or Collapse of Volcanic Edifices : Consequences for Magmatic Eruptions

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A volcanic edifice may get partially destroyed by landslides, phreatic explosions or collapse driven by forceful magma injection prior to eruption. Such events act to reduce stresses due edifice load on the upper crust and on the underlying magma reservoir. We present an analytical model for the deformation of a cylindrical cavity in an elastic half-space with loading at the upper boundary. Magma compressibility is taken into account. Partial destruction of an edifice acts to decrease magmatic pressures in the reservoir as well as the magnitude of stresses on the reservoir walls. Using a simple tensile threshold criterion for wall rupture, we show that edifice destruction may in some cases stop an incipient eruption. Using a second simple criterion for the closure of feeder dykes, we calculate the volume of magma which gets erupted. Depending on edifice size, magma reservoir size and depth, edifice destruction may increase or decrease the volume of magma which gets erupted. The former situation occurs only for small edifices. Most cases of interest involve large edifices and are such that edifice destruction implies a decrease of erupted volume. These results may be useful to discuss the effect of phreatic explosions. Most magmatic eruptions are preceded by phreatic explosions but all phreatic explosions are not followed by magmatic eruptions. Phreatic explosions may be due to perturbations in the hydrothermal system resulting from heating by ascending magma or stress changes generated by reservoir inflation. In such circumstances, phreatic explosions which lead to edifice destruction may in fact act to prevent a magmatic eruption.

V52C-05 1430h

Evidence for incomplete magma degassing during hydromagmatic explosions that produced the Keanakako'i Ash, Kilauea Volcano, Hawaii

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Between 1500 and 1790 AD, hydromagmatic and phreatic summit eruptions of Kilauea Volcano, Hawaii, produced three major depositional units (from bottom to top): (1) pyroclastic fall and low-energy surge beds of mostly juvenile debris; (2) high-energy surge beds containing both juvenile and lithic pyroclasts; and (3) lithic-rich block fall and cross-bedded surge deposits. The lowest unit contains two well-defined sequences, each grading upward from poorly vesiculated ash, to coarse ash and lapilli with vesicularity ranging from 0-90%. We have analyzed pyroclasts within this unit to constrain the pressure and depth within the conduit at which clasts quenched. Approximately 200 microprobe analyses of matrix glass fragments yield 330 +/- 200 ppm sulfur; comparison with S analyses of glass inclusions in olivine (1200-1500 ppm) suggests that matrix glass was 70-90% degassed in sulfur before quenching. Fourier-transform infrared measurements of 70+ matrix glass fragments yield no measurable CO_2 in the glass, and dissolved-water (dH_2O) concentrations of 0.19-0.45 wt% (all OH^-): higher than the 0.09 expected under equilibrium saturation conditions at 1 atm pressure. Ratios of H_2O/K_2O are 0.64-0.83, compared with 1.3 for undegassed melt (Wallace & Anderson, 1998, Bull. Volc. 59:327-344), suggesting that the magma was 20-50% degassed in H_2O prior to quenching. Measured dH_2O values do not vary significantly with MgO (which ranges from 6 to 10.3 wt%), or grain diameter (.2mm-6cm), and show a weak, inverse correlation with vesicularity. Measured dH_2O corresponds to equilibrium saturation at p=0.4-2.1 MPa; a pressure that would be reached at 30-200 m depth under a hydrostatic gradient (10 MPa/km), or 8-50 m under a lithostatic gradient (25 MPa/km). These results suggest that the magma did not degas in a lava lake prior to eruption, as suggested by Mastin et al. (1997, GSA Cordilleran Section abstract). Conditions that

prevented complete degassing may have involved: (1) rapid release into a surface water body, where quenching occurred before equilibrium degassing could take place; or (2) mixing of magma and inflowing water within a shallow chamber under confined conditions, followed by explosive release. We speculate that both of these mechanisms operated to varying degrees, producing the wide range of clast size and vesicularity in the deposits.

V52C-06 1445h INVITED

The Influence of Conduit Processes During Basaltic Plinian Eruptions.

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Basaltic volcanism is most typically thought to produce effusion of lava, with the most explosive manifestations ranging from mild Strombolian activity to more energetic fire fountain eruptions. However, some basaltic eruptions are now recognized as extremely violent, i.e. generating widespread phreatomagmatic, subplinian and Plinian fall deposits. These eruptions are particularly dangerous because the ascent rate of basaltic magma prior to eruption can be very rapid (giving warning times as little as a few hours) and because their precursors may be ignored or misunderstood.

The main question addressed in this talk is: what conditions in the conduit cause basaltic magma to adopt an eruption style more typical of chemically evolved, highly viscous magmas? Possible mechanisms (acting singly, or in concert) are:

(1) interaction between magma and water,

(ii) very rapid ascent producing a delayed onset of degassing then exceptionally rapid "runaway" vesiculation at shallow levels in the conduit,

(iii) microlite crystallization and degassing of the magma during ascent leading to increased viscosity.

We focus here on two examples of basaltic Plinian volcanism: the 1886 eruption of Tarawera, New Zealand, which is the youngest known basaltic Plinian eruption and the only one for which there are detailed written eyewitness accounts, and the well documented 122 BC eruption of Mount Etna, Italy. Field and laboratory evidence suggests that the Plinian phase of the 1886 eruption was a consequence of two processes. Firstly rheologic changes during magma ascent accompanied early (pre-fragmentation) interaction between the basaltic melt and water-bearing rhyolitic units forming the conduit walls and, secondly, late-stage magma:water interaction. In contrast, during the 122 BC eruption tectonic processes, such as slope failure or permanent displacement of a mobile flank of the volcano, appear to have triggered exceptionally rapid ascent, delayed onset of degassing and exceptionally rapid vesiculation at shallow levels in the conduit.

V52C-07 1520h INVITED

Experimental Study of Melt-Vapor Partitioning of Cl With Application to Cl Degassing Behavior During the Soufriere Hills, Montserrat Eruption.

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Experimental determinations of melt-vapor or melt-vapor-brine partitioning of Cl using a rhyolitic melt composition approximating the phenocryst-free matrix of the recently erupted Soufriere Hills andesite provide insights into the origin of Cl emitted to the atmosphere during the eruption. The experiments were done at 25-250 MPa, 860-890°C and they involved equilibration of the estimated matrix composition [$\sim$71 wt.% SiO_2, molar $(Na_2O+K_2O)/Al_2O_3 \sim 0.6$] with a Cl-bearing aqueous fluid or aqueous fluid + hydrosaline brine. Cl concentrations in glasses from the experimental run products (0.48 - 0.68 wt.% Cl) are significantly higher than those observed in natural matrix glasses ($\sim$0.20 wt.% Cl) and melt inclusions (0.30$\pm$0.07 wt.% Cl). These results indicate that if the pre-eruptive Montserrat magma was vapor saturated, the vapor phase would have been Cl poor and there was not a co-existing hydrosaline brine. This interpretation, based on Cl solubility data, is supported by the observed good agreement between remote sensing measurements of Cl emissions (as HCl) and petrologic estimates of Cl emissions based on the volume of magma extruded and Cl contents of melt inclusions and matrix glasses (with correction for crystallization of approximately 50% of the groundmass during ascent). Cl emissions during the Soufriere Hills eruption are thus proposed to simply reflect syn-eruptive degassing of magma during ascent. In other volcanic systems the efficiency and magnitude of Cl degassing will depend on magma ascent rates, the initial H2O/Cl in the magma, whether the magma is vapor saturation prior to ascent, and on the amount of groundmass crystallization occurring during ascent.

V52C-08 1535h

Petrological Evidences of a Complex Plumbing System Feeding the July-August 2001 Eruption of Mt.Etna

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After the 1991-93 eruption, which was the largest one of the last three centuries, Mt. Etna resumed flank activity on July 2001 through a complex system of eruptive fissures cutting the NE and the S flanks of the volcano down to 2100 m a.s.l. Explosive activity, including fire fountains, Strombolian and phreatomagmatic explosions, was clustered in the southern reach of the eruptive fissure (at 2550 and 2100 m hereafter Lower Vents, LV). Conversely, the NE fissure systems and the upper portion (above the 2550 m a.s.l) of the S one (hereafter Upper Vents, UV), produced mainly effusive activity. Here we present the main compositional features of volcanics produced during this eruption, allowing us to make inferences on the magmatic plumbing system.

UV produced porphyritic trachybasalts, with phenocrysts paragenesis dominated by plagioclase (10 vol%), minor clinopyroxene (6 vol%) and olivine (1 vol%). These characters are typical of most volcanics erupted during the last centuries. On the contrary, LV erupted products with quite unusual compositional features; they are trachybasalts, with phenocrysts assemblage dominated by large crystals of clinopyroxene (6 vol%), scarce plagioclase (2 vol%) and olivine (1 vol%). In these volcanics, subhedral crystals of kaersutite-hastingsite amphiboles are quite common, and frequently they form glomeroporphyritic aggregates with other mafic phases. Xenocrysts with a core of ortopyroxene rimmed by clinopyroxene were also found. LV products show abundant angular to subangular sedimentary nodules, ranging in size from a few tens of centimetres to a few hundreds of micron. Most of them are quartz arenites variously interacting with the host magma.

The contemporaneous outpouring of such different products suggests that a rather complex magmatic plumbing system fed the eruptive fissures: magmas erupted from UV experienced crystallisation, differentiation and degassing similar to those observed during summit activity of last decades. Conversely LV were fed by a magma that evolved in a closed system where high water pressure allowed the occurrence of the amphibole and inhibited the crystallization of plagioclase.

V52C-09 1550h

Modeling of Discharge Rate Variations on Santiaguito Volcano, Guatemala

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Santiaguito volcano has shown cyclic activity for about 80 years, starting in 1922. By 1984, continuous slow extrusion of dacite lava had built a 0.9 km3 complex of 22 distinct units, giving a time-averaged extrusion rate of 0.46 m3 s-1. Extrusion rates were variable. Between 1922 and 1984 the Santiaguito dome complex grew in a series of 3-5-year-long spurts of high (0.6-2.1 m3 s-1) extrusion separated by 10-12-year-long intervals of lower (0.2 m3 s-1) extrusion. A transient version of a magma ascent model in the case of highly-viscous, gas-saturated magmas (Melnik and Sparks 1999, Nature, 402: 37-41) takes into account crystal nucleation and growth kinetics in ascending magma, gas escape in permeable flow through it and visco-elastic deformations of conduit walls. Pressure variations in the chamber are governed by influx of basaltic magma into the chamber and evacuation of magma from it. Calculation shows that during the eruption cyclic variations in discharge rate can occur. The ratio between high and low discharge rate during the cycle can be up to two orders of magnitude. The period of oscillations could be from a month to years depending on the chamber size and magma properties. We study discharge rate variations on Santiaguito with the help of magma ascent model to reconstruct the parameters of the magma chamber and conduit for this eruption which cannot be measured directly. Preliminary calculations give good agreement with observations for duration of the cycles, amplitude of discharge rate variations and general trend of eruption behavior. We will also explore the possibility of a new explosive eruption by estimating internal overpressure in the system.

V52C-10 1605h

Monitoring Explosive Activity of the July-August 2001 Eruption of Mt.Etna by Ash Characterization

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From July 19 to August 7 2001 Mt.Etna showed explosive activity at several vents located at 2100 and 2550 m a.s.l. on its southern flank. Abundant ash from fire fountaining, Strombolian, and pulsed ash explosions, was dispersed mainly toward S and SE. Daily characterization of composition and morphology of this ash led us to: i) a timely insight on the conduit processes controlling the explosions; ii) to set up and calibrate a new, all-weather tool for monitoring explosive activity of Mt.Etna.

Ash samples were collected daily at different locations. The ash, in the size range 0.4-0.1 mm, comprises: microcrystalline tachylites, brown fresh sideromelane glass, crystals, and lithics. 3D shape, contour, surface texture, vesicularity, and vesicle shape of 50 clasts per sample were evaluated under Scanning Electron Microscope. In respect with time, only the explosions of 23-29 July produced vesicular sideromelane with irregular shape and smooth surface, while the ash erupted before, and specially after this interval, is mainly poorly vesicular, blocky tachylites with adhering particles and occasional hydration cracks. Lithic content is higher at the begin and at the end of the eruption.

On these grounds we propose the following evolution of the eruption. Initially, the rising magma reached a shallow water table causing hydromagmatic explosions, craterization and erosion of conduits. As magma flux and pressure in the conduit increased, fully magmatic activity generated fire fountaining, with a reappraisal of hydromagmatism during its waning phase. Later the eruption involved more degassed magma in a deeper level of a partly destabilized conduit. The above inferences, made during the eruption from ash studies solely, are also supported by visual and seismic monitoring data, and by the stratigraphy of the eruption products. The proposed characterization of ash provides a fast, all-weather tool for monitoring explosive activity, informative on the degassing state of the magma, and on the stability of conduit walls.

URL: http://www.ct.ingv.it

V52C-11 1620h

Plagioclase Zoning and Magma Decompression: Comparing the 1974 and 1999 Eruptions of Fuego Volcano, Guatemala

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We compare plagioclase zoning relationships in the 1974 vulcanian and 1999 strombolian (?) eruptions of Fuego volcano to test the hypothesis that styles of magma decompression differ between eruptions. Twenty-two crystals from 1974 and thirty-seven crystals from 1999 ash were weighed, oriented, sectioned and optically characterized to delineate zoning differences. Roughly one-half of the crystals were analyzed by electron microprobe. An exceptionally detailed study by Anderson (Am. Mineral. v.69, 1984) determined that a typical 1974 crystal has an unzoned core (An_{90}), an oscillatory-zoned margin (An_{85-80}) and a thin (<10μm) sodic rim (An_{65}). In addition, several patchy-zoned regions may be interleaved with oscillatory-zoned regions. In contrast, a typical 1999 crystal has an unzoned core (An_{90}), an oscillatory-zoned margin (An_{85-80}) and a wide (~50-100 μm) normally-zoned (An_{85} to $\sim An_{50}$) rim. Patchy zones are relatively uncommon and thin in 1999 crystals as compared to 1974 crystals. Microscopic analysis of 1999 crystals shows that patchy zones have parallel boundaries indicating a constructional origin as previously determined for 1974 crystals. Except for their unzoned calcic cores, which probably reflect stable growth conditions at depth, the zoning profiles of 1974 and 1999 crystals are distinct. Outward from their cores the zoning features become more variable in response to changing crystallization conditions and different styles of decompression. Crystals from both eruptions display fine-scale oscillatory zoning that probably reflects repeated, small pertubations such as magma convection or shearing, or localized wall rock fracture and volatile-loss. Patchy zones are a common and prominent feature of 1974 crystals but are rare and subtle in 1999 crystals. We agree with Anderson's interpretation that the fine- to medium-scale patchy zoning probably represents rapid crystal growth during sudden decompression. The rims of 1974 and 1999 crystals reflect growth conditions immediately before and during eruption. The thin sodic 1974 rims, which represent an abrupt transition from oscillatory zoning, probably grew rapidly during eruption and quenching. The wide, normally-zoned 1999 rims, with large An-range, probably formed by extended slow decompression.

V52C-12 1635h

Seismic, Acoustic, and Video Observations of Conduit Processes During Strombolian Explosions at Mount Erebus, Antarctica

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Mount Erebus hosts a persistently active, open-conduit magmatic system that produces 2-10 similar Strombolian eruptions per day from a persistent lava lake. The lava lake, an open skylight to a shallow magma chamber, is composed of phonolitic magma with a near-surface viscosity $\leq 10^3$ Pa-s. Since 1996, seasonal broadband seismic and infrasound data have been collected from the summit plateau and crater rim at vent distances between 0.66 and 2.5 km. Acoustic signals have very simple associated Green's functions and readily discriminate multiple and single gas slug eruptions. Acoustic observations show that typical Erebus Strombolian explosions consist of single gas slugs with mass flux rates of $\approx 5 \times 10^3$ Kg/s and cumulative gas fluxes of $\approx 2 \times 10^3$ Kg. Seismic signals show a complex short period ($f > 1$ Hz) signature dominated by lava lake refraction and seismic scattering in the upper volcano, accompanied at some stations by a ground-coupled airwave. Strombolian explosions are ubiquitously accompanied by oscillatory very-long-period (VLP) signals observed in the near-field by broadband seismometers. VLP signals have origin times that precede seismoacoustic origin times by approximately 4 s, persist for up to 6 minutes, and dominate the near-field Strombolian explosion displacement signal. VLP signals have modal spectra with principal periods near 20.7, 11.8, and 7.7 s and Q values around 10. Stacking of similar VLP signals significantly decreases noise (especially the strong microseism near 7 s), enabling the detection of higher VLP modes, particularly at periods near 4.8 s, 3.5, and 2.6 s. VLP particle motions are approximately vent-radial, but show significant azimuthal and dip inconsistencies, suggestive of an appreciably asymmetric quasistatic elastic response for the summit crater region due to strength and/or topographic variation. We postulate that Erebus VLP signals represent either a long period mechanical resonance of the conduit system during refilling or internal gravity waves excited in the pycnocline of the vesiculated lava lake system by the buoyant ascension of eruptive gas slugs. Comparing seismograms from 1996-1997 with more recent examples shows that the VLP signature of Erebus is temporally varying and is thus sensitive to shallow conduit conditions.

URL: http://www.ees.nmt.edu/Geop/Erebus/erebus.html

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