IMAGING THE SHALLOW SUBSURFACE OF ARMSTRONG RESERVE, TAUPO, NEW ZEALAND, USING GROUND PENETRATING RADAR

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ABSTRACT

Ground Penetrating Radar (GPR) was undertaken over the southern section of the Armstrong Reserve, located in Taupo, New Zealand, to image the shallow subsurface. Historically, hot springs were located in this area. These springs discharged silica-rich, alkali-chloride water resulting in the formation of siliceous sinter terraces. No discharging hot springs are visible at the site today, although the historic sinter is exposed along the banks of a stream creek that dissects the study area. This creek is fed by thermal springs further upstream. GPR was used to image the buried sinter and to identify fractures within the sinter. The GPR data revealed three distinctive rock types in the subsurface; (1) unaltered siliceous sinter producing strong GPR reflections, (2) Rock Type B consisting of a poorly-reflective unit, (3) Rock Type C producing discontinuous horizons of strong reflections mixed with zones of poorly-reflective material. Fractures within the subsurface were also identified. GPR data was collected to a depth of eight metres along thirty-eight transect lines. Transects were arranged in a grid system to enable 3D modelling of the subsurface.

1. INTRODUCTION

The Taupo area lies within the Taupo Volcanic Zone (TVZ) and is well-known for its thermal activity (Rosenberg et al., 2010). The Armstrong Reserve is located on the northern shores of Lake Taupo with the Onekeneke Stream dissecting the Armstrong Reserve (Fig. 1). Historically, hot spring rocks referred to as siliceous sinter are present underneath the grassed area at Armstrong Reserve and are exposed along the banks of the Onekeneke Stream. Thermal input to the Onekeneke Stream occurs further upstream. Currently there are no discharging hot springs at the study site. At the time of the survey the temperature of the Onekeneke Stream was 21.7°C and the pH was 8.5.

A Ground Penetrating Radar survey of the western area of the Armstrong Reserve was undertaken in April 2016. GPR is a high resolution geophysical tool that is used to image the shallow subsurface. Siliceous sinters image particularly well using GPR as they produce strong amplitude reflections (Dougherty and Lynne, 2011; Lynne and Sim, 2012; Lynne and Smith, 2013: Lynne et al., 2015). The aim of this study was to identify the lateral and vertical distribution of the buried sinter and any fractures present within the sinter.

2. METHODS

The GPR survey was undertaken using a Sir 3000 control unit with a 200MHz Antenna. A total of 38 GPR transects were collected at the Armstrong Reserve (Fig. 1). Estimated maximum depth imaged was 8 m. Both grayscale and colour GPR images were processed to clearly show the different subsurface features. Three rock types were identified in the shallow subsurface at Armstrong Reserve and were classified as follows:

Sinter: Unaltered siliceous sinter produces strong GPR reflections. Altered sinters produce moderate to weak reflections, depending on the degree of alteration. Saturated sinter produces moderate to weak reflections depending on the amount of saturation.

Type B: Unidentified, poorly-reflective material. Most likely to be soil, clay or water-saturated soil.

Type C: Likely to be discontinuous sinter horizons due to fracturing, hydrothermal alteration, incorporation of soil or sediments, or steam/water infilling fractures or voids.

Fractures: Subsurface fractures were also identified and image as black areas.

Due to permitting issues, no core samples were taken. However, buried sinter horizons exposed along the banks of the Onekeneke Stream enabled the GPR data to be ground-truthed. GPR transects were arranged in a grid pattern so 3D images of the subsurface could be created.

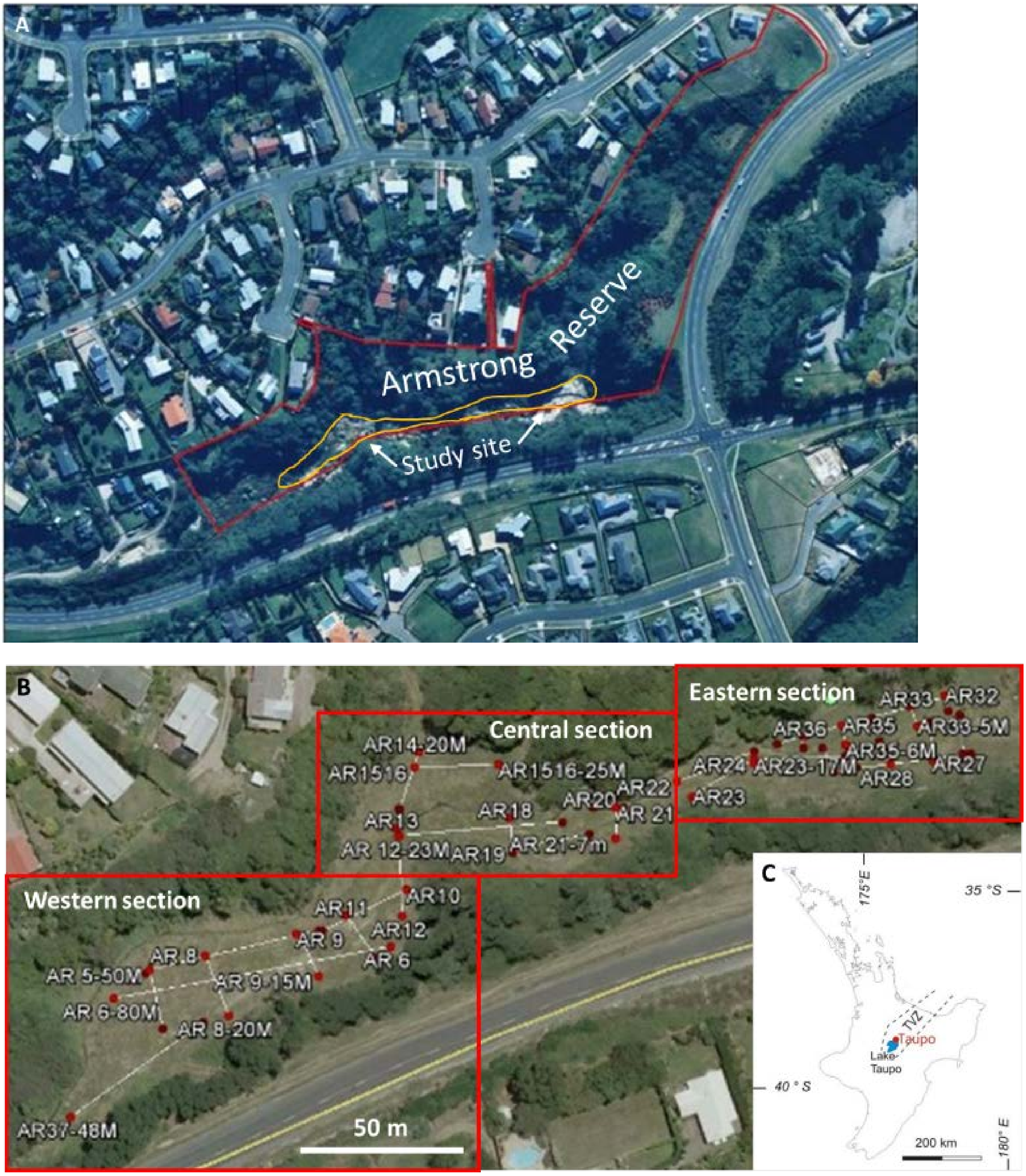

Figure 1: Location map. (A) Armstrong Reserve in Taupo, New Zealand showing location of study site. (B) GPR transect lines at Armstrong Reserve. (C) Location map of Taupo within the Taupo Volcanic Zone (TVZ), New Zealand.

3. RESULTS

3.1 Ground Penetrating Radar data

The aim of the survey was to locate the buried sinter and any fractures within it. Figure 2 provides examples of the GPR data and shows the distribution of fractures, sinter, Type B and Type C units recorded along transects 009, 010 and 037. Transect 009 and 010 show horizontal sinter sheets while transect 037 reveals the sinter at depth is brecciated. Fractures are visible in the GPR data for transects 010 and 037.

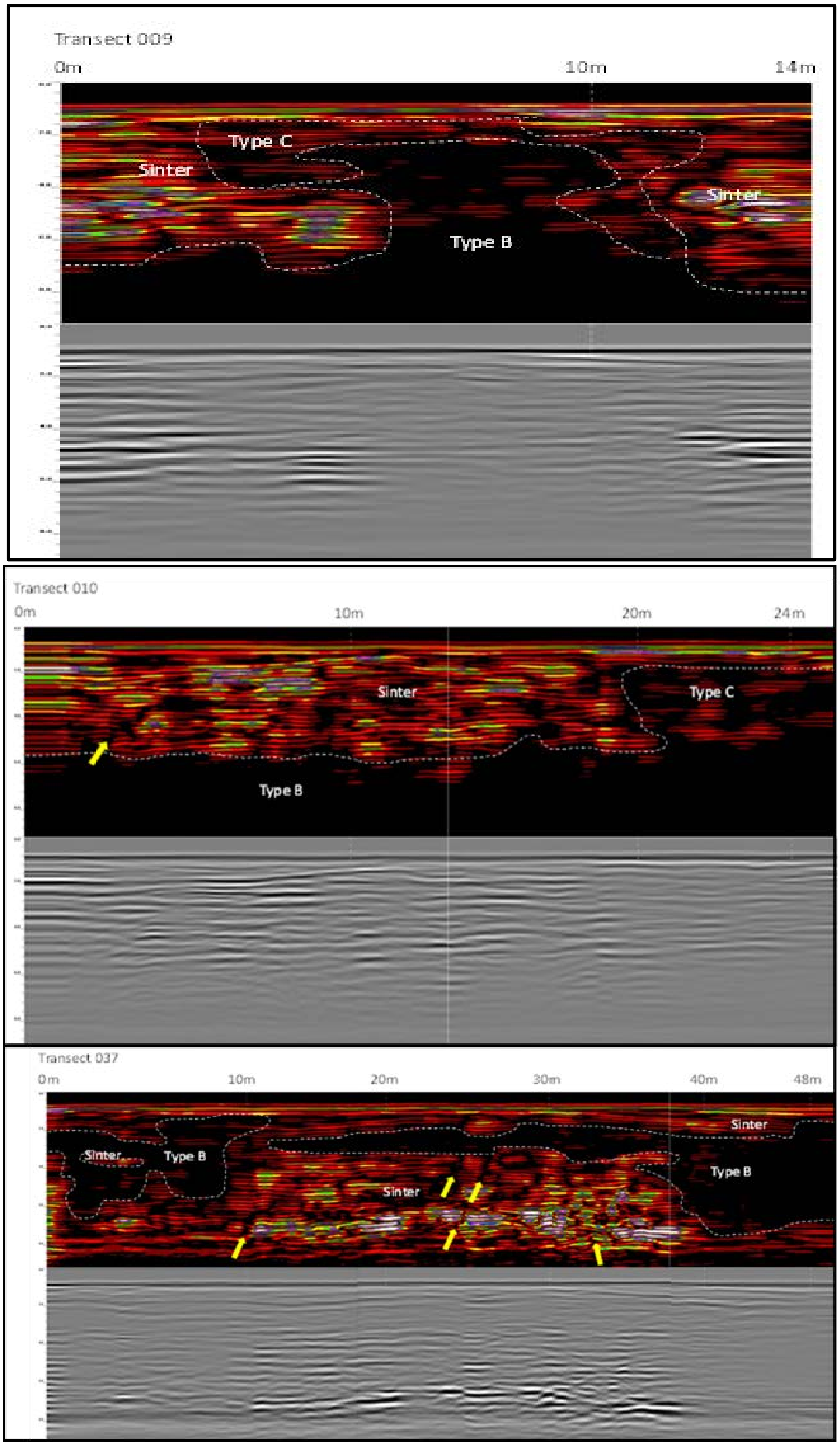

Figure 2: Three GPR images from Armstrong Reserve. Upper: 14 m profile line shows two pockets of sinter separated by ~5 m of Type B and Type C material. Sinter layers are dominantly horizontal with slight lateral variations in radar signal return indicating a variation in properties across the layers. Middle: Transect 010, 24 m long profile line showing sinter horizons between 0 and 20 m to a depth of ~6 m. From 20 to 24 m the sinter thins to ~ 1 m and Type C dominates this zone. Sinter layers are fractured (yellow arrow). Type B is present below the sinter. Lower: Transect 037, 48 m long profile. The majority of the transect area is sinter, with strong sinter reflections occurring at a depth 5 to 8 m, between the 10 to 37 m marks. Multiple vent pathways of similar orientation were imaged at 10 m, 25 m, 26 m and 33 m (yellow arrows). Discontinuous zones of Type B material occur within the sinter areas.

3.2 Spatial distribution of sinter

Data from individual GPR transects were compiled into 3D models to provide an overview of the shallow subsurface in the western and eastern sections (Fig. 3). Our study shows sinter is more abundant in the western area. For example along transect AR 6, the sinter reaches a thickness of 8 m at the start of the transect, thins to 1 m at 18 to 28 m before thickening again to 7 m until ~78 m, at which point the sinter thins to 1 m for the rest of the transect (Fig. 3). Sharp boundary contacts are visible between the sinter and the non-sinter units.

The 3D model of the eastern area reveals alternating zones of thick (9 m) and thin (<2 m) sinter sheets. In this area, more sinter occurs on the northern side of the Onekeneke Stream with minimal sinter on the southern side of the Stream.

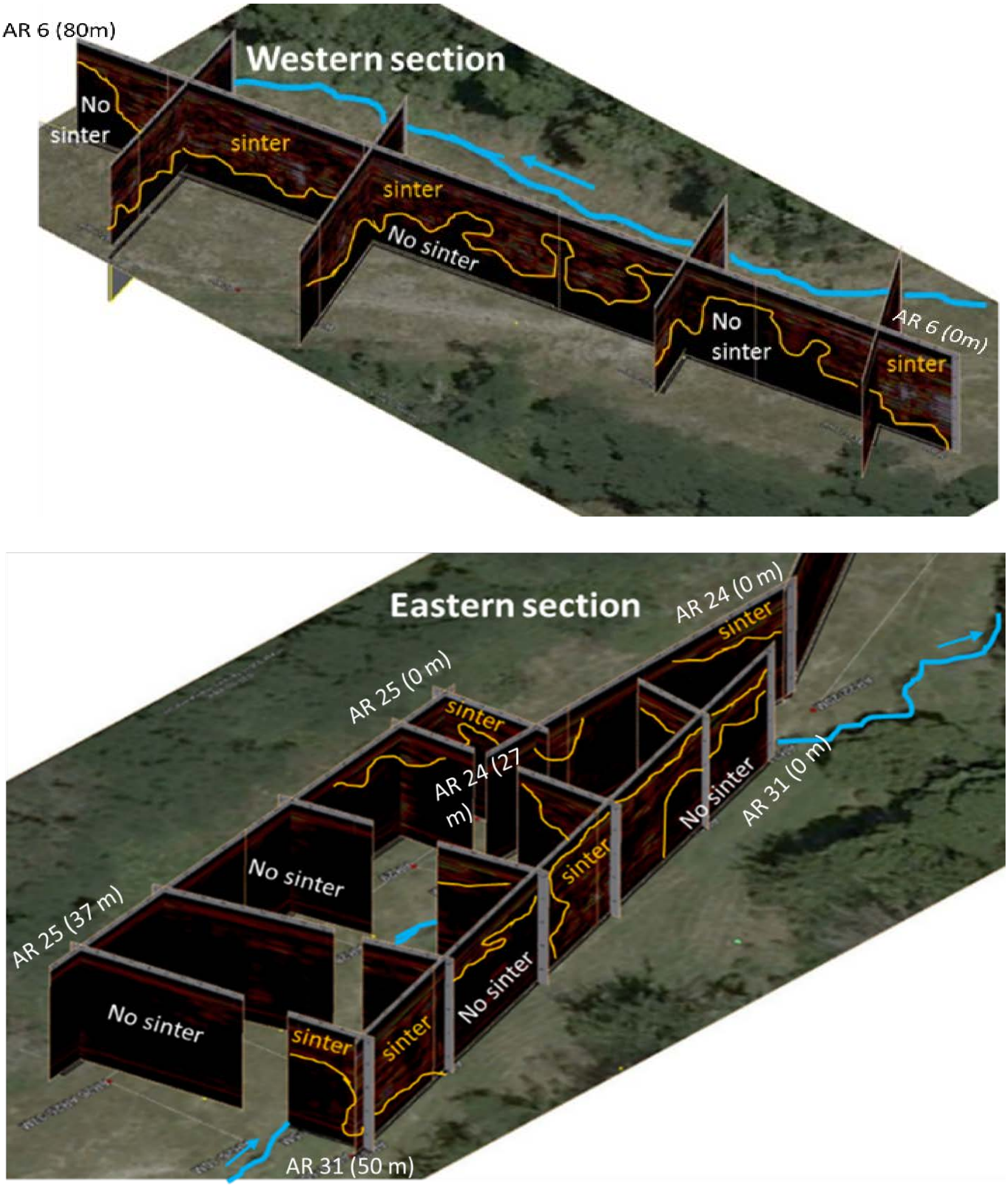

Figure 3: 3D compilation of GPR images. Upper: Western GPR transects at Armstrong Reserve. Lower: Eastern GPR transects at Armstrong Reserve.

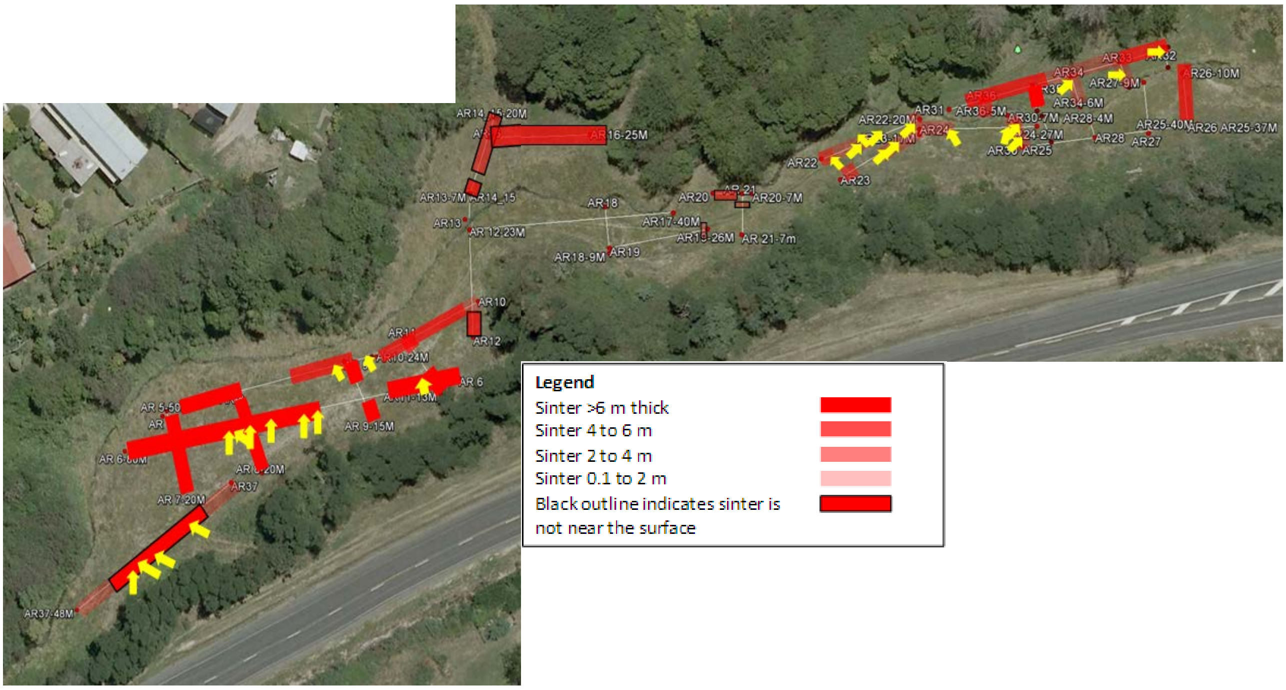

Figure 4: Map showing sinter thickness and spatial distribution at Armstrong Reserve, Taupo. Yellow arrows indicate fractures with arrow direction indicating fracture orientation.

From the GPR data, we constructed a map summarising sinter thickness, the spatial distribution of sinter, and fracture locations and fracture orientations within the sinter (Fig. 4). In summary, the sinter at Armstrong Reserve is thickest in the western area (>6 m) where it occurs immediately below a thin soil horizon. Minimal sinter was imaged in the central section with almost no sinter detected on the southern side of Onekeneke Stream. Sinter imaged on the northern side of the Onekeneke Stream is buried under the surface by ~4 m. The buried sinter sheets are ~5 m thick. Sinter in the eastern section is more abundant than in the central zone, but less abundant than in the western area. Sinter in the eastern zone varies in thickness up to ~2 m except in the northern part of this area, where the sinter is up to 8 m thick. The sinter in the eastern section is buried near the surface.

3.3 Fracture and fracture orientations

Fractures are easily visible on GPR data. Figure 4 shows the distribution and orientation of fractures observed in the sinter at Armstrong Reserve. No fractures were noted in the central section of the Reserve but fractures occur in both the western and eastern zones. The fractures in the western area are dominantly near-vertical, while the fractures in the eastern zone are inclined and dominantly strike northeast-southwest.

4. DISCUSSION

Cody (1993) documents extensive sinter terraces and discharging hot springs of the Waipahihi Valley in the mid-late 19th century, and concludes from anecdotal evidence that spring flow considerably reduced as a result of the 1931 Napier Earthquake of magnitude 7.9.

At Armstrong Reserve, historic sinter sheets are visible in the banks of the Onekeneke Stream, but no sinter outcrops occur in the Reserve. No cores were taken at Armstrong Reserve to ground truth the GPR data. However, GPR transects were collected along the banks of the Onekeneke Stream, over sites where sinter was visible. Previous GPR work in sinter areas show that sinter produces strong amplitude reflectors (Dougherty and Lynne, 2011; Lynne and Sim, 2012; Lynne and Smith, 2013; Lynne et al., 2015). Strong amplitude reflections occurred over the visible sinter in the banks of the Onekeneke Stream.

The results of the GPR survey suggest an expansive siliceous sinter terrace occurs beneath the present-day grassed area at Armstrong Reserve. GPR imaging reveals the western, central and eastern sections contain approximately 2000 m^2, 50 m^2 and 500 m^2 of buried sinter, respectively. For this quantity of sinter to have accumulated there must have been considerable and sustained discharge of silica-rich hot spring water in the Armstrong Reserve area in the past.

The Armstrong Reserve is located within the Wairakei-Tauhara geothermal area. The Wairakei-Tauhara geothermal system is dominated by northeast-southwest oriented fault structures (McNamara et al. 2016). We imaged shallow fractures in the buried sinter at Armstrong Reserve. While orientations of individual fractures were variable, the zone where fractures were observed shows a northeast-southwest orientation which correlates to the regional structural trend in the Taupo area.

5. CONCLUSION

GPR has proven successful in imaging buried sinter at Armstrong Reserve, as well as identifying fractures within the sinter. The application of GPR to identify buried, historic, siliceous sinter extends our ability to locate sites where silica-rich, hot spring water discharged at the surface in the past, but where no discharging hot springs occur today.

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