TRACKING MICRO-FRACTURE AND VOID CONNECTIVITY IN GEOTHERMAL HOST ROCKS USING SCANNING ELECTRON MICROSCOPY

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ABSTRACT

Scanning Electron Microscopy (SEM) was used to examine the characteristics of micro-fractures and voids, their dimensions, quantity and connectivity, in core recovered from two geothermal fields, referred to as A and B, located in the Taupo Volcanic Zone, New Zealand. SEM observations revealed significant variation in void structure exists between; (1) host rocks of the same lithologic unit, even over small depth intervals of <7 m, and (2) different lithologic units. In geothermal field A, void dimensions and micro-fracture connectivity increases with depth, while in geothermal field B, void dimensions and micro-fracture networks decrease with depth. The structure of voids control a rocks ability to transmit or store fluid, therefore it is important to understand site specific controls on permeability.

1. INTRODUCTION

Production and injection wells within geothermal fields around the world are dependent on good permeability to both extract and inject fluids. Permeability can be influenced by many different controls such as faults (Faulds et al., 2006; Moeck, 2014; Siler and Hinz, 2014), fractures (Wood et al., 2001) or lithologic units (Studt, 1958; Bignall et al., 2010). Whatever the process, connected voids are necessary to create permeable channels. Geothermal host rocks also experience hydrothermal alteration which may alter their permeability characteristics (Browne, 1970; Younker et al., 1982). For example, hydrothermal alteration of primary minerals to secondary minerals may alter the host rocks primary porosity, resulting in an increase in voids due to dissolution or a decrease in voids due to mineral deposition.

It is the structure of voids within host rocks that control the rocks ability to transmit or store fluid. Voids are any open space such as micro-fractures or discrete cavities. Voids may be connected, rare or abundant and their distribution, dimensions and connectivity influence a rocks permeability. For a permeable channel to exist, voids must be connected.

In our study, we used Scanning Electron Microscopy (SEM) to examine the structure of voids present in geothermal host rocks from two injection wells from different geothermal fields in New Zealand, referred to as geothermal fields A and B.

2. METHODS

Scanning Electron Microscopy (SEM) was used to examine the structure of voids within cored samples from two geothermal fields. Samples were mounted on aluminum stubs and coated with platinum using a high-resolution Polaron SC7640 sputter coater. Samples were examined using a Phillips (FEI) XL30S field emission gun at an accelerating voltage of 20 keV, spot size of 3 and a working distance of 10 mm.

3. RESULTS

Eight cored samples from geothermal field A and four cored samples from geothermal field B were chosen to better understand the controls on permeability in specific wells at a particular depth range of interest, within two different geothermal fields. Both sample sets cover a <7 m depth interval.

Samples from geothermal field A consist of andesite between 1871 and 1876 m depth. These samples show an increase in hydrothermal alteration with depth. Sample numbers correspond to increasing depth. For example, sample 2 is at 1871 m while sample 9 is at 1876 m (Fig. 1A).

All four samples from geothermal field B are tonalite from the depth interval of 3200.1 to 3206.9 m. The tonalite samples reveal a range of hydrothermal alteration that decreases with depth. Samples A, B, C and D represent tonalite as depth increases (Fig. 1B).

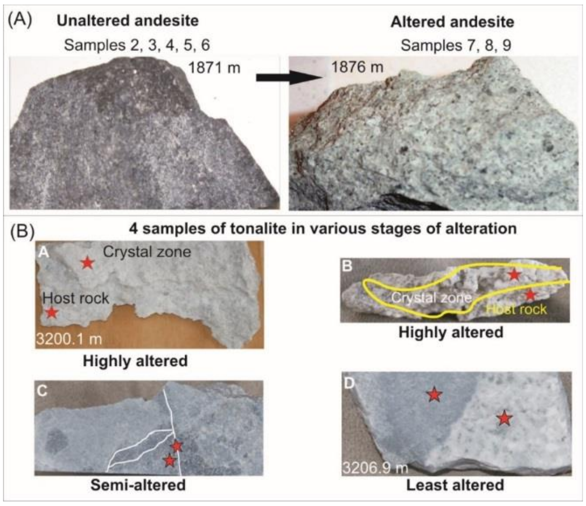

Figure 1: Hand specimen photographs of cored samples. (A) Geothermal field A. Samples representing the five unaltered andesite samples and the three altered andesite samples. (B) Geothermal field B. Four samples of tonalite in various stages of alteration. Red stars indicate location of SEM analyses. Sample depth increases from A to D (3200.1 to 3206.9 m).

3.1 Geothermal Field A: Void and micro-fracture structure

Andesite samples show a wide range of void dimensions from minimal voids in the unaltered andesite (samples 2-6) to a moderate amount of voids in the altered andesite (samples 7-9; Fig. 2). Within the altered andesite, void size increases with depth from 20 to 40 µm long. Minimal inter-connectivity of individual voids occurs as most voids remain isolated within the altered andesite.

Within the andesite samples micro-fracture dimensions increase with depth (Fig. 3A). With the exception of sample 4, all other samples show continuous micro-fractures, at least over small distances. The width and length of the micro-fractures increase significantly with depth, from 7-10 µm x 0.5 µm in the unaltered andesite, to 200 µm x 60 µm in the deepest altered andesite (i.e., sample 9). The quantity and length of connected micro-fractures also increases significantly with depth (Fig. 3B).

In summary, the altered andesite revealed significantly larger voids, wider and longer micro-fractures and an increased number of inter-connected fracture networks, than the unaltered andesite.

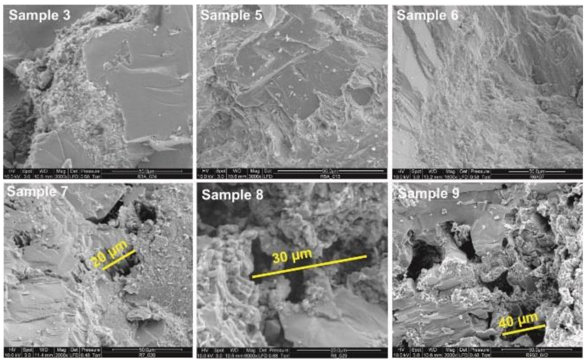

Figure 2: Host rock from geothermal field A shows an increase in void size with depth.

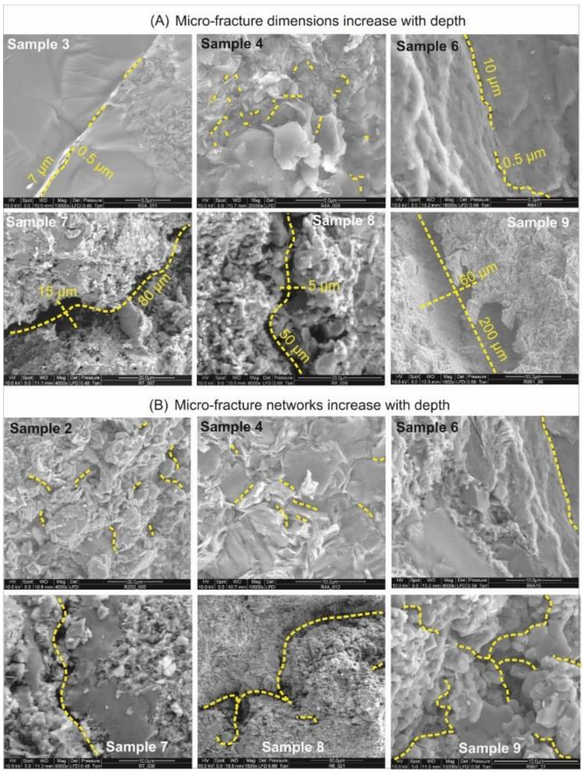

Figure 3: Host rock from geothermal field A. (A) Micro-fracture dimensions increase with depth. (B) Micro-fracture networks increase with depth.

3.2 Geothermal Field B: Void and micro-fracture structure

The tonalite host rock samples revealed void size decreases with depth (Fig. 4). Highly-altered tonalite samples A and B reveal isolated voids up to 15 µm x 10 µm, while the semi-altered tonalite sample C and unaltered tonalite sample D, reveal no voids.

Within the crystal-rich horizons of the highly-altered tonalite samples, voids are inter-connected and reach up to 1.2 mm long x 700 µm wide (Fig. 4). Within the micro-fracture of sample C, voids are contained within large anhydrite crystals and do not penetrate into the matrix (Fig. 4).

In the tonalite host rock samples, connected void networks decrease with depth (Fig. 5). The highly-altered tonalite host rock (samples A and B) reveal connected porous networks, while the semi-altered and least altered tonalite samples do not display such networks (samples C and D respectively). The crystal-rich zones in the highly-altered tonalite (samples A and B) reveal connected micro-fractures up to 3 mm in length. Semi-altered tonalite sample C has a >1 mm long continuous fracture.

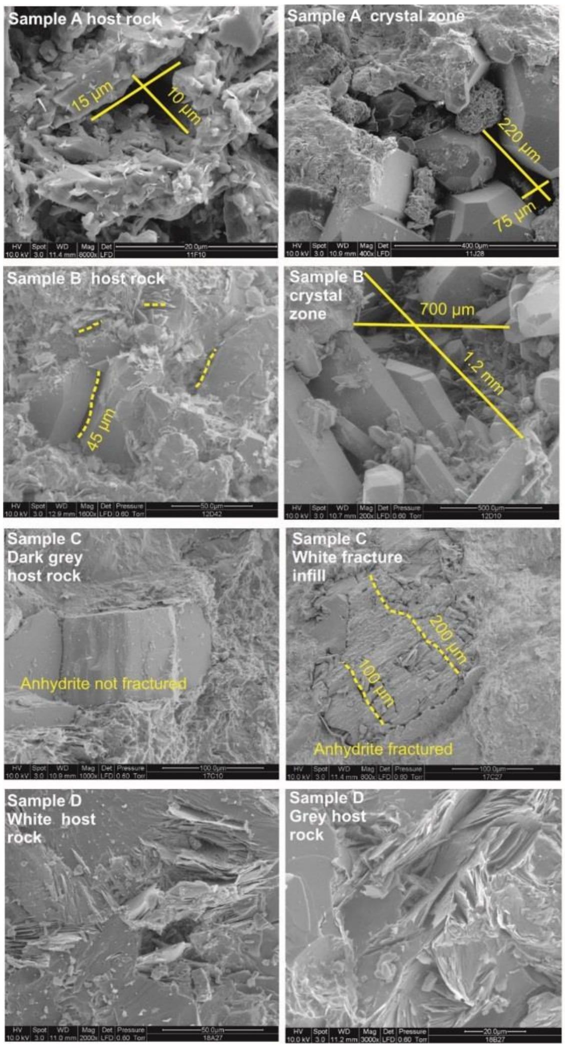

Figure 4: Host rocks from geothermal field B show a decrease in void size with depth. Sample depth increases from A to D (3200.1 to 3206.9 m).

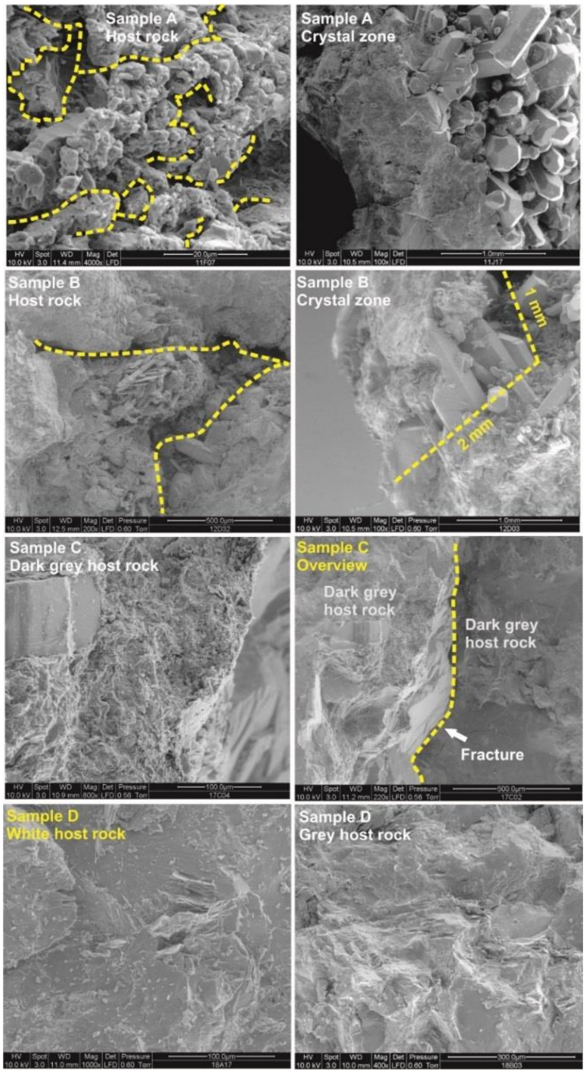

Figure 5: Host rocks, geothermal field B. Connected void network dimensions and void quantity decreases with depth. Sample depth increases from A to D (3200.1 to 3206.9 m).

3.3 Comparison of void structure in host rocks from geothermal fields A and B

Andesite host rock samples from geothermal field A and tonalite host rock samples from geothermal field B display significantly differences in their void structure as depth increases (Fig. 6). In geothermal field A, clay infills micro-fractures in the shallower samples (sample 2), while the deeper samples show minimal clay infilling voids (sample 9). Geothermal field B shows the reverse where extensive clay alteration has occurred in the shallower samples (sample A), but the clay does not infill the voids. However, the deeper tonalite host rock sample reveals voids almost completely infilled with clays (sample D).

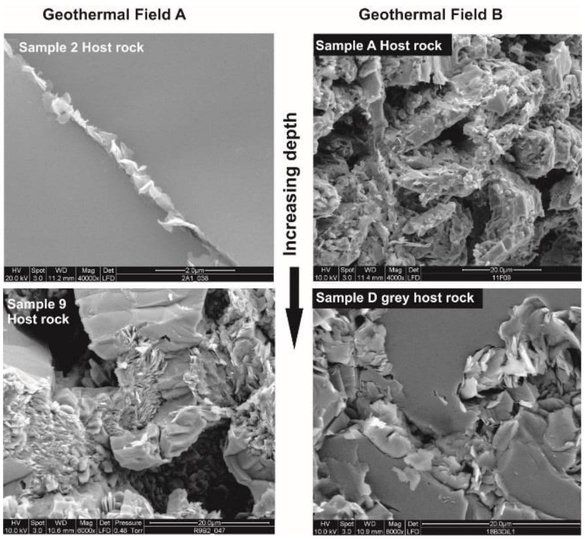

Figure 6: Comparison of void dimensions and hydrothermal alteration processes in andesite host rock samples 2 and 9 from geothermal field A (left) and tonalite host rock samples A and D from geothermal field B (right).

4. DISCUSSION

Permeability is a key factor in sustainable use of our geothermal fields. Sustainability of geothermal production wells is extremely important as drilling new wells is expensive. Sometimes well manipulation takes place to increase well productivity (e.g., acid dosing). If possible, it is better to increase the life span of existing production wells, but to do this a thorough understanding of permeability controls is required. Careful management of injection wells is also necessary to prevent problematic issues such as thermal break-through. This study shows how SEM can help better understand controls on permeability by assessing the structure of voids and micro-fractures, their connectivity and their influence on a host rocks ability to store or transmit fluid.

Samples from the two geothermal fields examined show site specific void structure and micro-fracture networks occur within their associated host rocks. Andesites in geothermal field A revealed an increase in connected permeable pathways as depth increases. However, the tonalite samples from geothermal field B show a decrease in connected permeable pathways with depth. Also, void dimensions increase with depth in the andesite host rocks, but decrease with depth in the tonalite host rocks. These differences highlight the importance of examining specific “depth intervals of interest” to understand controls on permeability, as they can differ widely between geothermal fields. Our study also shows that over a distance of <7 m, void and micro-fracture network dimensions, connectivity, and distribution can differ significantly even within the same lithologic unit. These subtle differences in fluid-rock interaction may have large consequences for permeability and on-going sustainability of our production and injection wells. These examples show how tracking void structure, dimensions and connectivity enables an easy assessment of the potential permeability at any given depth interval.

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