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Granite Fracture Initiation and Growth: Petrographic Evidence of Hydrothermal Alteration

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Abstract

Granite contains biotites that have undergone varied degrees of modification. In order to determine the origin and progression of granite fractures, this study examines the correlations among alteration markers, areal microvoid fractions in chloritized biotite, and macroscopic fracture frequencies in the Toki granite, central Japan. Understanding potential hydrogeological applications can help with proper characterizations of the frequency distribution of macroscopic fractures in granite, which supports safety assessments for geological disposal and storage. To collect samples for the analysis, 191 m of borehole 06MI03 were bored. A total of 24 samples that showed variations in the frequency of macroscopic fractures were chosen. The amount of hydrothermal alteration and the frequency of fractures inside granites are to be assessed utilising novel approaches such as biotite chloritization and petrographic alteration indicators [1]. The ratio of the alteration product area to the original mineral area is known as the alteration indicators. Additionally, through image analysis, the area fraction of microvoids in minerals was used to quantitatively define the volume of microscopic fractures and micropores in the mineral. Samples with high areal microvoid fractions and large alteration markers also have significant macroscopic fracture frequencies. Macroscopic fractures are caused by microvoids, which form at temperatures between 350 and 780°C. Alteration markers and other intrinsic characteristics can be used to assess microvoids. Later faulting and unloading (extrinsic processes) transformed microscopic fractures into macroscopic ones. The characterization of the existing and future distributions of macroscopic fracture frequencies depends on intrinsic parameters, which are utilised to determine the origin of macroscopic fractures [2].

Keywords: Granite; Chloritized biotite; Microvoid; Cathodoluminescence

Introduction

Several nations are now conducting analyses of the viability of storing natural gas and oil in crystalline (granitic) rocks for geological nuclear waste disposal (e.g., Sweden, Finland, and Japan). High-level nuclear waste must be completely isolated from above-ground human society for the time when it will be characterised by harmful radiation levels in order to be disposed of geologically. Oil and gas must be immobilised within the chamber of the granitic rock mass in geological storage until their utilisation. Evaluations of the safety of geological disposal and storage are aided by mass transfer characterisation in granite. Granitic rocks in an orogenic region, like the Japan Arc, invariably develop cracks and minor faults that serve as channels for fluid flow and the transportation of contaminants. Therefore, proper fracture distribution, frequency, and network characterisation are needed for hydrogeological applications of granite. To gain knowledge of fracture features, it is appropriate to analyse the petrography of a granitic rock mass. Based on polarised light microscopy and cathodoluminescence pictures, the distribution of open microfractures in granitic materials was characterised in a prior work on the investigation of fracture distribution. Mazurek demonstrated that variations in the rock facies affect the frequency of fractures in granite [3]. According to Chigira, the grainsize of the constituent minerals is associated with the spacing of micro-sheeting. Although Mazurek and Chigira showed a connection between granite petrography and fracture frequency, these investigations did not go into detail about how granite fractures form and develop. In order to effectively characterise the fracture frequency distribution, the Mizunami Underground Research Laboratory (MURL) in central Japan is used as an example in this study to demonstrate a new petrological method to assess the degree of hydrothermal alteration.

In this work, macroscopic fractures are defined as large-scale fractures seen in borehole television (BTV) data that contribute to rapid mass transport inside the granite. The combination of intrinsic factors related to thermal stress and external factors related to tectonic faulting and unloading results in macroscopic fractures in granites. The characterizations of petrography provided by Mazurek and Chigira match intrinsic characteristics. During the cooling of a pluton, differential contraction causes thermal stress. Based on a thermo-mechanical stress study and the assumption of two-dimensional conductive cooling, Bergbauer and Martel estimated thermal stress for the Lake Edison Granodiorite in California [4]. The most compressive thermal stress trajectories within the pluton were modelled with orientations that were compatible with the striking of the macroscopic fractures, indicating that thermal stress may play a role in the development of fractures in a pluton. The local cooling indicator (LCI) and the thermochronological evaluation are the metrics that are used to evaluate the fracture distribution since they represent the thermal stress within granite. The formation of sub-solidus reaction textures, which take place during cooling during the exsolution (690–780°C) and deuteric (below 500°C) stages, is used to determine the LCI. The thermochronological evaluation is in accordance with the temperature range between crystallization/solidification (about 780°C) and biotite K-Ar closure (350–400°C) [5-7].

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Materials and Methods

Ethics statement

In 2015, we were given approval by the Lixian Forestry Bureau to gather the testing soil in a nearby forest. Because only a small number of soil samples were used in this study's microcosm experiment, our work had little impact on how the larger ecosystem functioned. The laws of the People's Republic of China were also followed in the conduct of this investigation. No measurements of people or animals were used in the research, and no endangered or protected plant species were used [8].

Experimental design

At the Long-term Research Station of Alpine Forest Ecosystems (31°18′N, 102°56′E, 3023 m a.s.l., Southwest China), 20 kg or so of tested soil was collected in October 2015. Using a soil auger with a 15 cm depth and 5 cm diameter, earth was extracted from five forest plots (2 m 2 m in size) and combined after being cleared of all visible trash and new litter. According to the IUSS Working Group WRB, the soil type was a Cambic Umbrisol, and the basic soil chemical characteristics (0–15 cm depth) were as follows: pH 6.5 0.3, bulk density of the soil 1.04 0.11 g kg-1, total organic carbon 153.9 27.4 g kg-1, total nitrogen 7.8 1.3 g kg-1, and phosphorus 0.9 0.1 g kg-1 are all acceptable values. After being sieved (2 mm), the collected soil was combined. To prepare the samples for the soil microcosm experiment, stones, obvious animal and plant remains, and live macrofuana (such as earthworms and millipedes) were removed [9].

Soil incubation and respiration measurement

45 microcosms (40 soil microcosms and 5 blanks) were divided into a control group and a treatment group for the microcosms. At the start of the trial, the treatment group was given 0.35 g of naphthalene per bottle. A control group was the other group (without naphthalene). 52 days were required for the soil to incubate, and two more 0.35 g applications of naphthalene were made on days 17 and 38. In line with field application rates, the overall application rate (100 g m-2).

For three weeks, the rate of soil microbial respiration was allowed to stabilise. Plastic vials (8 cm height x 10 cm i.d.) holding 20 ml of 0.01 N NaOH were put into culture bottles prior to the incubation. After the incubation, the culture bottles were sealed and kept in temperature-controlled biochemical incubators at 10°C and 45% moisture. The temperature and moisture of the culture agreed with the findings of our earlier field monitoring. By measuring the carbon dioxide (CO2) generation over the course of 52 days while adhering to the sampling schedule, the soil microbial respiration rate in each culture bottle was calculated. Titration with 0.02 N HC1 was used to measure the amount of CO2 produced after adding 1 ml of 1 N BaCl. As a control, empty bottles without soil were used [10].

Data calculation and statistical analyses

The change in NH4+-N (ammonium), nitrate (NO3—N), and inorganic N (NH4+-N + NO3—N) contents in the microcosms between the start and conclusion of the incubation was used to determine the net ammonification, nitrification, and inorganic N mineralization at the end of the incubation (52 days). Additionally, data were calculated as the differences in the average values of the measured variables between the naphthalene treatments and the controls for the entire incubation time in order to quantify the impact of naphthalene addition on soil biochemical characteristics [11].

Student's independent-sample t-test was performed to compare the outcomes of naphthalene application at particular sampling times. To examine the effects of naphthalene administration, sampling time, and their interactions on the observed variables, we utilised repeated measures analysis of variance (ANOVA). For all analyses, differences were deemed significant at the P 0.05 level. Using the Windows version of the SPSS 18.0 software package, all statistical analyses were carried out [12].

Results

Markers of change for biotite chloritization

The biotite chloritization indicator's mean values (N = 24: S2 and S3 Tables) range from 0.13 to 0.74. The biotite chloritization alteration indicator in sample No. 1 had a mean of 0.33 and a standard deviation of 0.12 in the control experiment with samples No. 1 and 7. The average for Sample No. 7 was 0.22, and the standard deviation was 0.08. Sample No. 1's standard deviation range and Sample No. 7's standard deviation range overlap. This implies the usefulness of the indicators and technique when assessing the level of hydrothermal alteration in a rock sample because two distinct samples obtained from the same depth range show similar alteration indicator values [13].

Microvoid area fractions in the chloritized biotites

In the chloritized biotites, the mean values for the areal fractions of microvoids vary from 0.02 to 0.11 (N = 24: S2 and S4 Tables). The mean areal fractions of microvoids in sample No. 1 in the control experiment with samples No. 1 and 7 had a mean of 0.08 and a standard deviation of 0.03 The average value for Sample No. 7 was 0.06 with a standard deviation of 0.02 Samples No. 1 and 7 have a standard deviation range, indicating that they both reflect similar areal fractions of microvoids [14].

Conclusions

In conclusion, by introducing naphthalene to subalpine forest soil, this microcosm experiment investigated the nontarget impacts of naphthalene on soil microbial activity and soil nutrients. According to our findings, adding naphthalene to subalpine soils can act as an external C source for soil microbial respiration. According to the statistical studies, the application of naphthalene had no overall negative effects on soil microbial PLFA abundances and biomasses or the majority of enzyme activity over the entire incubation period. Overall, the microcosms showed that naphthalene administration seems to boost fungal abundance while having the reverse effect on bacterial abundance. Contrary to the net immobilisation result of the controls, the biocide application reduced increases in DON, NH4+-N, and NO3—N contents as well as urease activity and caused inorganic N (NH4+-N + NO3—N) net mineralization. Therefore, when administering naphthalene to soil animals in a field experiment in subalpine forests, nontarget impacts on the processes of soil nitrogen mineralization may happen. When employing naphthalene to deter soil animals in field research, care should be given when attributing any changes in soil processes. It should be noted that aboveground vegetation does not absorb or change much in microcosms, therefore it is important to investigate whether this non-target impact occurs naturally. Ecosystem types, soil properties, soil-plant transformations, soil organism diversity, and other aspects of the soil biochemical cycle need to be taken into account in order to better predict the potential nontarget effects of naphthalene application on soil biochemical properties in different ecosystems.

Acknowledgement

None

Conflict of Interest

None

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