Journal of Volcanology and Geothermal Research 337 (2017) 98–110

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Magmatic degassing, lava dome extrusion, and explosions from Mount Cleveland volcano, Alaska, 2011–2015: Insight into the continuous nature of volcanic activity over multi-year timescales

Cynthia Werner [a,*,1], Christoph Kern [a], Diego Coppola [c], John J. Lyons [b], Peter J. Kelly [a], Kristi L. Wallace [b], David J. Schneider [b], Rick L. Wessels [d]

[a] U.S. Geological Survey Cascades Volcano Observatory, 1300 SE Cardinal Ct., S100, Vancouver, WA 98683, United States
[b] U.S. Geological Survey Alaska Volcano Observatory, 4230 University Dr., S100, Anchorage, AK 99508, United States
[c] Dipartimento di Scienze della Terra - Università degli Studi di Torino, Via Valperga Caluso 35, 10125 Turin, Italy
[d] U.S. Geological Survey Reston, 12201 Sunrise Valley Dr., MS562, Reston, VA 20192, United States

ARTICLE INFO

Article history:
Received 4 November 2016
Received in revised form 1 March 2017
Accepted 1 March 2017
Available online 2 March 2017

Keywords:
Degassing
Extrusion rate
Magma flux
Mount Cleveland volcano
Explosion
Dome growth
Open vent

ABSTRACT

Mount Cleveland volcano (1730 m) is one of the most active volcanoes in the Aleutian arc, Alaska, but heightened activity is rarely accompanied by geophysical signals, which makes interpretation of the activity difficult. In this study, we combine volcanic gas emissions measured for the first time in August 2015 with longer-term measurements of thermal output and lava extrusion rates between 2011 and 2015 calculated from MODIS satellite data with the aim to develop a better understanding of the nature of volcanic activity at Mount Cleveland. Degassing measurements were made in the month following two explosive events (21 July and 7 August 2015) and during a period of new dome growth in the summit crater. SO_2 emission rates ranged from 400 to 860 t d^{-1} and CO_2/SO_2 ratios were <3, consistent with the presence of shallow magma in the conduit and the observed growth of a new lava dome. Thermal anomalies derived from MODIS data from 2011 to 2015 had an average repose time of only 4 days, pointing to the continuous nature of volcanic activity at this volcano. Rapid increases in the cumulative thermal output were often coincident with visual confirmation of dome growth or accumulations of tephra in the crater. The average rate of lava extrusion calculated for 9 periods of rapid increase in thermal output was 0.28 m^3 s^{-1}, and the total volume extruded from 2011 to 2015 was 1.9–5.8 Mm^3. The thermal output from the lava extrusion events only accounts for roughly half of the thermal budget, suggesting a continued presence of shallow magma in the upper conduit, likely driven by convection. Axisymmetric dome morphology and occasional drain back of lava into the conduit suggests low-viscosity magmas drive volcanism at Mount Cleveland. It follows also that only small overpressures can be maintained given the small domes and fluid magmas, which is consistent with the low explosivity of most of Mount Cleveland's eruptions. Changes between phases of dome growth and explosive activity are somewhat unpredictable and likely result from plugs that are related to the dome obtaining a critical dimension, or from small variations in the magma ascent rate that lead to crystallization-induced blockages in the upper conduit, thereby reducing the ability of magma to degas. We suggest the small magma volumes, slow ascent rates, and low magma viscosity lead to the overall lack of anomalous geophysical signals prior to eruptions, and that more continuous volcanic degassing measurements might lead to more successful eruption forecasting at this continuously-active open-vent volcano.

1. Introduction

Mount Cleveland volcano (52.825°N, −169.944°W, 1730 m) is an andesitic stratovolcano and one of the most active volcanoes in the Aleutian arc, having had eruptive activity recorded every year since 2005 (Herrick et al., 2014; Dixon et al., 2015; Cameron et al., 2017; Dixon et al., 2017). The volcano is part of a complex of volcanic centers called the Islands of Four Mountains (IFM), and lies about 1500 km SW of Anchorage, Alaska (Fig. 1). Mount Cleveland's remote location makes volcano monitoring, and thus characterizing the magmatic processes leading to various volcanic behaviors, a real challenge. Permanent geophysical instrumentation and a web camera were only installed in mid-2014. Thus, until recently, eruptions and changes in activity were

* Corresponding author.
E-mail address: cwerner@volcanogeochemistry.com (C. Werner).
[1] Now U.S. Geological Survey Contractor, 392 Tukapa St., RD1, New Plymouth, 4371, New Zealand.

http://dx.doi.org/10.1016/j.jvolgeores.2017.03.001
0377-0273/

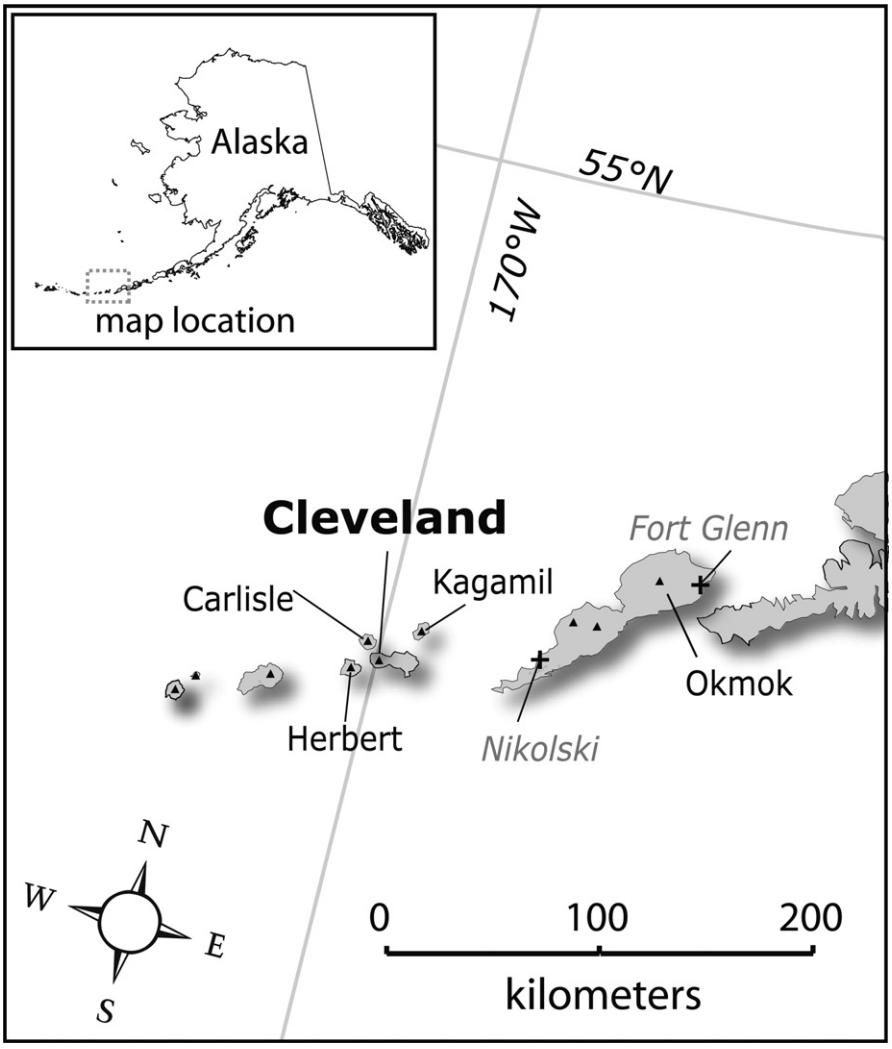

Fig. 1. Location map of Mount Cleveland volcano in the Island of Four Mountains. Cleveland lies approximately 70 km west of the settlement of Nikolski, Alaska, in the Central Aleutians. Volcanoes are shown with triangles and settlements with plus symbols.

almost exclusively detected using satellite data and from pilot reports (McGimsey et al., 2014). Since late 2011, distant infrasound arrays proved very useful for detecting explosions (De Angelis et al., 2012; Dixon et al., 2015), but of the explosions since 2014, none have been accompanied by enhanced seismicity recorded by permanent seismic monitoring stations.

The observations of eruptive activity and the appearance of the crater area and volcanic deposits at Mount Cleveland are documented in the Alaska Volcano Observatory's annual reports for years 2011–2015 (McGimsey et al., 2014; Herrick et al., 2014; Dixon et al., 2015; Cameron et al., 2017; Dixon et al., 2017). During this period, the activity was characterized by elevated temperatures and nearly-continuous degassing, intermittent minor explosions (often accompanied by limited tephra deposits in the summit crater), and dome growth. In most years, the emplaced domes would be completely destroyed in subsequent explosions (see Herrick et al., 2014, for a good example), but on two occasions, in 2011 and 2014, the recently emplaced domes were observed to deflate, or drain back, into the conduit. Sometimes these periods of subsidence were marked by ring fractures around the crater walls (McGimsey et al., 2014). Typically no activity would be observed in the summit crater during periods with no other indication of heightened volcanism (e.g. thermal anomalies). Satellite images suggest that the central crater is often funnel shaped when a dome is not present, and in many years the active vent area is visible as a central pit that varies from ~10–30 m in diameter at the surface, either in the center of the dome or pit. Satellite data also indicate that small lava flows sometimes extend several hundred meters down the flanks of the volcano, but more often flank deposits are described as patchy or as a dusting of ash, rather than extensive in nature (Herrick et al., 2014).

Since the installation of a web camera on nearby Chuginadak Island in 2014 (https://www.avo.alaska.edu/webcam/Cleveland_CLCO.php), the volcano is often observed emitting a low-altitude volcanic plume, and occasionally more robust plumes that extend 10s of km downwind of the volcano are observed both in web camera images and satellite data. While the majority of eruptive activity at Mount Cleveland is minor (VEI 0–2), major ash producing eruptions (VEI 3+) pose a threat to aviation and are a hazard in the region. Between 1970 and 2008 there were 14 eruptions from Mount Cleveland in which the ash cloud extended to >5 km height (VEI 3) above sea level (ASL) (Dean et al., 2015; Dean et al., 2004). In one of the most recent major eruptions of Mount Cleveland in 2001, three explosive events resulted in ash clouds that rose 12 km (39,000 ft) ASL (Dean et al., 2004). This eruption resulted in one documented non-damaging encounter between an aircraft and the volcanic cloud in the vicinity of San Francisco, California (Simpson et al., 2002; Guffanti et al., 2010).

Here, we report the first measurements of volcanic gas composition and emission rates ever made at Mount Cleveland volcano, and compare with the longer-term record of degassing obtained from OMI (Ozone Monitoring Instrument) satellite data (Fioletov et al., 2016). The on-site measurements were obtained during a campaign to the central