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Thermo-chemical reactions of sedimentary rocks from Mt. Etna volcano: implications for flank instability

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In volcanic regions, the mechanical, physical and chemical properties of rocks under high temperature and pressure, are crucial for the accurate modelling of routinely monitored data (e.g. ground deformation, seismicity, gas emission) and the calibration of damage-mechanics criteria for the weakening of volcanic edifices.

Mt. Etna (Sicily, Italy) is the largest volcano in Europe, and one of the most active on Earth. Its volcanic edifice is 1200-km2-wide and 3300-m-high, made up of a pile of lava flows above a thick sedimentary sequence. In particular cycles of hazardous flank eruptions occurred in the recent years, preceded by intense seismic activity and high rates of ground deformation, eventually leading to abrupt opening of eruptive fracture systems in the eastern flank. Consequently, basaltic rocks of Mt. Etna volcano have been the subject of a number of experimental studies in recent years, with the aim to determine the mechanical parameters needed for ground deformation and seismicity modelling, as well as for the modelling of the weakening mechanisms destabilising the volcano eastern sector.

However, reconstructions of the sub-volcanic morphology show that only ~373 km3 of the bulk total volume of ~1400 km3 of the edifice at Mt. Etna and its substratum is comprised of volcanics. The rest comprise a laterally-extensive culmination of sedimentary rocks that reach a vertical thickness of about 2 km in the central portion of the edifice.

No data are available to assess the influence of such magmatic activity on the thermal weakening of the sedimentary rocks that mainly constitute the volcanic edifice.

Here therefore we report results from an experimental study of the influence of temperature on the mechanical, physical and chemical properties of representative volcanic and sedimentary rocks that comprise the edifice of Mt. Etna.

Two basaltic lavas and a marly limestone representative of the volcanic and of the substratum sedimentary rocks at Mt. Etna were heated at 760 and 800 °C and loaded to failure in a uniaxial apparatus; seismic velocity of these rock samples were also recorded in-situ.

For the two lavas, the variations of uniaxial compressive strength (UCS) and P-wave velocity did not change significantly increasing temperature up to 800 °C from ~ 165 and 105 MPa and ~ 3.2 and 4.1 km/s. In contrast, the UCS and P-wave velocity of the marly limestone drastically decreased from 167 to 89 MPa and 5.45 to 4.16 km/s respectively upon increasing sample temperature from 25 to 760 °C; Back scattered SEM images, XRPD data and TG analyses reveal that this observed thermal weakening is the result of two thermo-chemical transformations: i) at temperatures below 600 °C, clay dehydroxylation causes the collapse of kaolinite crystal structure; ii) at temperatures above 600 °C, calcite initiates its dissolution, releasing CO_2 and forming new CaO-bearing minerals.

Our results provide evidence that thermal weakening controls the changes of rock strength and physical properties for the sedimentary terms. This implies that even relatively low temperatures can promote failure or reactivate slip surfaces, responsible for instability processes.