Mineralogical and compositional features of rock fulgurites: A record of lightning effects on granite

CHIARA ELMI1,*, JIANGZHI CHEN1, DAVID GOLDSBY1, AND RETO GIERÉ1

1Department of Earth and Environmental Science, University of Pennsylvania, 240 S. 33rd Street, Philadelphia, Pennsylvania 19104-6313, U.S.A.

ABSTRACT

Fulgurites are a naturally occurring glass formed when sand, rock, or soil is struck by atmospheric electrical discharges (lightning). The aim of this paper is to provide insights into the conditions occurring in rocks during the lightning strike. Rock fulgurites collected from Mt. Mottarone, Baveno (Piedmont, Italy) have been investigated to assess the mineralogical and compositional changes occurring in granite due to a lightning strike. X-ray powder diffraction showed that the samples represent the dominant granitic rock type of the Baveno massif, the so-called “Pink Baveno.” Fulgurite coats the surface of the granite as a brown-black, glassy to very fine-grained porous layer. Powder diffraction data for the fulgurite reveal the presence of cristobalite and quartz crystals in a glass matrix, suggesting that temperature exceeded ~1700 °C at near atmospheric conditions, assuming thermodynamic equilibrium. Electron probe microanalysis of the glass revealed that it is mainly composed of SiO2 and Al2O3 and that it has a porosity of 5–7 area% in the studied zones. The presence of the amorphous phase indicates that the abrupt electrical (Joule) heating of the rock surface yielded high temperatures, producing a thin melt layer on the surface, which then cooled adiabatically. Idealized physical model was developed to simulate the effects of Joule heating and subsequent thermal conduction close to the rock surface during and after a lightning strike. The quantity of organic matter in the glass, obtained via Elemental Analyzer, suggests that rapid quenching of the melt trapped NOx and COx gases produced during heating. Raman spectroscopy revealed the presence of polyaromatic hydrocarbon molecules, which, combined with the Elemental Analyzer data, suggest that organic matter was pyrolyzed at around 300–350 °C and then trapped in the glass matrix of the studied rock fulgurites.

Keywords: Lightning, rock fulgurites, mineralogy, compositional features, physical models

INTRODUCTION

Lightning is a transient, high-current discharge occurring within a thundercloud, between clouds, or between a cloud and the ground whose path may be many kilometers long (Uman and Krider 1989). Christian et al. (2003) estimated the frequency of lightning across the globe at 1.2 × 109 flashes per year. The majority (~90%) of these lightning flashes occur over continental landmasses as opposed to the open ocean (Lay et al. 2007). Any type of clouds can potentially cause lightning or some related form of electrical discharge, as can snowstorms, volcanic eruptions, and dust storms (Uman and Krider 1989).

Over half of the flashes occur within clouds, known as intra-cloud (IC) discharges. Cloud-to-ground (CG) lightning, although accounting for only about one-third of lightning flashes (Rakov 1999), are the most studied because of their impact on human life (Uman and Krider 1989). Each CG lightning strike involves an energy of 108–1010 J, most of which is consumed to produce thunder, hot air, light, and radio waves (Rakov 1999; Saikia et al. 2008). On the ground, typical peak currents can reach 30 kA, and their half-life is about 50 μs (Uman and Krider 1989). The term fulgurite (from the Latin fulgur, lightning) describes a naturally occurring glass formed when sand, rock, or soil is impacted by CG lightning strikes. The occurrence of fulgurites has also been documented on man-made structures (e.g., Martin Crespo et al. 2009).

Pasek et al. (2012) classified fulgurites into four types based on morphology and mineralogical composition. Type-I fulgurites are sand fulgurites consisting of hollow glass tubes with sand adhering to the outside, formed when lightning strikes a body of sand; type-II fulgurites are clay fulgurites, consisting of thick, melt-rich walls; type-III fulgurites are caliche fulgurites, consisting of thick, glass-poor walls; and type-IV fulgurites are rock fulgurites, formed when lightning strikes the surface of rocks, appear mostly as thin glassy crusts, which may be relatively low in silica, and exhibit a wide variety of colors depending on the composition of the rock (Essene and Fisher 1986; Clochiatii 1990; Grapes and Müller-Sigmund 2009; Martin Crespo et al. 2009; Carter et al. 2010b).

Although a fulgurite specimen that may be as old as 15 ky was collected in the Libyan Desert (Navarro-Gonzalez et al. 2007), fulgurite materials are typically geologically young and are sometimes collected within days of formation. They commonly contain non-melted precursor minerals cemented into the fulgurite glass. Shock, while proposed to occur in association with fulgurites, remains controversial, since fulgurites typically do not contain high-pressure SiO2 polymorphs or quartz exhibiting planar deformation features. However, there is some evidence...