SCANNING ELECTRON MICROSCOPY AND COMPRESSIBILITY MEASUREMENTS: A DUAL APPROACH PROVIDING INSIGHTS INTO HYDROTHERMAL ALTERATION AND ROCK STRENGTH AT TAUHARA GEOTHERMAL FIELD, NEW ZEALAND.

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ABSTRACT

Scanning Electron Microscopy (SEM) enables micro-scale 3D imaging of rock constituents. This provides unique information about the complexity of subsurface environmental conditions and fluid-rock interactions within geothermal fields. These dynamic thermal environments drive chemical and physical changes within rock units altering their physical properties, such as porosity and compressibility. Core recovered from drilling within the Tauhara geothermal field, Taupo Volcanic Zone, New Zealand has been characterized using multiple techniques. Core was recovered as part of a subsidence study to specifically identify soft and hard horizons at depth, in an effort to determine the cause of local subsidence bowls. Analytical techniques included X-Ray Diffraction (XRD) and petrographic microscopy to identify the mineralogy, as well as a range of geotechnical techniques to determine rock compressibility. It was SEM imaging that provided a window into the complex nature of these subsurface environments and identified processes driving the physio-chemical conditions acting on and either hardening or softening rocks at specific depths. As geothermal environments are constantly changing and each environment leaves a footprint which is preserved within the rock, SEM can be used to track these changes placing them in a spatial and temporal context. SEM 3D imaging compliments 2D petrographic examination and other standard analytical methods traditionally used to determine rock mineralogy and physical properties.

1. INTRODUCTION

Cored samples were recovered from drillholes in the Tauhara geothermal field, Taupo Volcanic Zone, New Zealand as part of a wider study to investigate the nature of subsidence within the area. Drillholes were located inside, on the margins and outside known subsidence bowls (Fig. 1). This allowed direct comparison of the compressibility of the same stratigraphic unit identified in each drillhole, in an effort to understand the formation of localized subsidence bowls.

Multiple geotechnical tests were performed on each cored sample to evaluate the strength and compressibility of the various rock units encountered. Geotechnical tests on the soil-like material recovered included; pocket penetrometer, shear vane, stiffness, Atterberg limit and compressibility tests. The strength of the rock-like cores was indicated by point load testing and the compressibility was obtained from the constrained modulus measured in K_o triaxial testing (Pender, 1996), on selected cores. The mineralogy and physical properties of the cored samples were characterized using XRD, density and porosity measurements and petrographic microscopy. The combination of these multiple techniques is commonly used to characterize stratigraphic units. However, it was the addition of SEM that illuminated the complexity of the geothermal subsurface environmental processes altering and weakening the subsurface rock units. These processes were not evident using standard analytical techniques. SEM imagery was critical in evaluating subsurface processes, their impact on rock compressibility and placing the various subsurface processes into a spatial and temporal context.

There are several published reports where SEM has been used to examine the finer-scale detail of rocks in compressibility studies. For example, SEM has been used to observe thermally induced micro-cracking in granites (Homand-Etienne and Houpert, 1989), and to investigate lithological or architectural changes that may have occurred in carbonates after compressibility testing had taken place (Carles and Lapointe, 2004).

The dual technique approach of SEM and compressibility testing is highly applicable to all geothermal systems as subsidence is a common problem. Micro-scale SEM observations combined with rock strength testing provides insights into subsurface processes affecting rock compressibility, which in turn, could influence subsidence susceptibility. The dual approach links qualitative results (SEM observations) with quantitative data (compressibility values). This study is the first to directly compare SEM observations with compressibility values of cored rock from within a geothermal field where subsidence is known.

2. RESULTS

Samples from four drillholes at Tauhara were examined in this study. Drillholes THM 13 and THM 14 are located outside the subsidence bowls. Drillhole THM 12 was drilled on the margin of the Rakanui bowl and THM 16 is located inside the Crown Road bowl (Fig. 1). Some of the stratigraphic units encountered during the Tauhara Subsidence Drilling Programme include the Taupo Ignimbrite, an eruption breccia, post-Oranui Formation, Oranui Formation, Upper, Mid and Lower Huka Falls Formations and the Waiora Formation. These units are described in detail in Rosenberg et al. (2009).

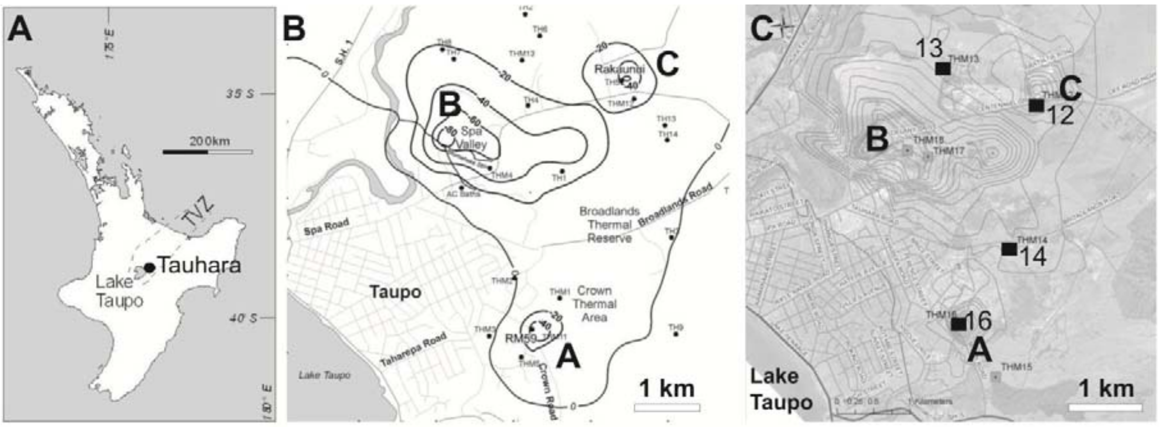

Figure 1: Location maps of Tauhara geothermal field and study sites, Taupo Volcanic Zone (TVZ), New Zealand. (A) North Island of New Zealand showing the location of Tauhara geothermal field within the TVZ. (B) Location of three subsidence bowls within Tauhara. A = Crown Rd bowl, B = Spa bowl, C = Rakanui bowl. (C) Location of cored drillholes from which samples in this study were analysed. Contour lines shown in (B) and (C) represent subsidence rates in mm/year. Numbers represent drillhole number. A = Crown Rd bowl, B = Spa bowl, C = Rakanui bowl.

2.1. Scanning electron microscopy, petrographic microscopy and compressibility testing

Presented within this paper are SEM images, petrographic microscopy images and constrained modulus values (CM) of cored samples from the Tauhara geothermal field. Petrography was used to identify the mineralogy. Constrained modulus values, the inverse of the compressibility, are given herein as they are more conveniently expressed than compressibility. Constrained modulus values typically ranged from 10 MPa (relatively compressible) to 2500 MPa (relatively incompressible) for the set of samples studied during the Tauhara programme. SEM was used to examine subsurface processes affecting both the mineralogy and overall rock compressibility. Each analytical technique was applied to the same sample so a direct comparison of results could be made.

Within drillhole THM 16 significant environmental changes were documented by SEM imagery in samples located only a vertical distance of 8 m apart (Fig. 2). At 22 m depth there is an unaltered pumice-rich horizon from the Taupo Ignimbrite Formation (Fig. 2A and B). However at 30 m depth this unit has been extensively altered as indicated by the dissolution textures observed by SEM (Fig. 2D). These textures are not visible by petrographic microscopy (Fig. 2C). It is this dissolution that accounts for the softening of the unit at 30 m depth (CM = 108 MPa) compared to the same unit at 22 m which has a higher CM of 294 MPa.

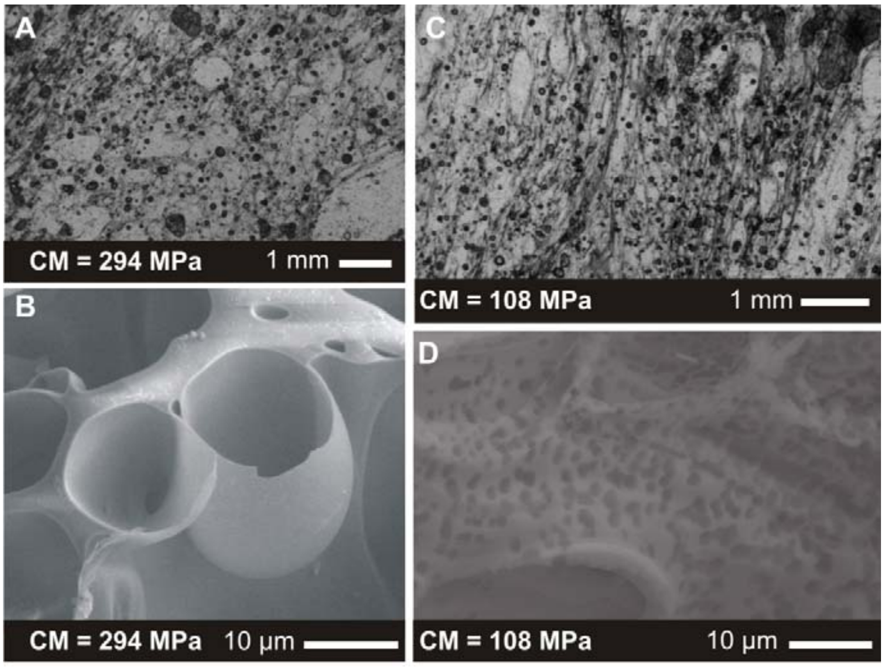

Figure 2: Taupo ignimbrite. Drillhole THM 16 inside a subsidence bowl. (A-B) Unaltered pumice-rich horizon at 22 m depth, CM = 294 MPa. (A) Thin section photomicrograph (dark spots = holes in slide). (B) SEM image. (C-D) Altered, pumice-rich horizon at 30 m depth, CM = 108 MPa. (C) Thin section photomicrograph (dark spots = holes in slide). (D) SEM image reveals extensive voids throughout the sample, a typical dissolution texture.

At 98 m depth in drillhole THM 16, within a hydrothermal eruption breccia, SEM revealed a decrease in the pH with time. This is indicated by the occurrence of illite and kaolinite, whereby kaolinite is observed resting on top of illite (Fig. 3A). Micro-environmental conditions for illite and kaolinite differ where a pH of 5 favours illite formation and a pH of 3 encourages kaolinite to form. This finer-scale detail is not visible using petrographic microscopy (Fig. 3B). The softening of rock via dissolution is encouraged under these corrosive acidic conditions and could contribute to compaction of this unit which is subsequently reflected by subsidence at the surface.

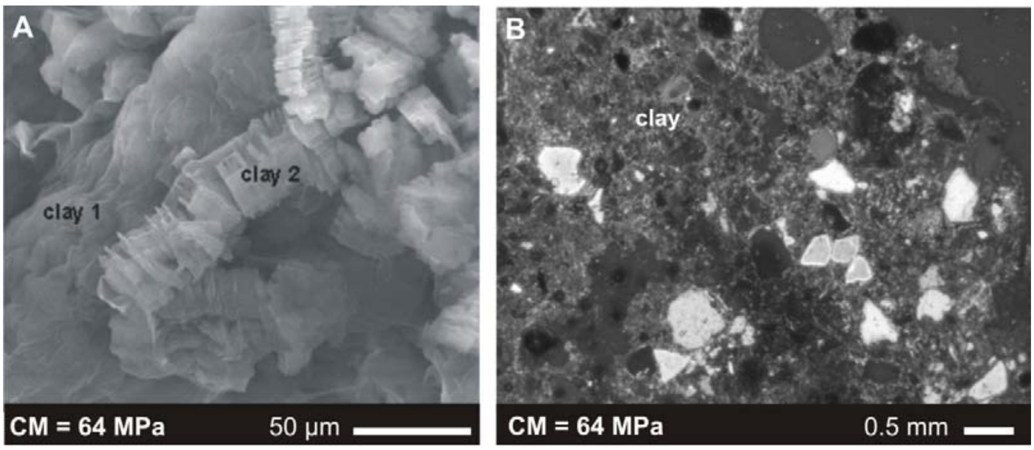

Figure 3: Hydrothermal eruption breccia. Drillhole THM 16, inside subsidence bowl at 98 m depth, CM = 64 MPa. (A) SEM image reveals the presence of two different clays. Clay 1 (illite) formed first and clay 2 (kaolinite) developed second and can be seen resting on top of the illite. The change from illite to kaolinite indicates a decrease in pH from around 5 to 3. (B) Thin section photomicrograph reveals crystals in a clay matrix but does not reveal the finer-scale illite-kaolinite relationship.

Petrography of the Oranui Formation (THM 13 at 89 m depth) reveals the unit to consist of lithic fragments and crystals in a clay matrix (Fig. 4A). SEM provided greater detail of this unit documenting the relationship between chlorite and lithic fragments (Fig. 4B). SEM clearly shows chlorite embedding a lithic fragment and the micro-scale detail whereby considerable voids can be seen between the chlorite coating and the lithic fragment creating space for subsequent compaction. These chlorite-fragment observations, which are not visible by petrographic microscopy, give useful insight into the potential nature of compaction in this formation.

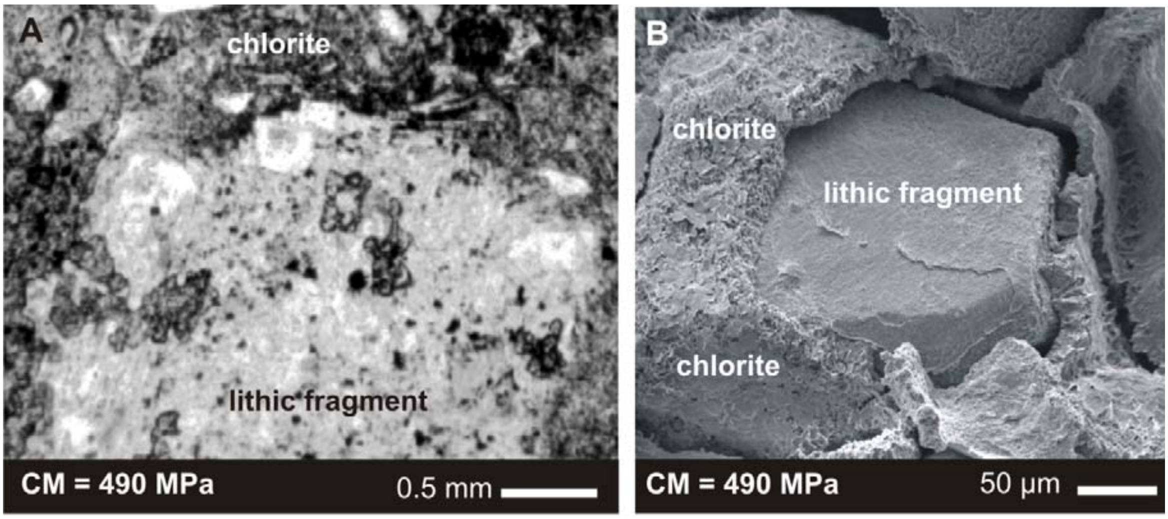

Figure 4: Oranui Formation. Drillhole THM 13, outside subsidence bowl at 89 m depth, CM = 490 MPa. (A) Thin section photomicrograph shows a lithic fragment with slightly degraded edges and surface, in a chlorite matrix. (B) SEM image reveals chlorite coating lithic fragment with voids between chlorite and fragment clearly visible and rough fragment surface.

Alteration of feldspars by illite clay is associated with low CM in samples from the Upper Huka Falls Formation, drilllhole THM 12, at 263 m depth. While petrographic microscopy revealed fracturing and etched edges of the primary feldspar crystals (Fig. 5A), it is SEM that showed the nature of the illite-feldspar alteration. SEM revealed illite attached to feldspar surfaces (Fig. 5B), reducing the amount of crystals present and increasing the clay content, which in turn, would decrease the overall hardness of the rock.

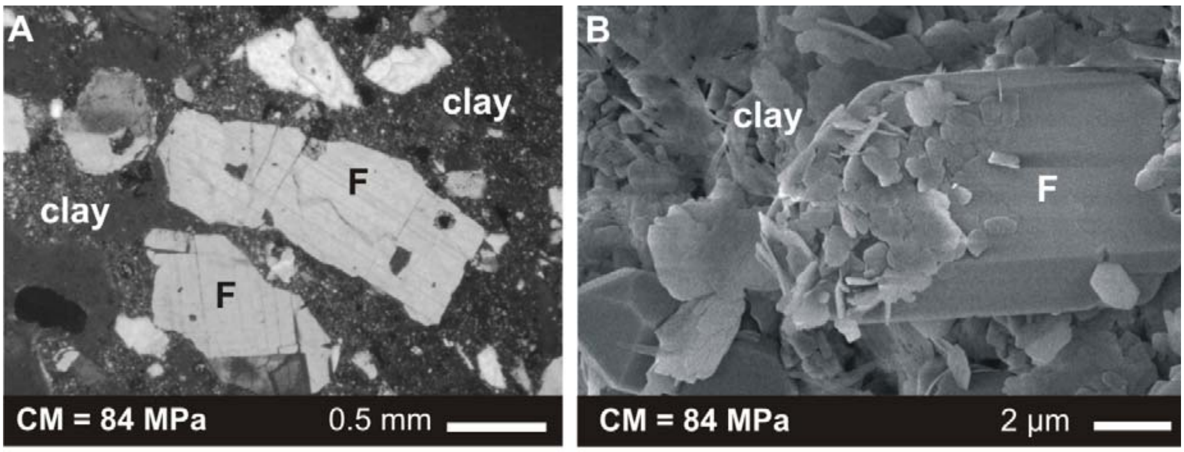

Figure 5: Upper Huka Falls Formation. Drillhole THM 12 on margin of subsidence bowl, 263 m depth, CM = 84 MPa. (A) Thin section photomicrograph shows fractured feldspar crystals (F) with etched edges in a clay matrix. (B) SEM image shows clay (illite) attached to the surface of a feldspar (F) crystal severely degrading the crystal.

Figure 6 shows the character of the Lower Huka Falls Formation in THM 13 at a depth of 411 m. Here, crystals and lithic fragments within a clay matrix maintain sharp edges suggesting minor degradation and the preservation of structural integrity (Fig. 6). This crystal structural integrity most likely accounts for the high CM value of 1730 MPa. In comparison, Figure 4 shows a lower CM value of 490 MPa and is associated with lithic fragments and crystals that revealed signs of the initiation of surface deterioration and degraded edges, while the crystals in Figure 5 show major degradation and a low CM value of 84 MPa.

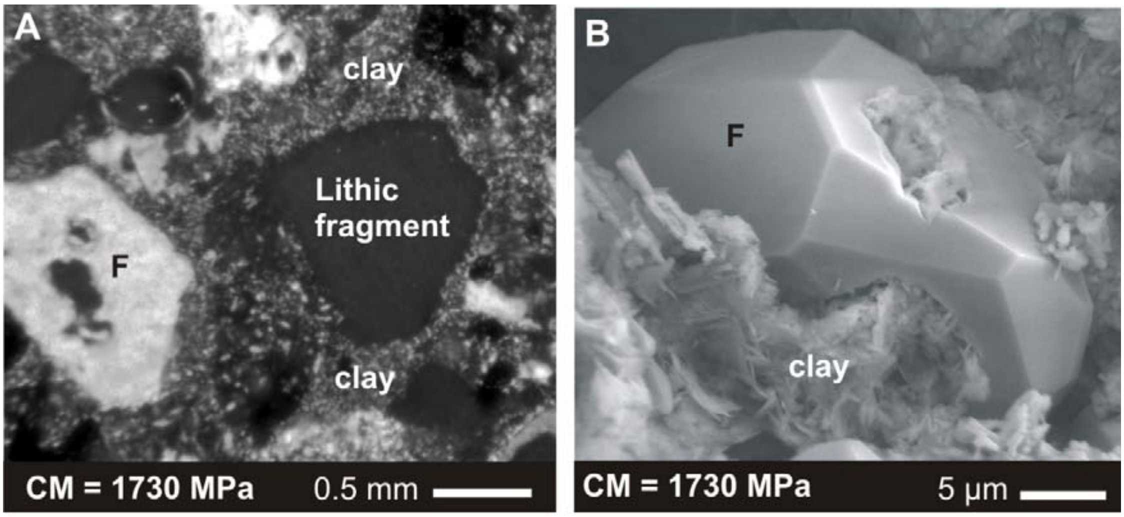

Figure 6: Lower Huka Falls Formation. Drillhole THM 13 outside subsidence bowl, 411 m depth, CM = 1730 MPa. (A) Thin section photomicrograph of feldspar crystal (F) and lithic fragment in a clay groundmass. (B) SEM image shows clay (illite) infilling cavity within a feldspar crystal (F) but crystal edges remain sharp and do not show signs of degradation.

3. CONCLUSION

SEM proves a useful method for unraveling complex geothermal environmental processes taking place in subsurface rocks. The fine-scale detail that SEM provides enables a better understanding of fluid-rock interactions and the processes driving the physio-chemical conditions acting on and altering rock units. SEM played a critical role in the investigation towards identifying micro-environmental conditions that could be softening the rock at depth and influencing the formation of subsidence bowls within the Tauhara geothermal field.

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