Change of crackling noise in granite by thermal damage: Monitoring nuclear waste deposits

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ABSTRACT

High-sensitivity detection of acoustic emission from granite under uniaxial stress, together with advanced statistical analysis, shows changing collapse mechanisms when a sample is pre-heated. Massive microstructural changes occur at temperatures >500 °C while low-temperature (<<500 °C) treatment leads to scale invariant crackling noise with a mixed fix-point behavior. After treatment at higher temperatures, the collapse occurs via acoustic signals that show energy distributions with systematic deviations from the Gutenberg-Richter law while the Omori’s and Båth’s laws are not influenced by the thermal treatment. The granite samples stem from the site in the Beishan mountains where a new burial site for nuclear waste will be constructed. According to the 13th Five-Year Plan of the P.R. China, Chinese nuclear power installed capacity will reach 58 million kilowatts in 2020 and produce about 3200 tons of high-level nuclear waste every year. Monitoring the stability of the host rock at high temperatures becomes hence a key issue. Our analysis can serve as a blueprint for a protocol for continuous monitoring of the burial site.

Keywords: Crackling noise, granite, thermal damage, acoustic emission

INTRODUCTION

Mechanical and thermal damage of brittle matrix rocks is a key issue for nuclear waste disposal engineering. During the operation of a repository, the high-level radioactive waste will release heat continually. Constrained thermal expansion of the rock induces stresses, which modify the pre-existing stress field and could affect the long-term stability of a depository. The heat generated from high-level radioactive decay can aggravate rock stresses (Zhao et al. 2018). Additionally, new disposal techniques at very great depth (near 800 °C) to generate a substantial zone of partial melting in the granite surrounding the containers. As the heat output of the waste decreases, the melt slowly cools and recrystallizes to seal the packages into a sarcophagus of solid granite surrounded by zones of thermal metamorphism in which any pre-existing fractures are sealed by annealing and low-temperature hydration mineralization (Fergus and Philip 2013). Consequently, as discussed by a U.S. Geological Survey report (Bredehoeft et al. 1978), the thermal problem is an important factor in nuclear waste disposal. During the past three decades, many studies covered the mechanical behavior of rocks, few related to heating to high temperatures (Sethna et al. 2001; Castillo-Villa et al. 2013; Salje and Dahmen 2014; Soprunyuk et al. 2017). The Chinese development plan has foreseen to store nuclear waste in Beishan granite in the Gansu Province. This remote locality was chosen because of its low permeability and high mechanical integrity. A key element for the suitability of this granite for the final deposition depends largely on its mechanical stability. A central issue is the uniaxial compressive strength, and elastic moduli of granite and its component minerals (Davidsen et al. 2007; Nataf et al. 2014a, 2014b). Furthermore, it is desirable to measure changes in the tectonic environment after the underground facilities are built. In this study, we identify acoustic emission (AE) for the detection of crackling noise as a preferred, highly sensitive surveillance method.

Crackling noise as a manifestation of mechanical avalanches is widely studied in porous materials and in natural earthquakes (Sethna et al. 2001; Castillo-Villa et al. 2013; Salje and Dahmen 2014; Soprunyuk et al. 2017). Critical distributions (power-law or double power-law) of energies, aftershocks, and waiting times (Davidsen et al. 2007; Nataf et al. 2014a, 2014b; Ribeiro et al. 2015) have been reported from lab-quake experiments (Baró et al. 2013) in minerals and man-made materials (Salje et al. 2011, 2013; Castillo-Villa et al. 2013; Nataf et al. 2014a, 2014b; Soto-Parra et al. 2015) using the acoustic emission detection as an experimental tool. AE activity typically increases near stress collapse (Byerlee 1978; Mansuruv 1994), confirmed by discrete element simulation of porous materials (Kun et al. 2013, 2014).