COMPUTERISED TOMOGRAPHY (CT) SCANNING OF CORE FROM TAUHARA GEOTHERMAL FIELD, NEW ZEALAND: A PILOT STUDY

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ABSTRACT

Computerized Tomography (CT) was used to scan core from the Tauhara geothermal field, Taupo Volcanic Zone, New Zealand. Six samples, representing the Mid and Lower Huka Falls Formation, Waiora Formation, Taupo Formation and the Crown Road Breccia were chosen for analysis. CT scans imaged individual 0.02 mm incremental slices, which provided a 3D image of the cored rock. CT imaging is sensitive to density changes, a property that readily changes in rocks as they undergo hydrothermal alteration. CT scanning has tracked zones of hydrothermal alteration within the Tauhara core and shown that even within one centimetre thick slices of rock, hydrothermal alteration and thermal fluid flow through a rock, is spatially patchy. This technique also enabled the mapping of void and fracture size, dimensions and connectivity. Scanning Electron Microscopy and petrographic microscopy provide supporting information for the CT scan observations.

1. INTRODUCTION

Computerized Tomography (CT) is a non-invasive technique that images density changes through a cross-sectional slice of an object. Since the early 1980's micro-CT scanners have been used to characterise rock properties (Elliot and Dover, 1982). Reviews of the various applications of CT scanning for rock characterisation can be found in the literature (Wellington and Vinegar, 1987, Kantzas, 1990; He, 1998; Akin and Kovscek, 2001; Withjack et al., 2003) and is summarised by Siddiqui and Sarker (2010). In summary, CT scanning has been used to: (1) qualitatively identify formation boundaries and lithology changes; (2) assess the condition of preserved cores; (3) depth matching by comparing CT scans with density logs; (4) estimating mineralogical composition; (5) measuring fracture volumes; and (6) evaluating rock heterogeneity. CT scanning has also been used to measure void structure and permeability (Pender et al., 2009) and in-situ water saturation and rock porosity (Dastan, 2006).

CT scanning is an excellent tool for identifying changes in rock density. As fluid-rock interaction occurs in geothermal host rocks, hydrothermal alteration of primary to secondary minerals takes place. Hydrothermal alteration of geothermal reservoir rocks usually results in an increase or decrease in the density of the primary minerals. Therefore CT scanning is a useful tool for detecting zones of hydrothermal alteration in geothermal reservoir host rocks.

CT scanning provided a broad-scale overview of sites where density changes occur within the samples. Petrographic microscopy shows microscale textures, while Scanning Electron Microscopy (SEM) images revealed detailed hydrothermal alteration processes specific to each sample. The combination of these techniques enabled a direct comparison of density variations relating to hydrothermal alteration processes.

For this study, six samples were selected from 4 different drillholes located within the Tauhara geothermal field (Fig. 1). Samples ranged in depth from 22 to 411 m and represent different lithologic units within the Tauhara geothermal system (Table 1).

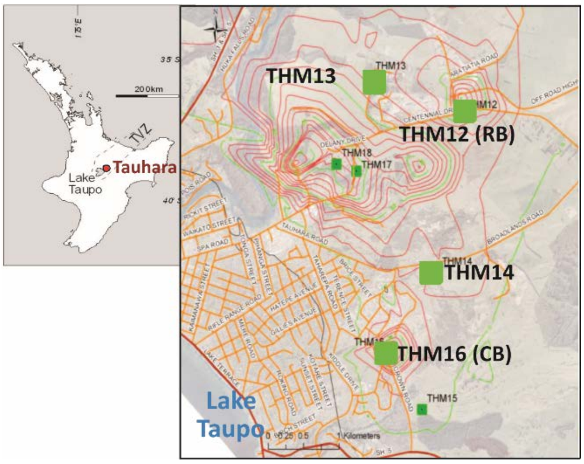

Figure 1: Location of cored drillholes (THM12, 13, 14, 16), Tauhara geothermal field, Taupo Volcanic Zone (TVZ), North Island, New Zealand.

Table 1: Drillhole, sample depths and Formation for samples used for CT scanning.

Drillhole	**Depth (m)**	**Stratigraphic Unit**	**Lithology**
THM 12	276	Mid Huka Falls	Pumice
THM 12	320	Mid Huka Falls	Breccia
THM 13	411	Lower Huka Falls	Lithic Tuff
THM 14	383	Waiora Formation	Lithic Tuff
THN 16	22	Taupo Formation	Pumice
THM 16	143	Crown Rd Breccia	Crystal Lithic Tuff

2. METHODS

2.1 Computerised Tomography

For the computerised tomography images, samples were scanned using a Skyscan 1172 µCT (Bruker-MicroCT, Kartuizersweg. 3B, 2550, Kontich, Belgium) at 50 kV, using a 0.5 mm aluminium filter at 17.25 µm per pixel resolution. Images were captured using a 10 megapixel, 12 bit digital, cooled CDD camera. Rotation step during data acquisition was 0.4 degrees, using a frame averaging of 2 and 180 degrees total rotation. Slice data reconstruction was performed with Skyscan's NRecon software (version 1.6.9.3). On the CT scans dark colours represent low density areas, light colours represent high density areas and black areas are voids.

2.2 Scanning Electron and Petrographic Microscopy

SEM sample preparation consisted of mounting a representative section of core onto an aluminum stub and powder coating it with platinum (10 nm coating thickness) for ~ 7 minutes at 10 mA using a high resolution Polaron SC7640 sputter coater. Samples were examined under the SEM using a Phillips (FEI) XL30S field emission gun. Operating conditions were 10 keV accelerating voltage, a spot size of 3 µm, and a working distance of 10 mm. Petrographic microscopy used standard petrographic thin sections.

3. RESULTS

3.1 Mapping voids

To assess the potential for fluid movement within a geothermal reservoir, we need to understand the structure and connectivity of voids and fractures within their host rocks. CT scanning of core from THM 12 at 276 m deep (Mid Huka Falls Formation) revealed large voids within the sample. However CT scanning shows that the same void changes its dimensions with depth of penetration into the sample. At 6.5 mm depth of penetration, Figure 2 reveals one large void, ~3 mm x 3 mm to the right of the cross-hairs and two smaller voids,~ 1 mm x 1 mm, below the cross-hairs. At 10.6 mm depth these voids are no longer present. Instead, one large, irregularly-shaped void occurs under the cross-hairs (~3 mm x 4 mm). By imaging individual slices we were able to map how the voids change in shape, size and depth, providing a better understanding of their structure and connectivity.

Secondary crystal growth into voids and open fractures is commonly associated with hydrothermal alteration of geothermal host rocks. Sample THM 13, at 411 m depth, shows the presence of crystals in cavities. These crystals have moderate density while the bulk of the rock has low density (Fig. 3A). SEM imaging of the same sample shows the presence of large crystals in voids surrounded by clay. The presence of crystals in voids surrounded by clay would create density variations in the rock at the micro-scale.

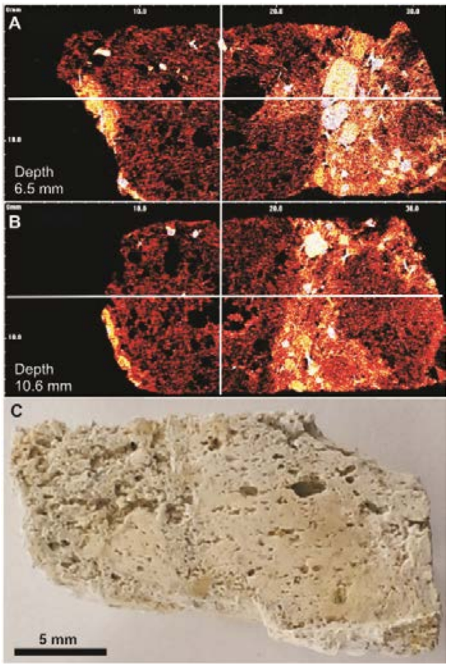

Figure 2: Void dimensions vary with depth. Black areas are voids. Sample THM 12, 276 m depth. Cross-hairs mark the same location on the sample but at 6.5 mm (A) and 10.6 mm depth of penetration (B). (C) Hand specimen photograph.

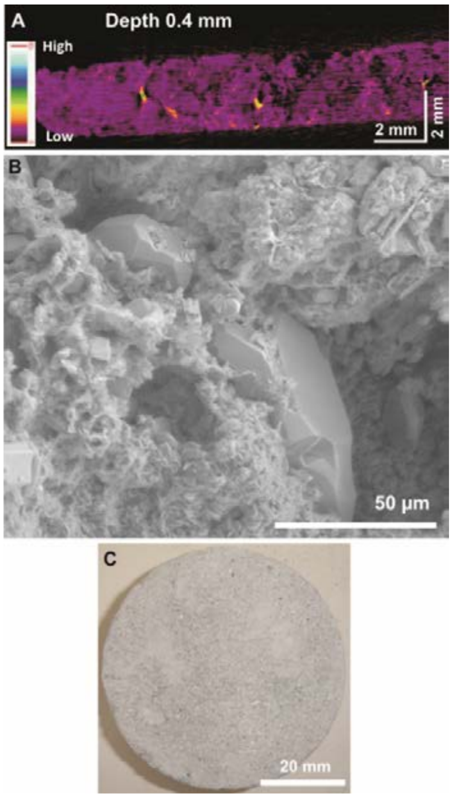

Figure 3: Crystals growing into voids. Sample THM 13, 411 m depth. (A) CT scan at 0.4 mm depth of penetration shows moderate density crystals (yellow, green areas) growing into voids (black areas). (B) SEM image of partially altered crystals in a void surrounded by clay. (C) Hand specimen photograph.

3.2 Zones of hydrothermal alteration

CT scans detect changes in rock density. Areas of high density appear as light colours while zones of low density produce dark colours. Figure 4 shows two slices of sample THM 12 at 320 m depth. One slice represents the density of the rock at 5 mm penetration into the sample (Fig. 4A) while the other represents the density of the rock at 6.5 mm (Fig. 4B). In both samples, hydrothermal alteration has taken place creating areas of density variation within the rock. This is detected by the CT scan and shown in Figure 4A-B. SEM images of platy calcite indicate hydrothermal alteration has indeed taken place within this sample. Platy calcite is a secondary hydrothermal alteration mineral that forms when reservoir fluid boils and releases CO_2.

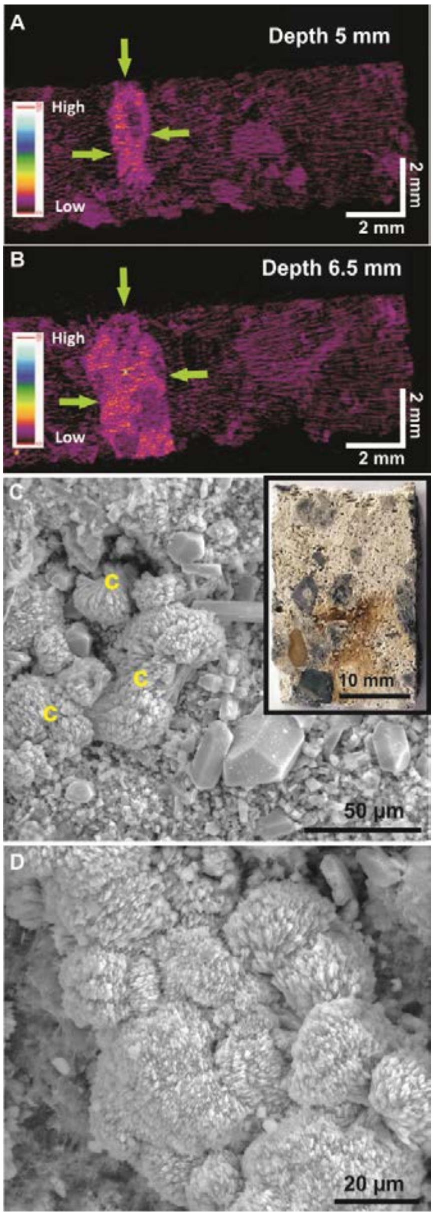

Figure 4: CT scans and SEM images of sample THM 12 at 320 m depth. (A-B) Two slices of rock at 5 and 6.5 mm depth of penetration show a large zone of moderate density (arrows) surrounded by lower density rock. (C-D) SEM images reveal platy calcite (c) formed as a result of boiling at depth. Insert: Hand specimen photograph.

The CT scan of sample THM14 at 383 m depth show two distinct patches of high density, within a lower density rock (Fig. 5A). On the CT scan, the two high density areas are multi-coloured suggesting density variations within these areas. Petrographic microscopy images show the sample to consist of well-defined, localized areas of hydrothermal alteration where calcite and adularia have completely replaced primary minerals and have subsequently been rimmed by chlorite (Fig. 5B-C). The density of adularia (2.56 g/cm^3), calcite (2.71 g/cm^3) and chlorite (2.6 to 3.3 g/cm^3) differ and it is this difference in density that the CT scan has detected, producing the multi-coloured areas on the scan.

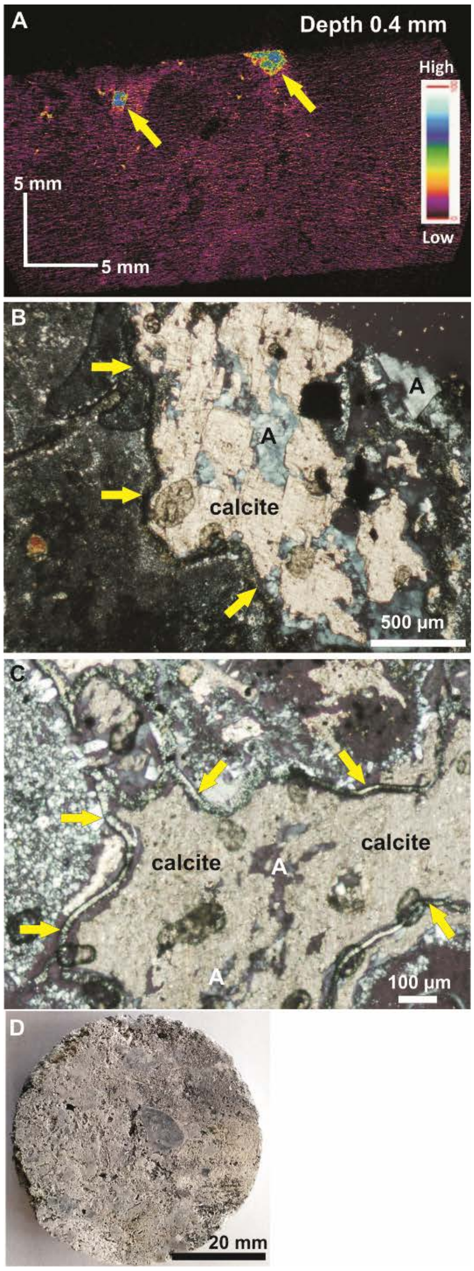

Figure 5: CT scan, petrographic microscope images and hand specimen photograph of sample THM 14 at 383 m depth. (A) CT scan shows two brightly- coloured areas of medium to high density mineralisation (arrows) in a groundmass of low density rock. (B-C) Petrographic microscopy reveals alteration of primary minerals to calcite

and adularia (A) which is rimmed by chlorite (arrows). (D) Hand specimen photograph.

3.3 Silicification

CT scans of a sample from 276 m depth from THM 12, tracked silicification of a pumice-rich rock (Fig. 6). In hand specimen, the sample consisted of a small area of partially silicified, soft pumice (area 1 on Fig. 6) and a large zone of highly silicified, well-indurated pumice (area 2 on Fig. 6). Multiple, individual CT slices of this sample demonstrates how the size and shape of the highly silicified zone changes with depth of penetration into the rock. The darker areas correlate to the less silicified zones (area 1, Fig. 6) while the lighter coloured areas correspond to the highly silicified zones (area 2, Fig. 6).

The CT scans in Figure 6 clearly show that even within a small sample of rock, permeability varies considerably within each slice. The uppermost 10 mm of the rock shows a decrease in the amount of silicification with depth of penetration, while from 10 to 17 mm depth the amount of silicification increases. This indicates that the level of thermal fluid flow through the rock varies on a millimetre by millimetre scale, both vertically and laterally.

SEM images of sample THM 12 at 276 m depth (Fig. 7) reveal mineralogical and morphological differences between the partially and highly silicified areas. The partially silicified zone consists of a mixture of clay and a moderate amount of small quartz crystals that reach up to 20 µm in length (Fig. 7A-B). In contrast, the highly silicified area consists of abundant, large quartz crystals, up to 50 µm in length and only minor clay is present (Fig. 7C-D). While quartz crystals in both zones have the same density value, it is the difference in size and quantity of the quartz crystals that is creating the density differences visible on the CT scans.

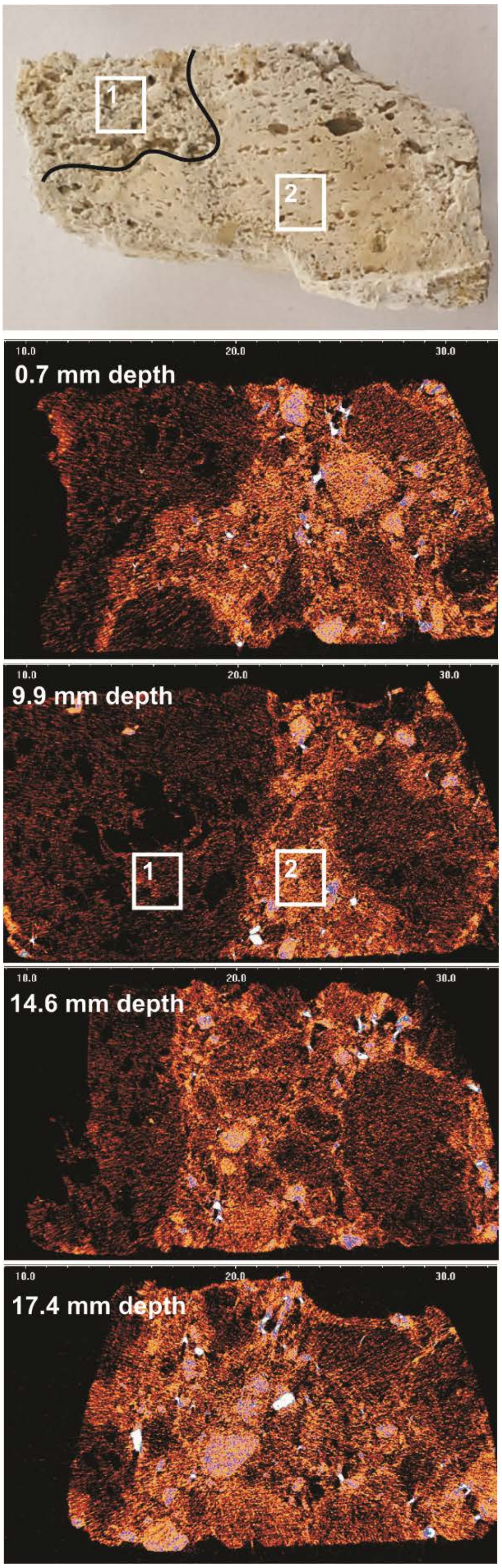

Figure 6: Mapping silicification of a pumice-rich rock using CT scans. THM 12, 276 m depth. Hand specimen photograph and CT scans at four depth intervals. Partially silicfied pumice is shown as dark zones and area 1, while the highly silicified pumice is shown as the lighter coloured zones and area 2.

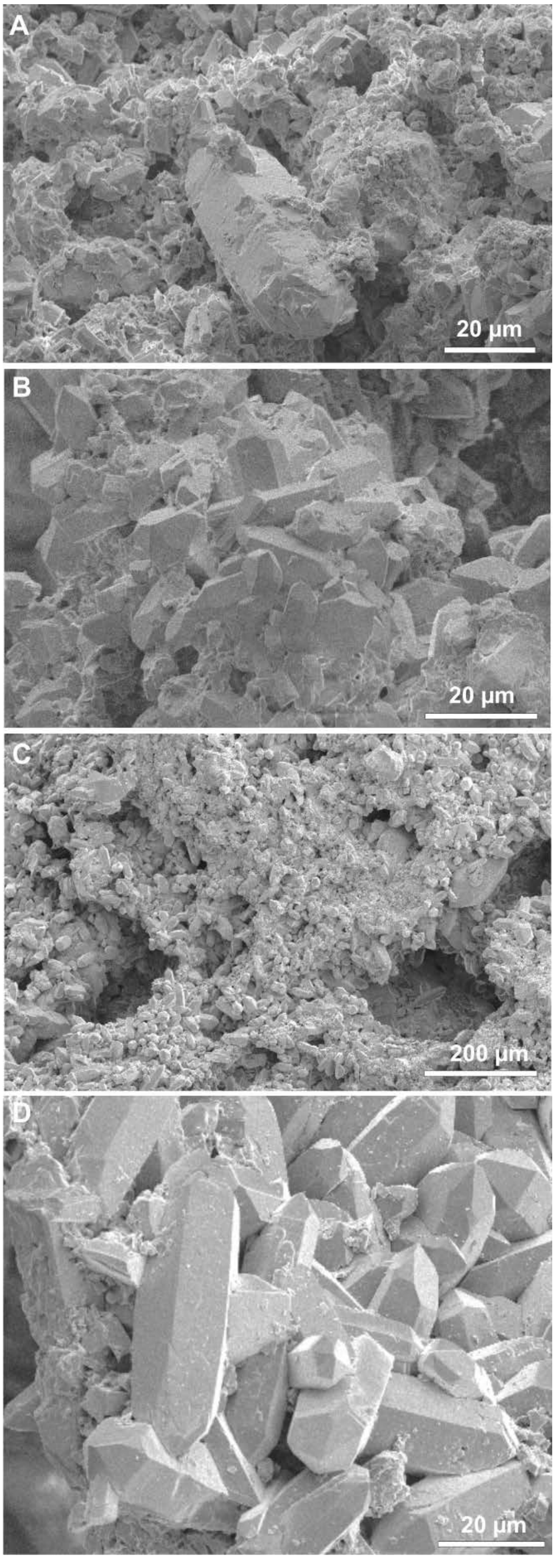

Figure 7: SEM images showing differences in quartz crystals within silicified zone (area 2 on fig. 6) and unsilicified zone (area 1 on fig. 6.) (A-B) Unsilicified zone shows quartz crystals up to 20 μm in length embedded in clay minerals. (C-D) Silicified zone. Abundant quartz crystals up to 50 μm in length with rare clay minerals.

4. CONCLUSION

As thermal fluid flows through host rocks, hydrothermal alteration processes take place. Hydrothermal alteration is a common process in geothermal reservoir rocks. This process alters primary minerals via dissolution, precipitation or replacement, and often results in the formation of secondary minerals. Once a rock has undergone hydrothermal alteration, its physical properties will differ to those of the primary rock. For example, dissolution may increase the number and size of voids in a rock and decrease its density. Conversely, precipitation of minerals into fractures and voids will decrease its porosity and increase its density. As CT scans are sensitive to density changes, it has proven to be a useful method for examining hydrothermal alteration processes.

CT scanning has been used to map hydrothermal alteration within samples of cored rock from the Tauhara geothermal field. This study shows that CT scanning is a useful method for tracking:

- broad-scale hydrothermal alteration processes
- changes in the physical properties of a rock void
- size, shape and connectivity
- permeability variations within a rock

CT scans are an excellent tool for mapping sites where thermal fluids have reacted with host rocks and caused a change to the density of the rock. However, CT scanning does not provide information on subsurface processes, other than indicate the amount of hydrothermal alteration in any given slice of a rock. The combination of CT scanning with SEM and petrographic microscopy provides a useful tool for tracking hydrothermal alteration, subsurface processes and fluid flow through geothermal reservoir rocks.

Mapping voids using CT scans enables their size, shape and connectivity to be visualized in 3D. Other methods such as scanning electron and petrographic microscopy show void characteristics in 2D. Being able to image slices of a rock at 0.01 mm increments enables us to map void size, shape and connectivity with depth of penetration. Mapping void connectivity at the micro-scale is an advantage as the role voids play in thermal fluid flow through rocks is not well understood. Void mapping using CT scans could have an application for understanding fluid flow in both production and injection Formations.

Understanding fluid flow through different rock types is important. This study has shown that even within a single sample (Fig. 6) the morphology of void space varies both laterally and vertically over small distances. Understanding how particular Formations or lithologic units transmit fluid is important for the development of our conceptual models, well targeting and sustainability of the resource.

5. FUTURE WORK

The next steps in this study would be to:

- Measure the shape and size of voids and the connections between voids to determine quantitative numbers which could be included into reservoir models, GIS databases or Leapfrog models.

- Evaluate the dimensions of flow limiters, such as narrow throats between voids or narrowing of connective voids due to mineral precipitation.
- Couple observations with numerical testing of the way void morphology may impact flow through a rock.

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