Tracking heat flow migration

The Geothermal Institute
University of Auckland

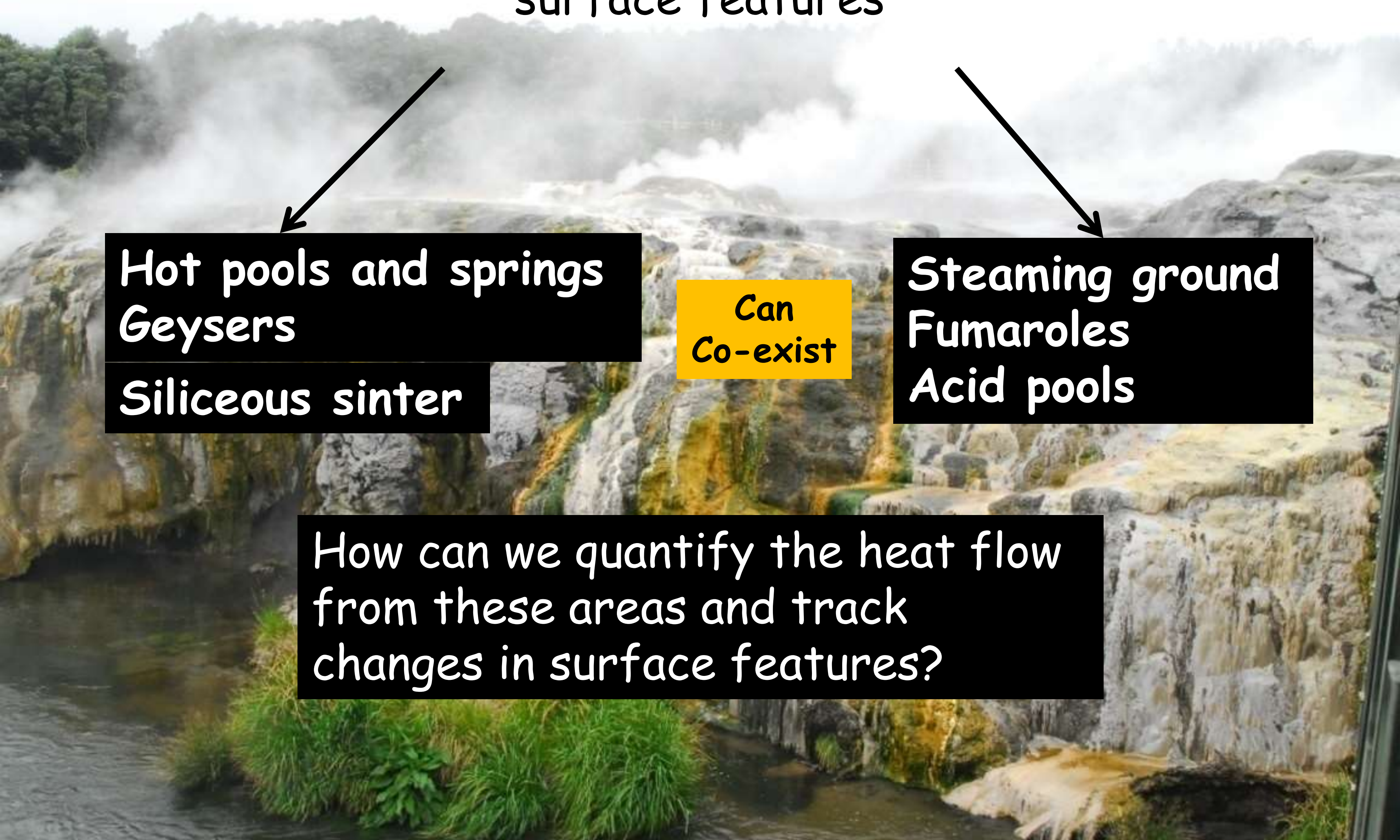
Bridget Lynne

Santiago de Chile, 26-29 May 2014

Tracking heat flow migration pathways in the shallow subsurface

Bridget Y. Lynne

Common alkali chloride and acid sulphate surface features



Comparison of data collected over different time periods is powerful

To assess heat flow in an area we require specific data sets

Let's examine what we need and how to get it for **quantitative heat flow measurements**

Geothermal systems commonly change from alkali chloride to acid sulphate

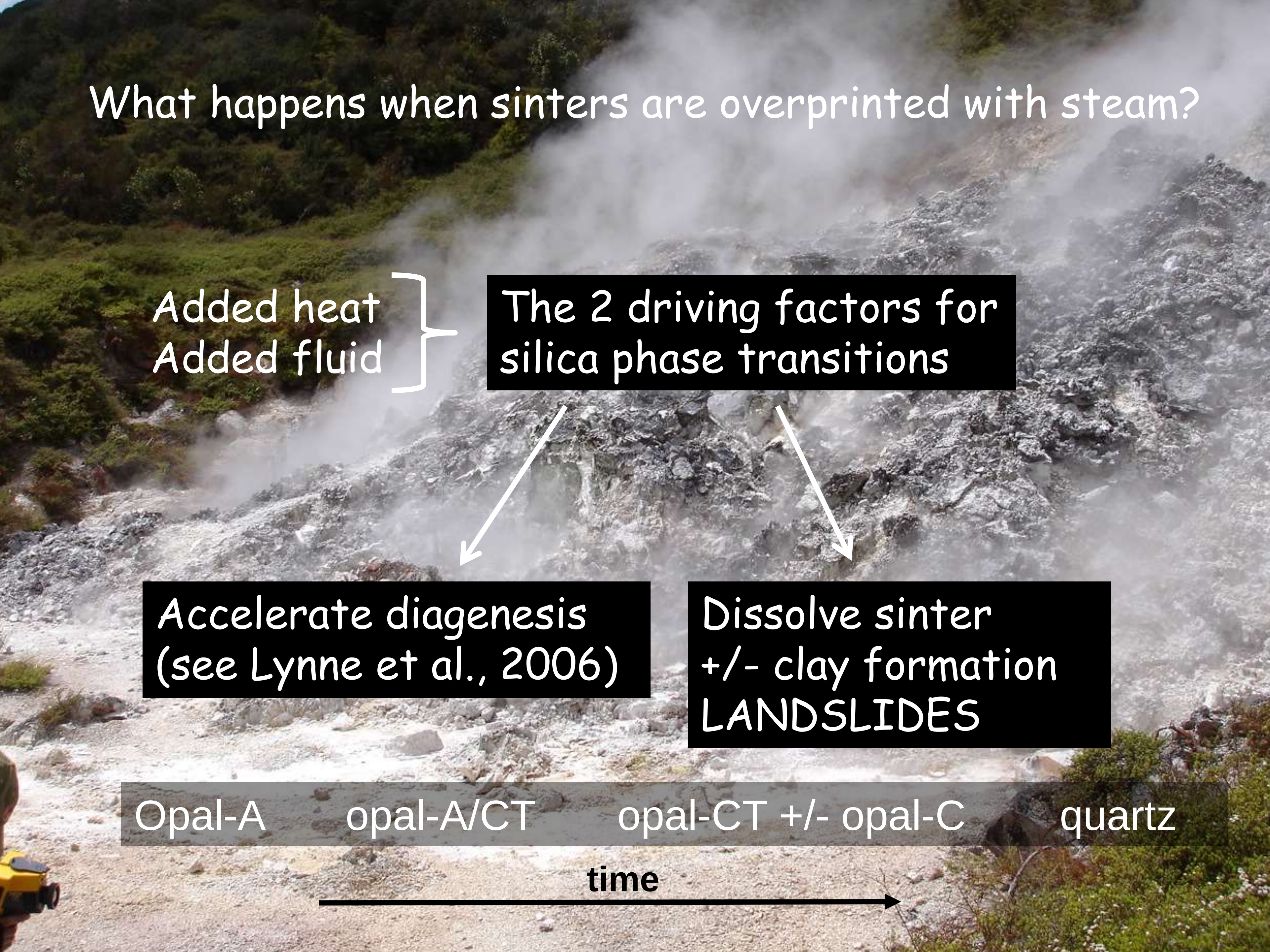
Hot pools, hot springs
Geysers, sinter

→

Steaming ground
Fumaroles
Acid pools

→

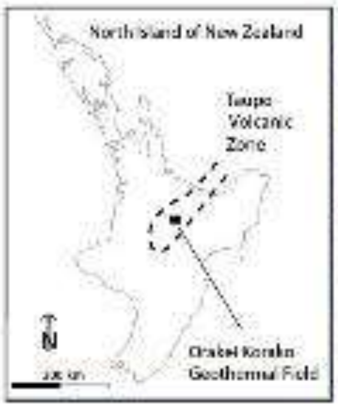
overprinting of sinter


What happens when sinters are overprinted with steam?
Added heat
Added fluid
The 2 driving factors for silica phase transitions
Accelerate diagenesis (see Lynne et al., 2006)
Dissolve sinter
+/- clay formation
LANDSLIDES
Opal-A
opal-A/CT
opal-CT +/- opal-C
quartz
time

Can we identify heat over-printed sinters?

Heat Flow – New application of existing techniques

Case Study: Orakei Korako, NZ

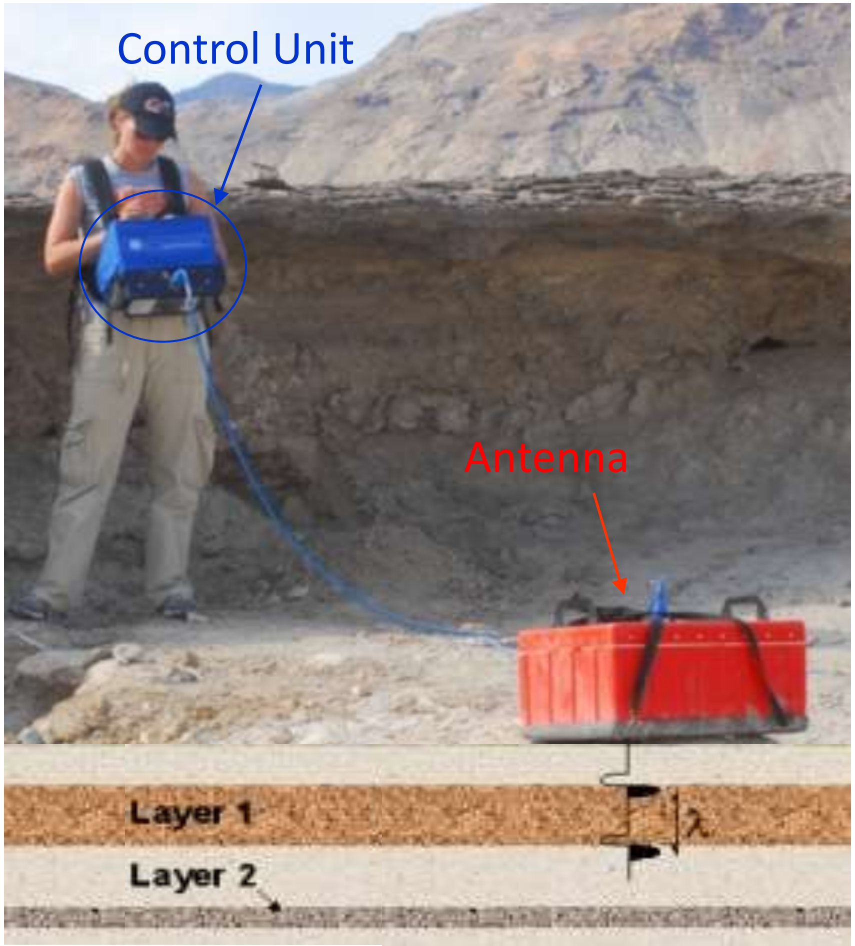


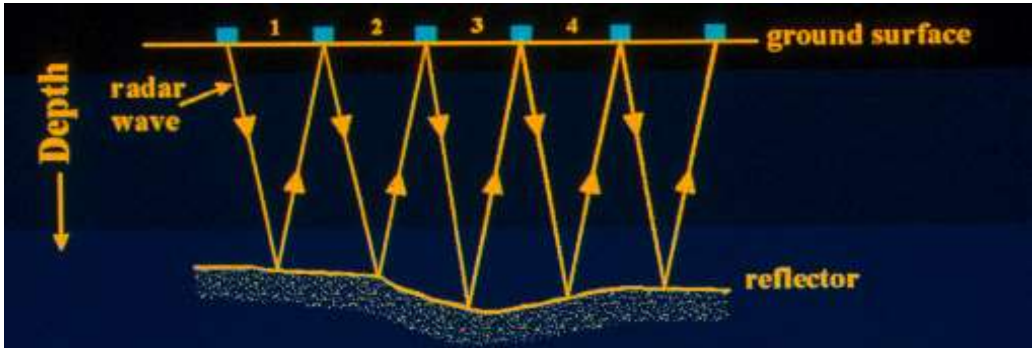
Multi-technique approach

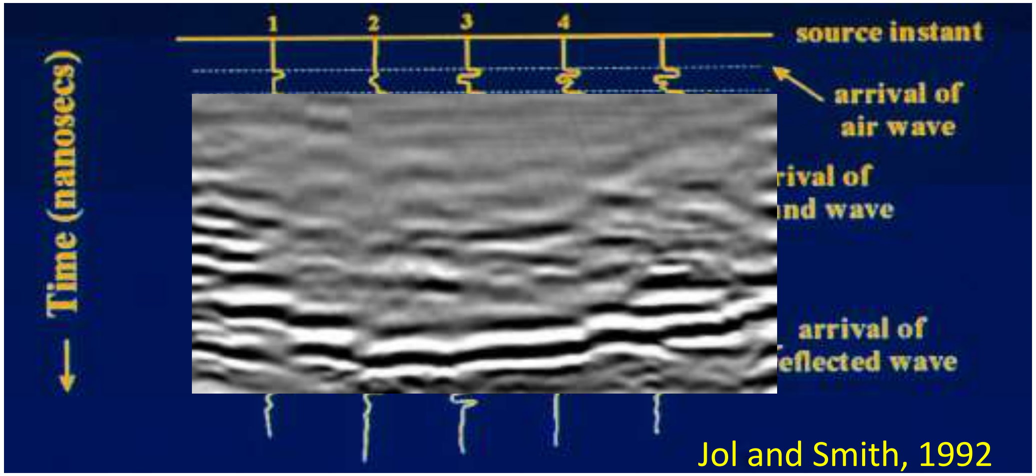
- Infrared imaging
- Ground Penetrating Radar
- Downhole temperature measurements
- Scanning Electron Microscopy
- X-Ray Diffraction

Purpose of study: Map heat flow migration pathways

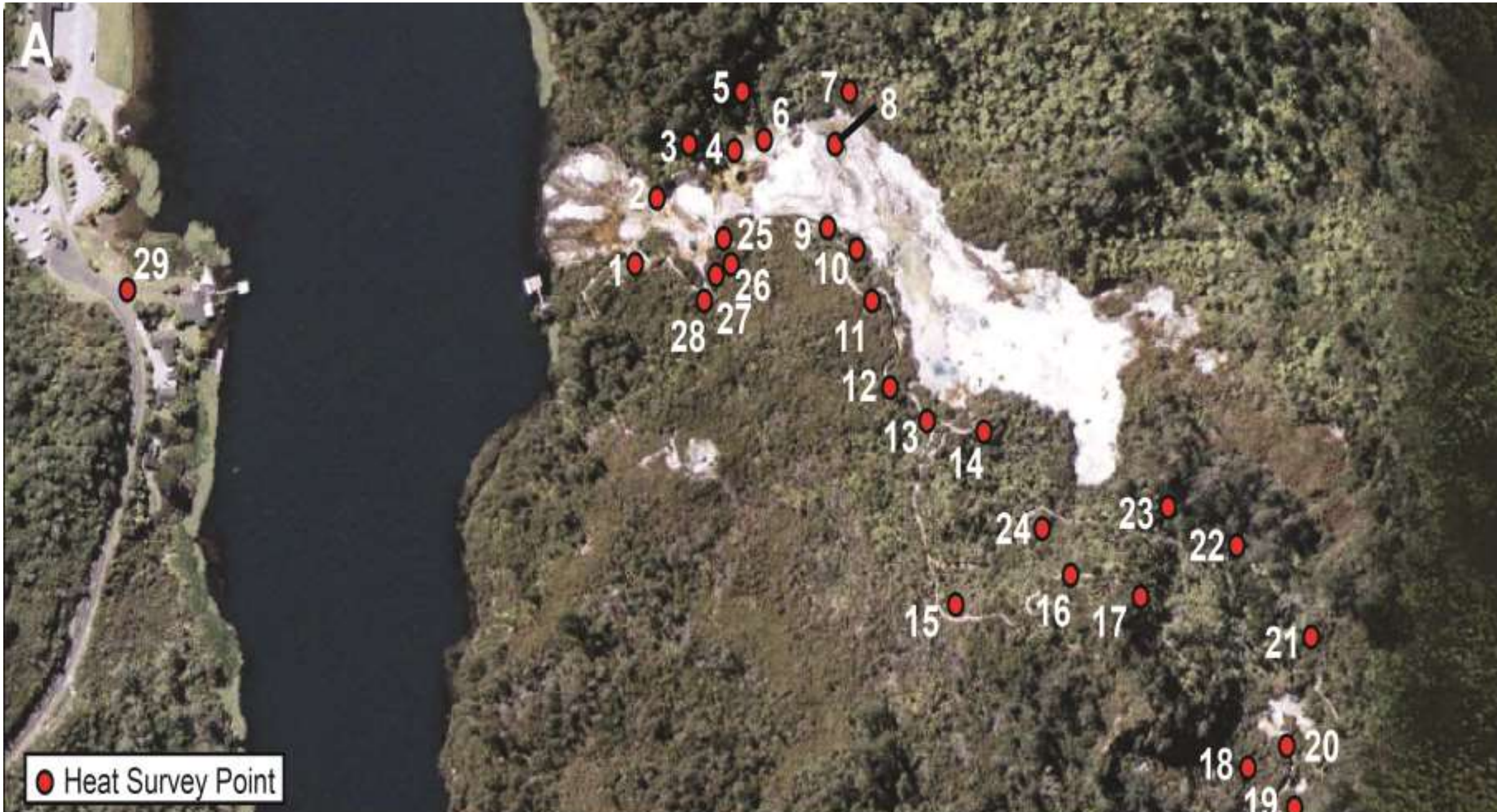
GPR
(GSSI-SIR 2000 and SIR 3000)
200 and 270MHz Antennas
Range 50-300ns







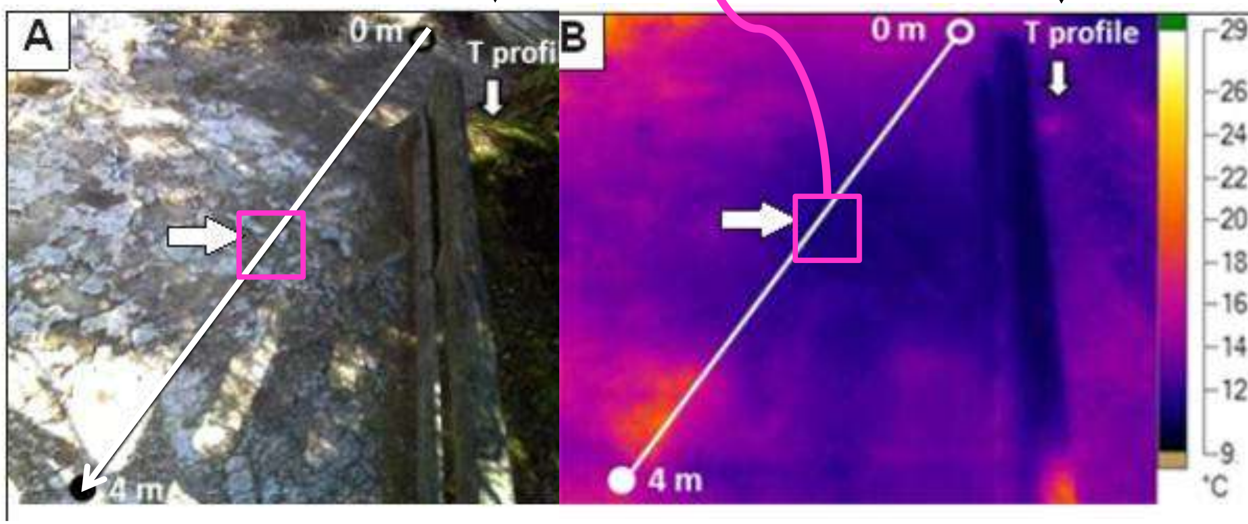
Mapping Orakei Korako heat distribution



29 GPR + 1.5 m deep temperature measurements

EXAMPLE 1

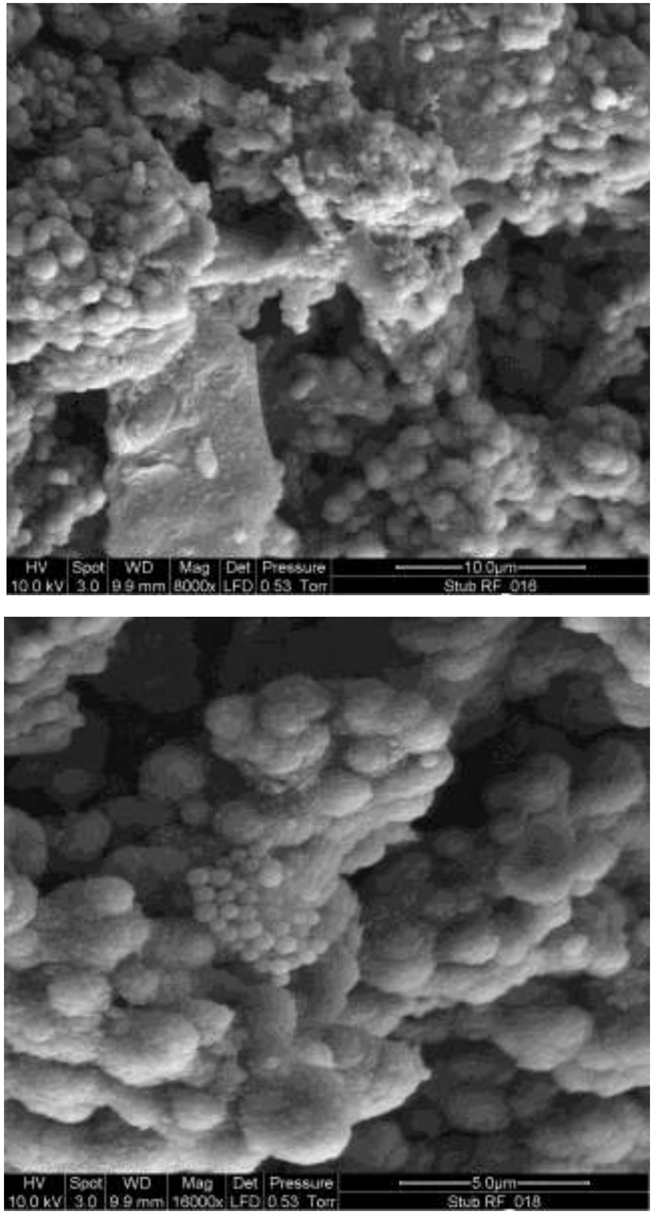
T profile site



GPR transect

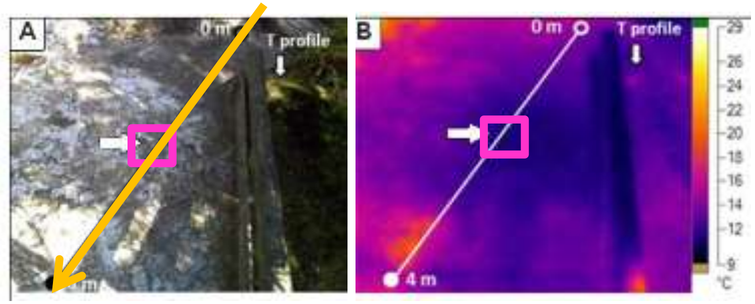
Infrared Image

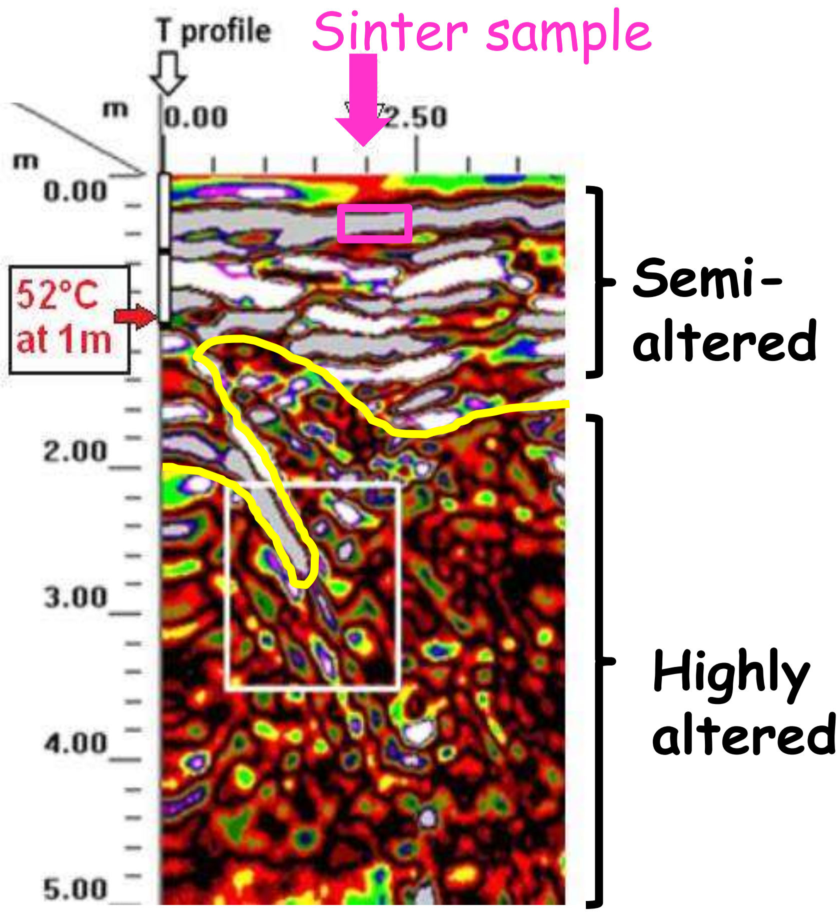
EXAMPLE 1



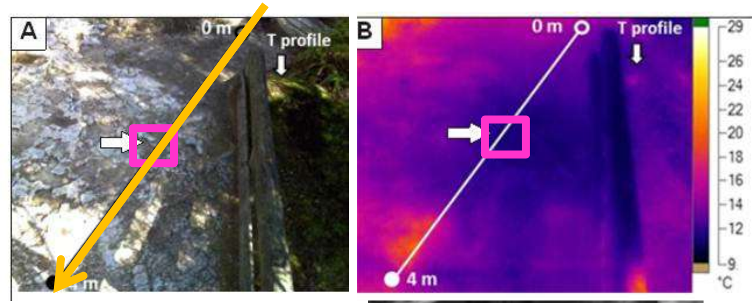
Unaltered opal-A sinter

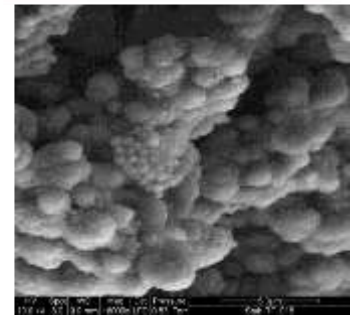
FWHM = 7.5

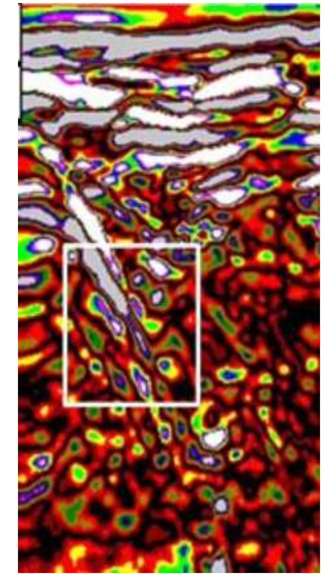




Example 1 shows …



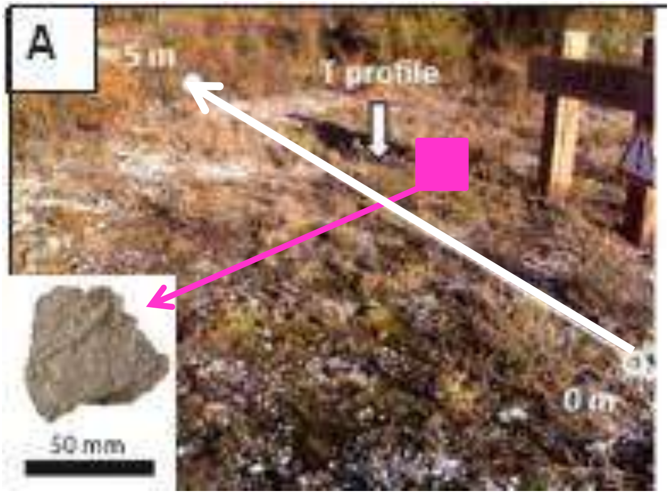


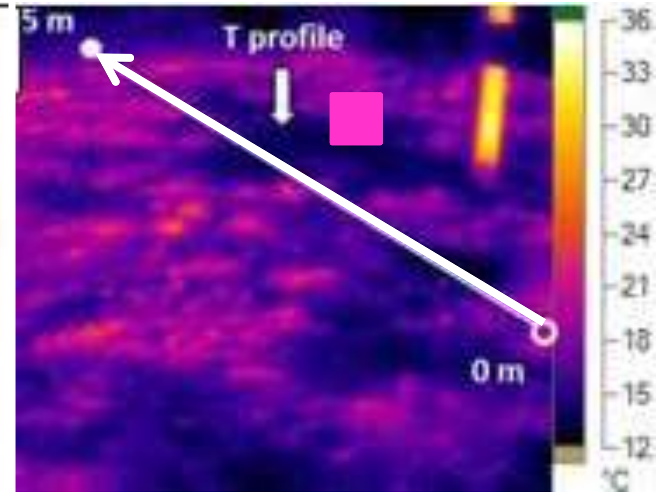


- Elevated T in subsurface (52 °C at 1 m) not indicated at surface
- Sinter unaffected by heat overprinting

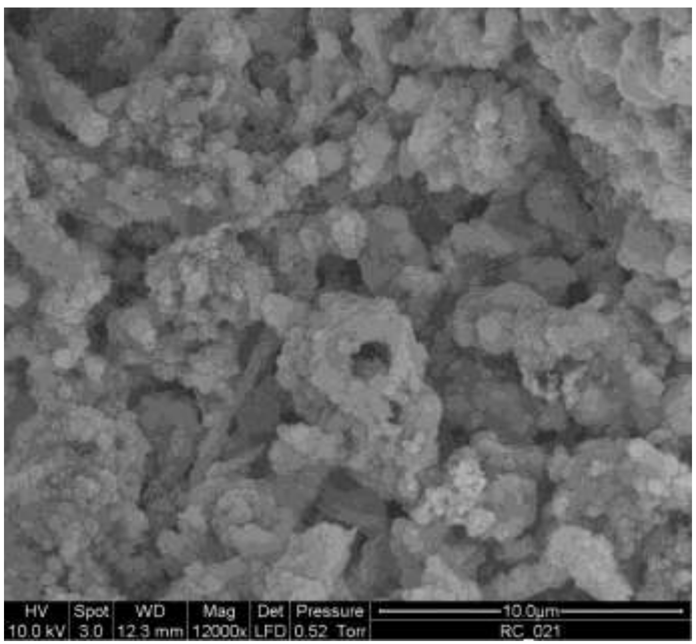
Conclusion: Sinter may be a cap to ascending steam or more likely, this area is newly heated ground that has not been hot for long enough to alter the sinter at the surface

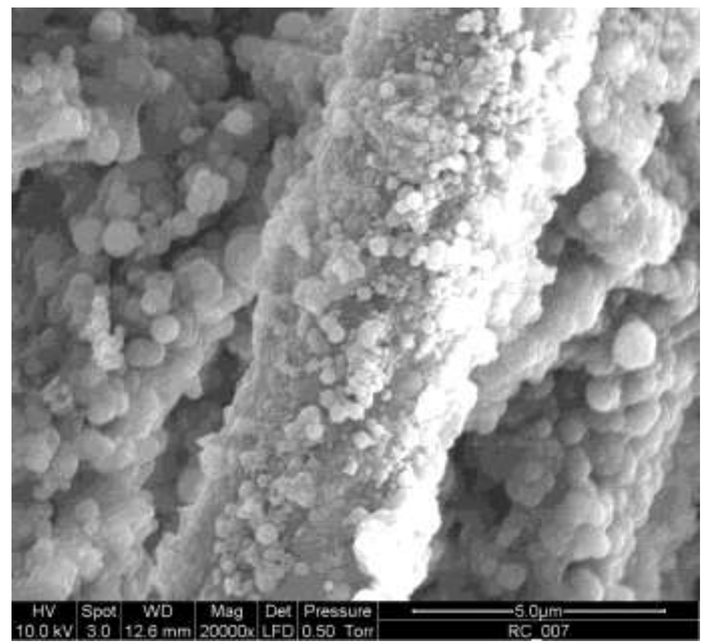
EXAMPLE 2





Spatially patchy heat at surface

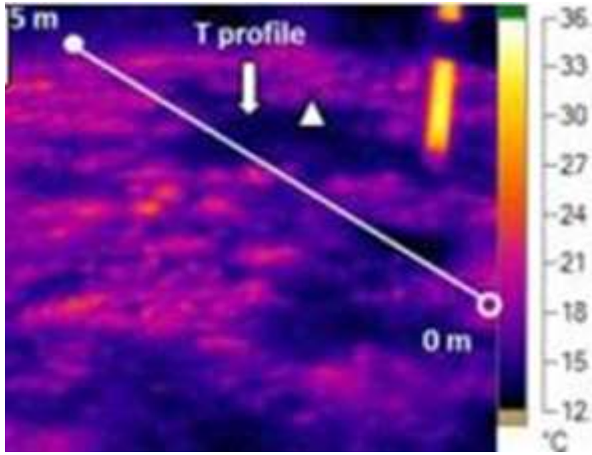


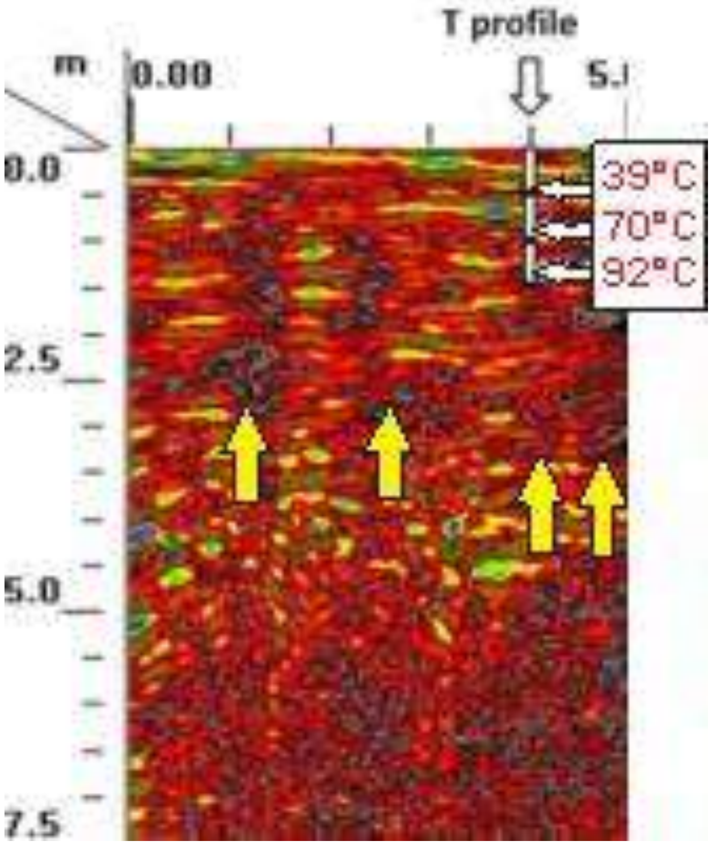


FWHM = 7.6
Opal-A

Unaltered opal-A sinter with low T filaments (<35 °C)

EXAMPLE 2

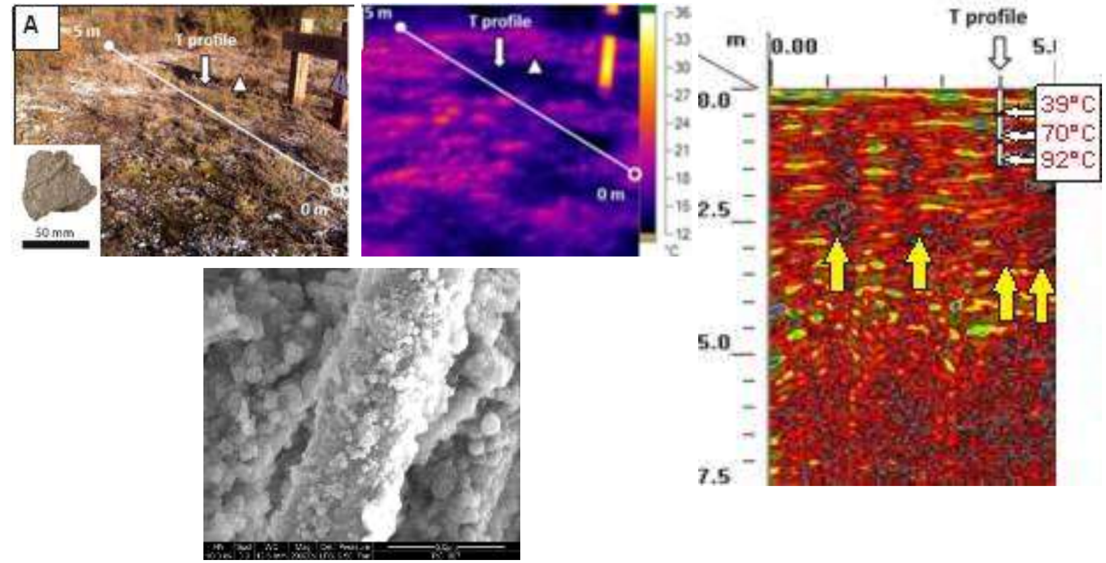




Elevated Temperatures

Highly altered subsurface

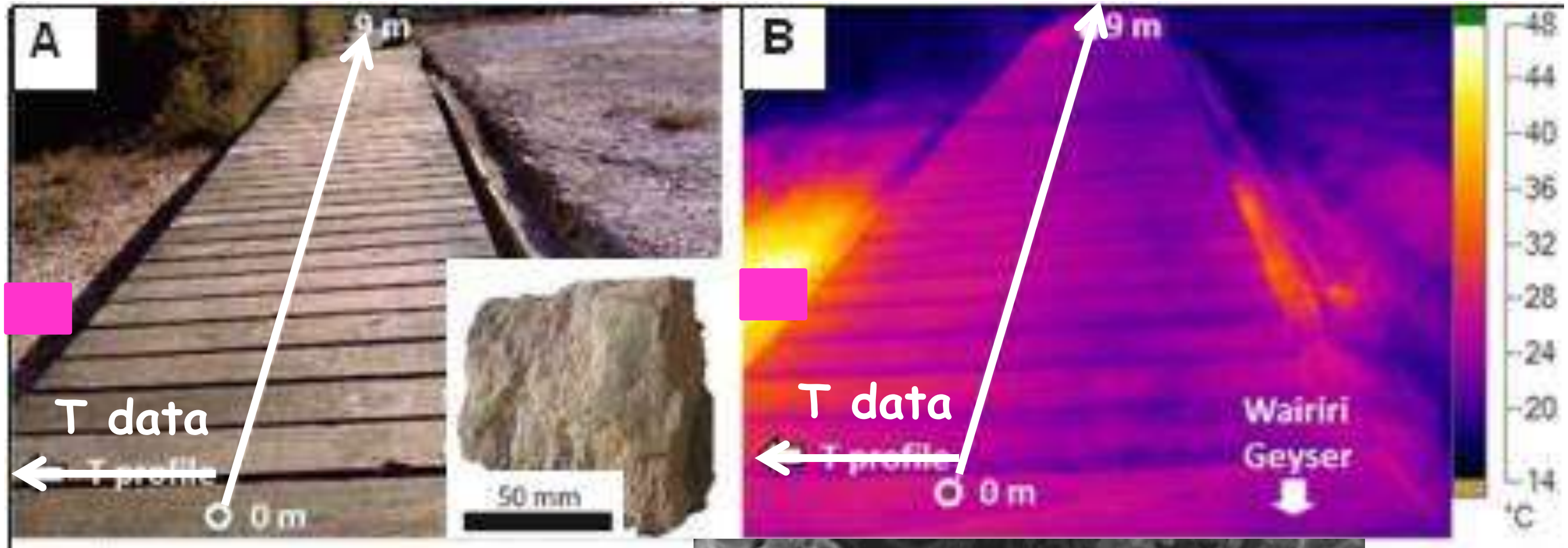
Example 2 shows …

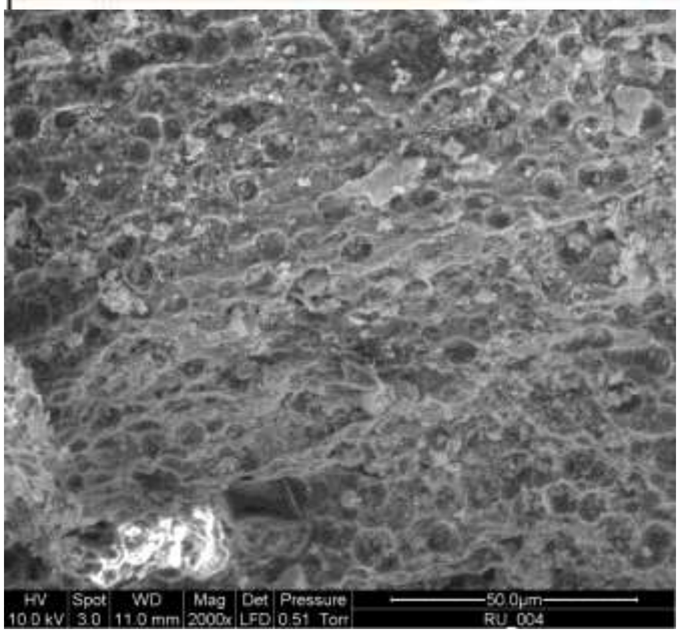


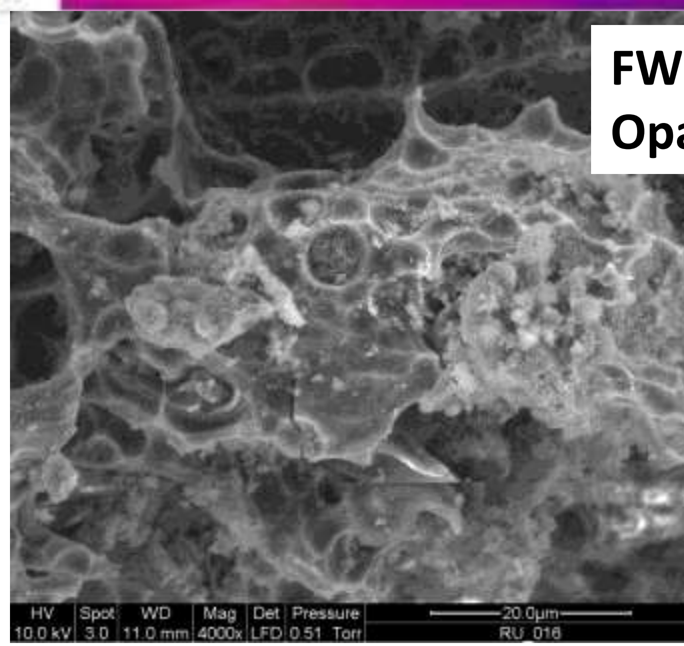
- No evidence of heat overprinting the sinter
- GPR shows extensive alteration in subsurface
- Elevated downhole temperatures (92°C at 1.5 m depth)
- IR shows spatially patches areas with elevated temperatures at the surface

Conclusion: Area heating up but not hot for long enough to alter sinter at the surface

EXAMPLE 3

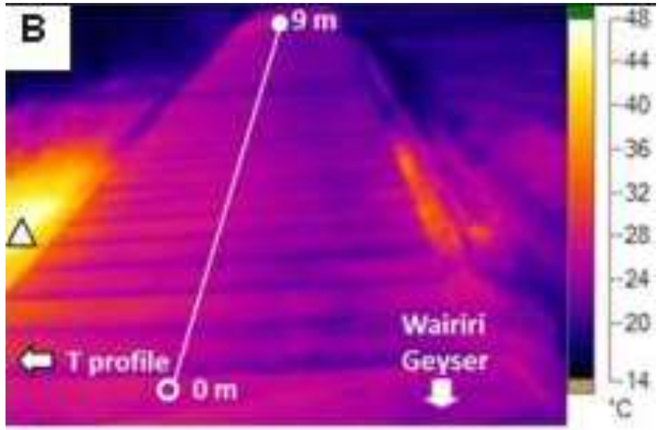


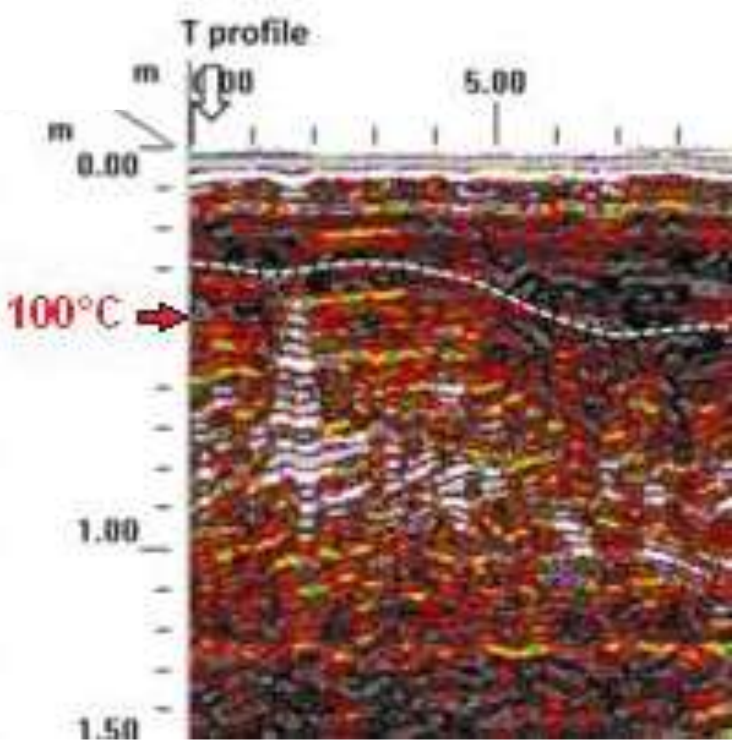




FWHM = 0.9
Opal-CT

EXAMPLE 3

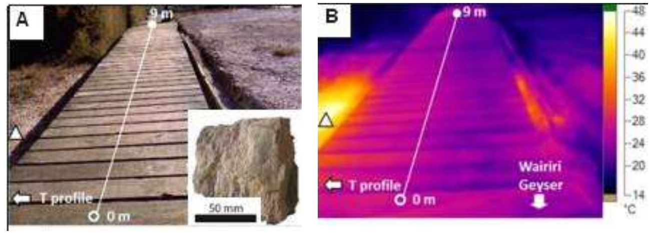


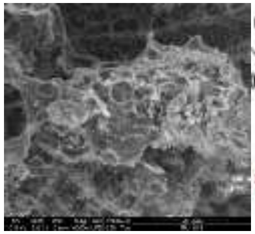


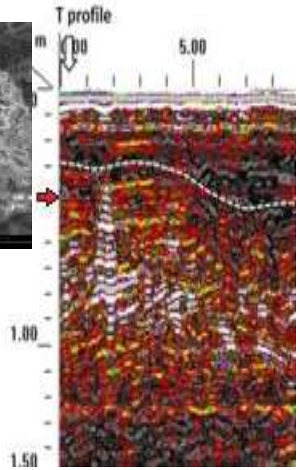
100 °C at 0.5 m depth

Extensive subsurface alteration

Example 3 shows …



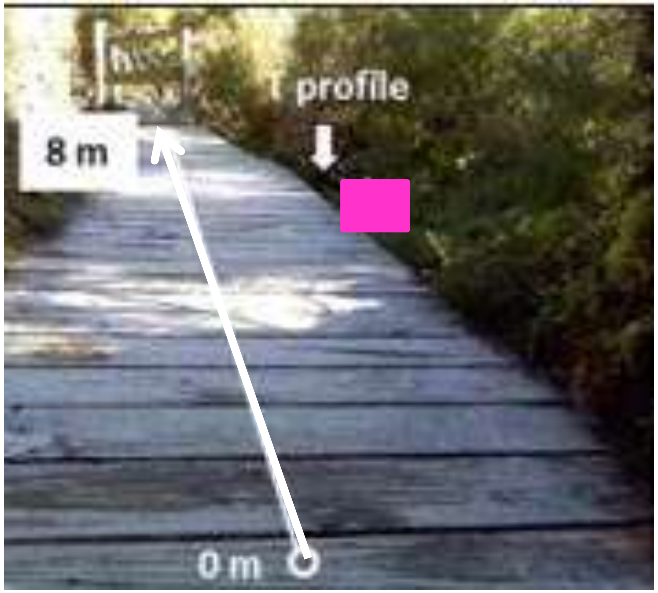


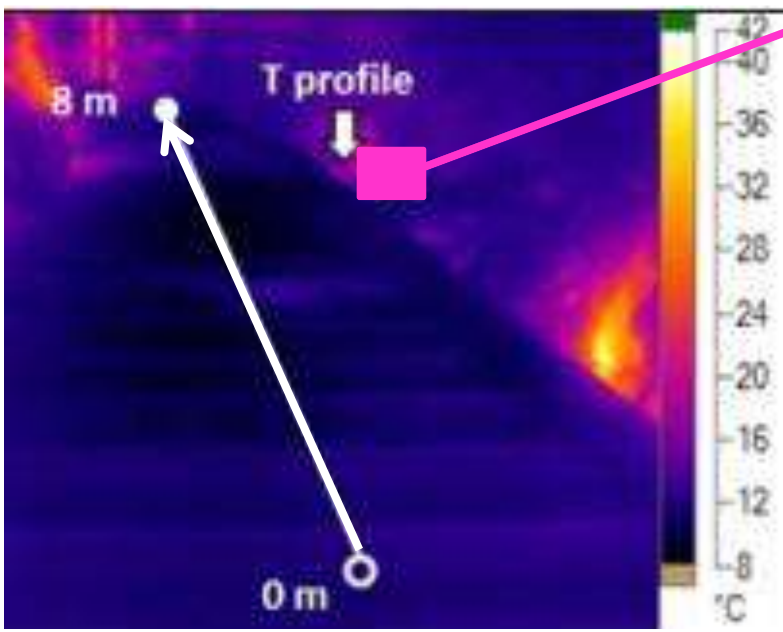


- IR shows elevated surface temperatures
- SEM shows extensive heat overprinting of sinter
- GPR profile reveals extensive subsurface alteration
- 100 °C at 0.5 m depth = elevated temperatures in subsurface

Conclusion: Prolonged and extensive elevated subsurface temperatures at surface altering sinter

EXAMPLE 4



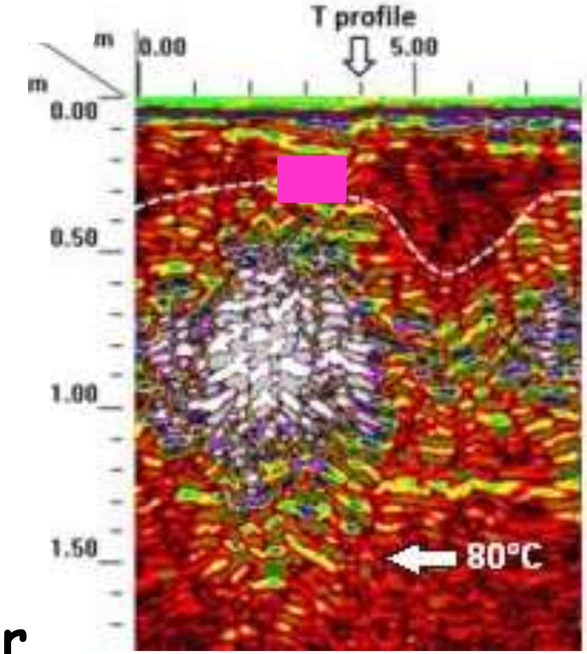


Opal-CT sinter

FWHM = 2.7

Isolated hot spots

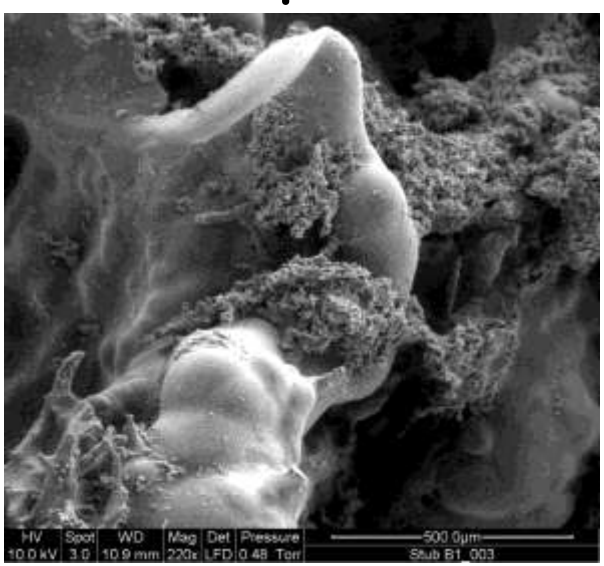
EXAMPLE 4

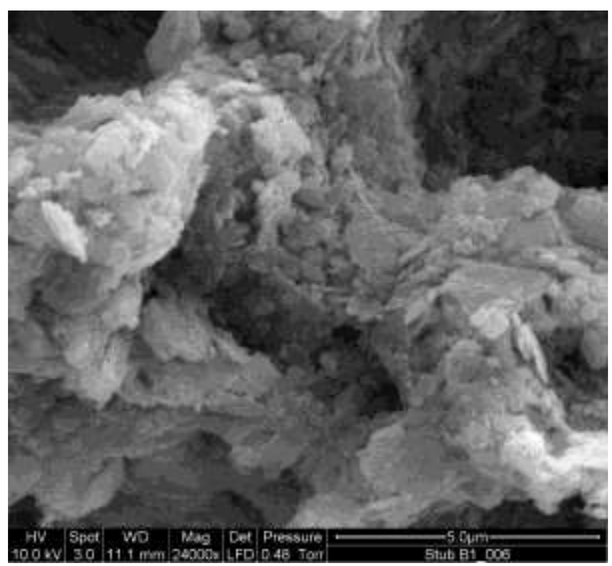


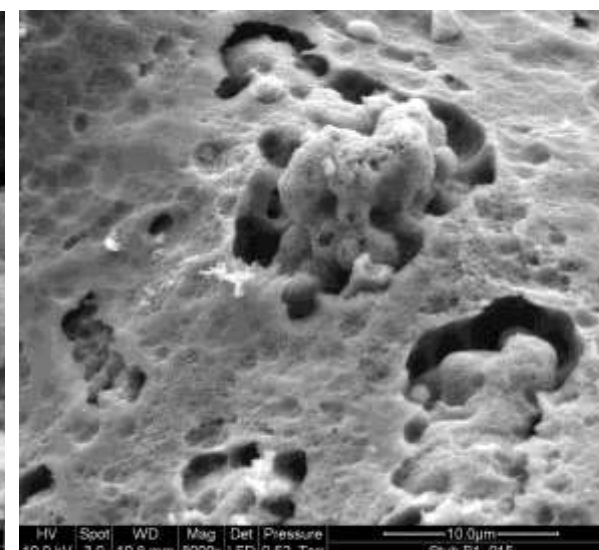
Semi-altered subsurface

Elevated T

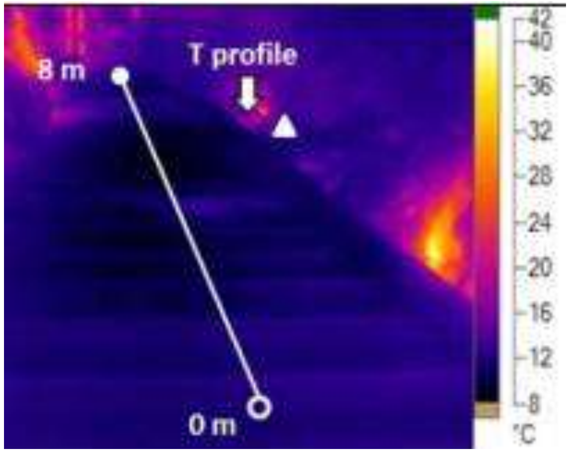
Altered opal-CT sinter

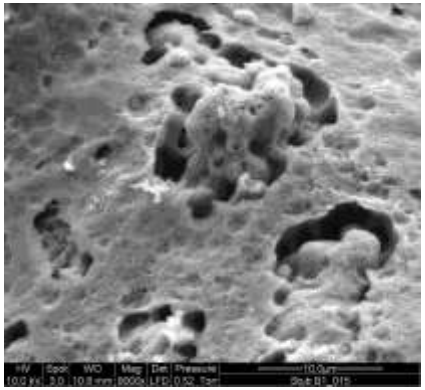


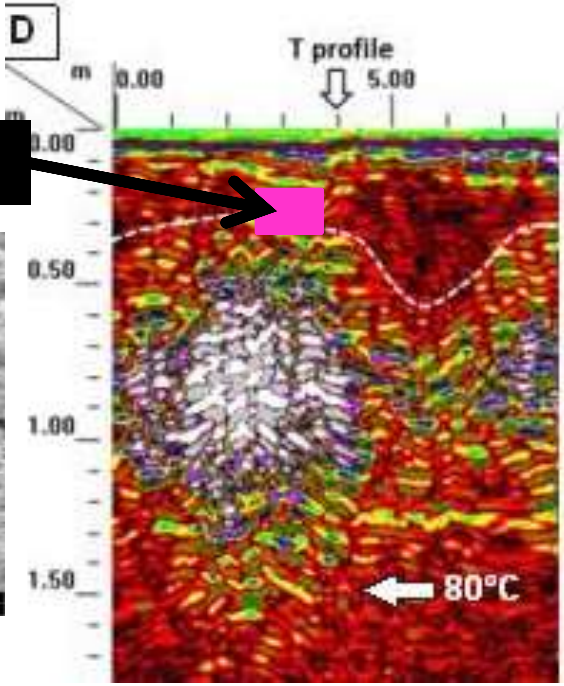




Example 4 shows …







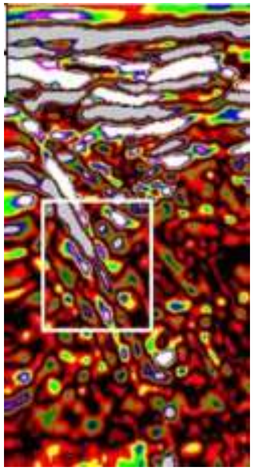
- Isolated hot spots at the surface
- Considerable heat overprinting of sinter (dissolution)
- Semi-altered subsurface shown by GPR profile
- Elevated subsurface temperatures (80 °C at 1.5 m)

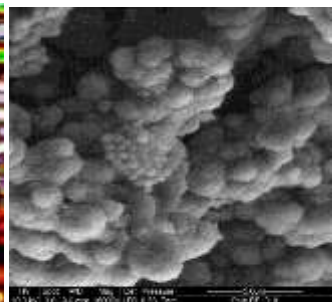
Conclusion: Sustained heat in subsurface for long enough to overprint sinter at the surface

4 examples show how heat moves around in the shallow subsurface and can be mapped using a combination of techniques

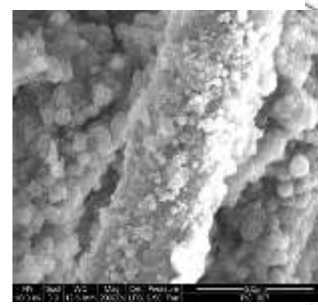
Unaltered sinter

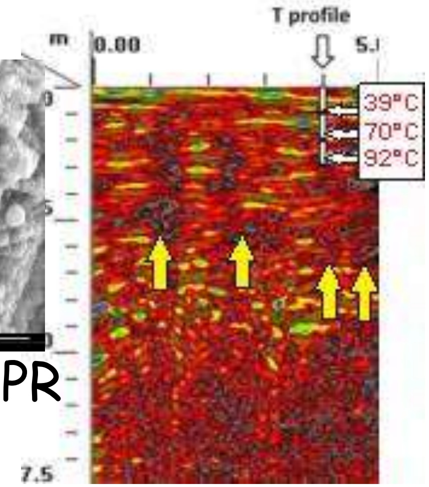
52°C





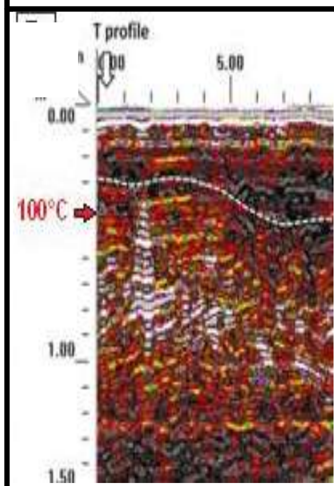
Unaltered GPR
52°C at 1 m
Recent heat

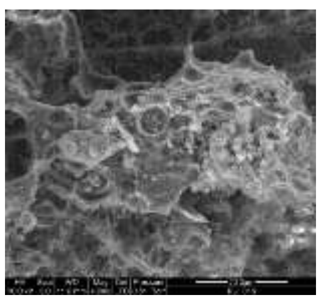




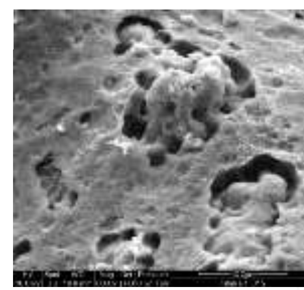
Highly altered GPR
92°C at 1.5 m
Recent heat

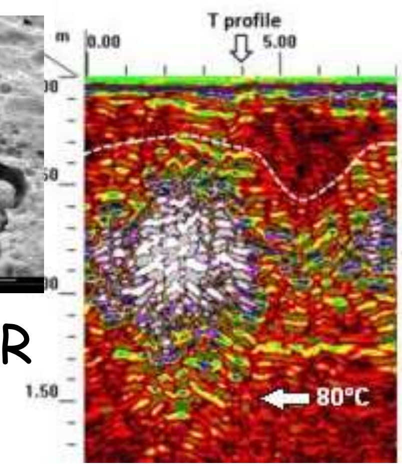
Altered sinter





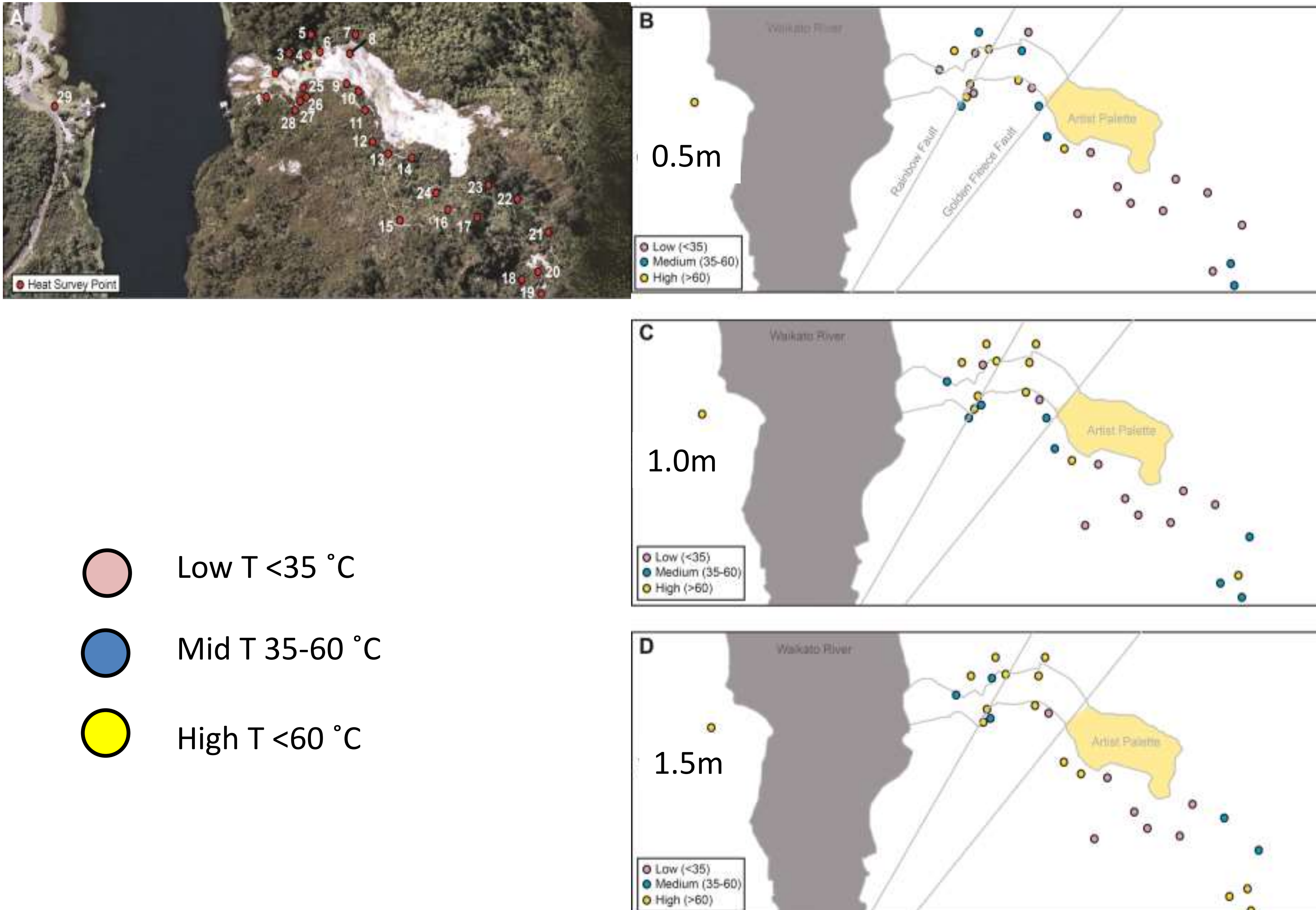
Highly altered GPR
100°C at 0.5 m
Prolonged heat

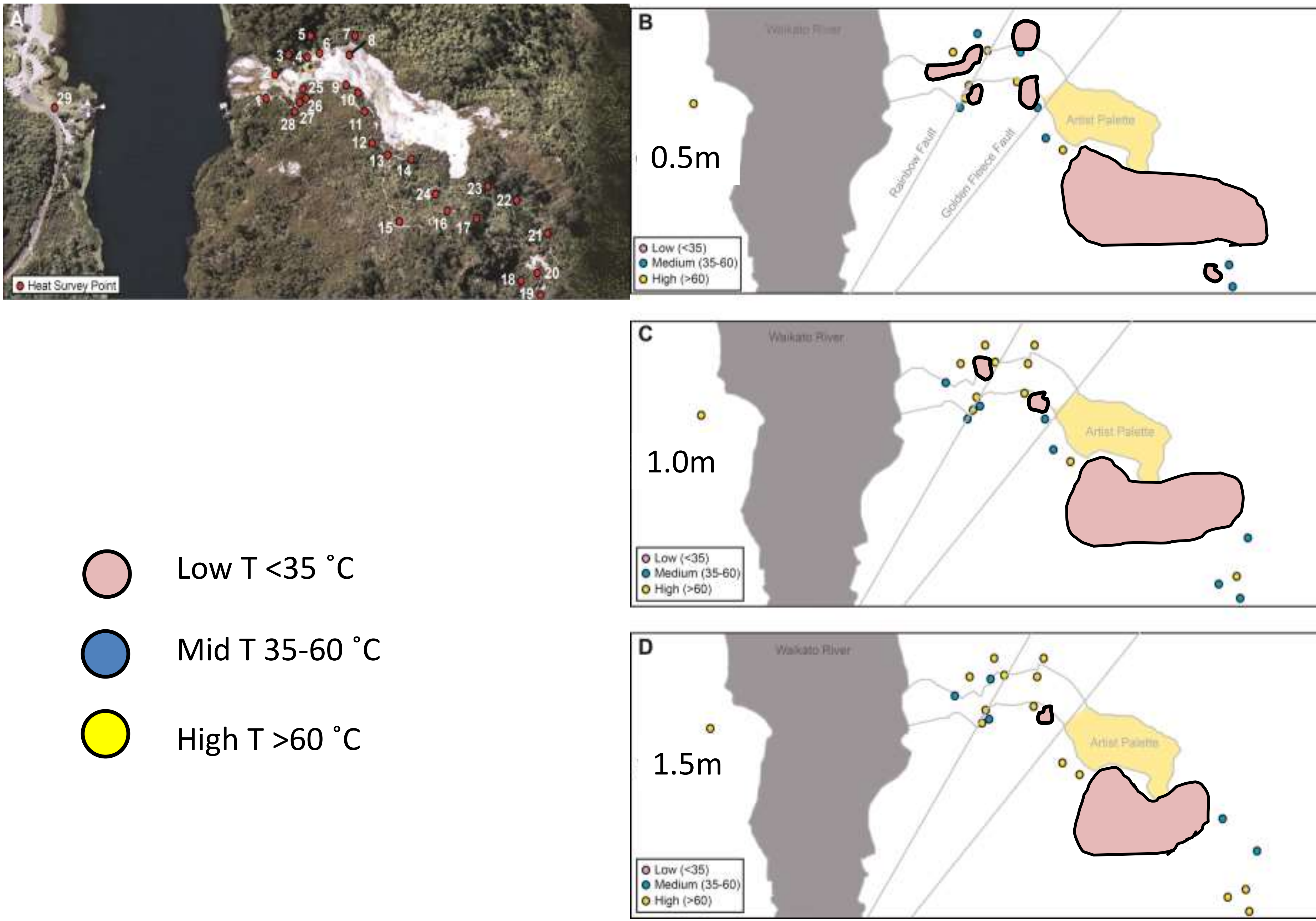


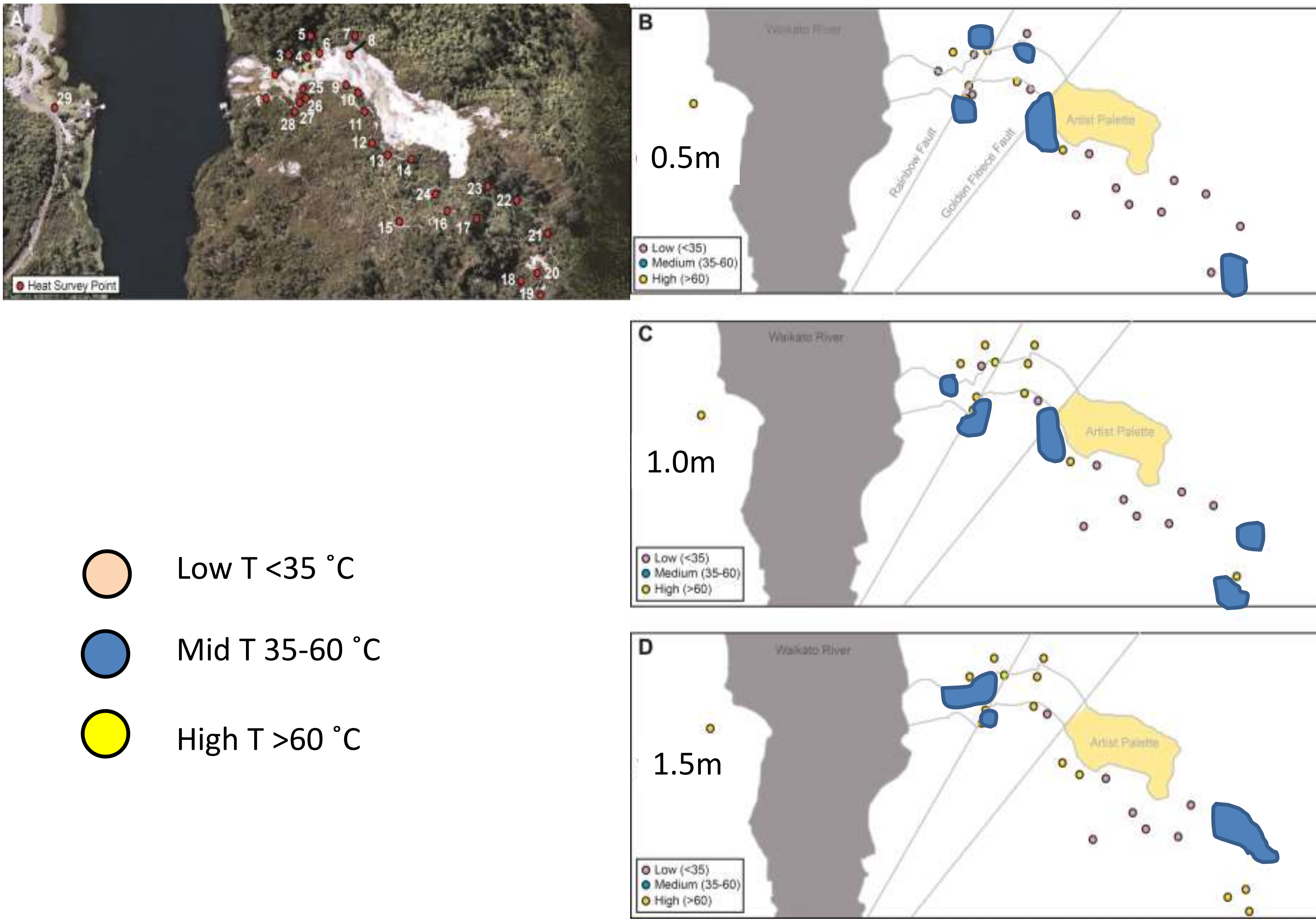


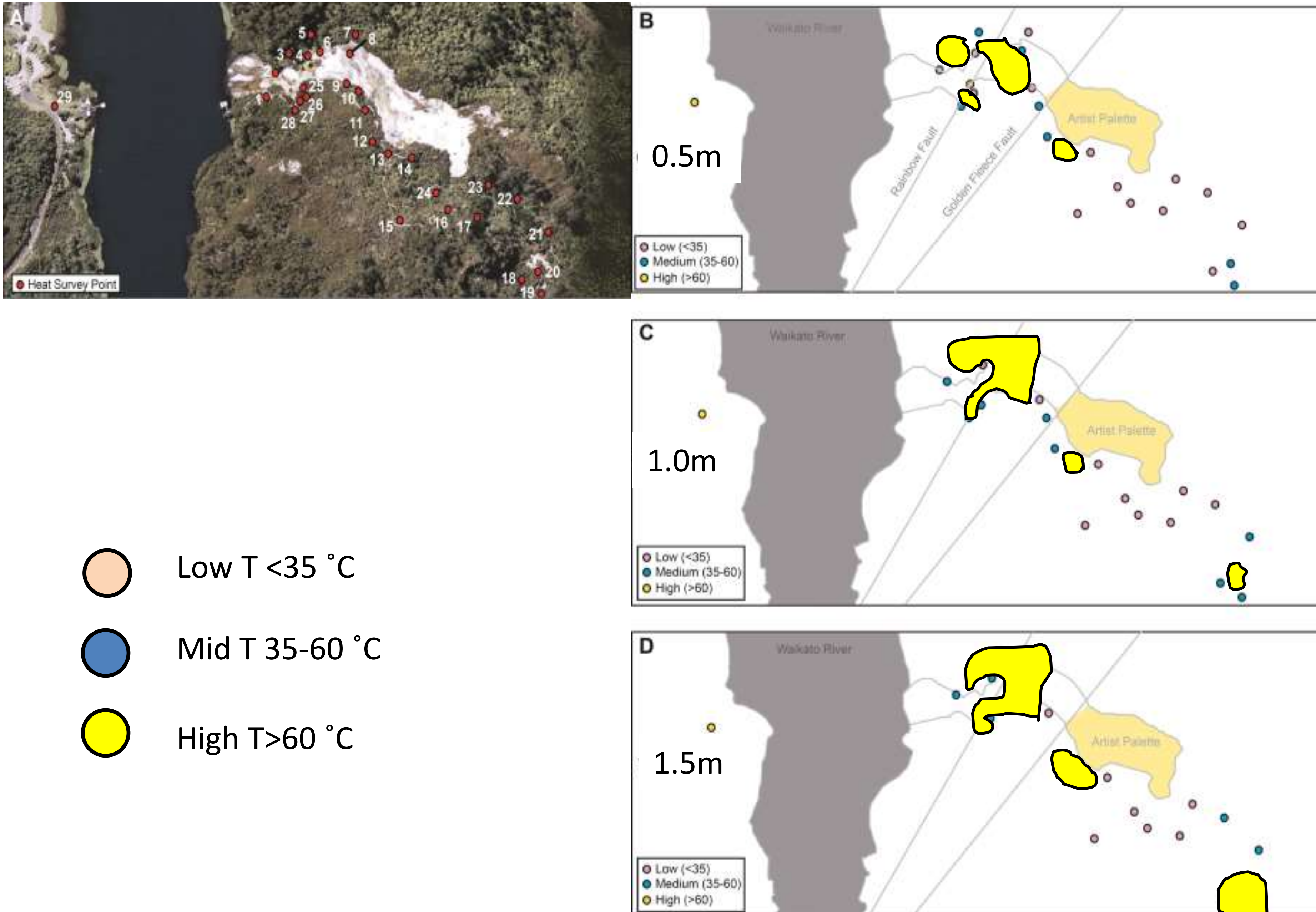
Semi-altered GPR
80°C at 1.5 m
Prolonged heat

Combine with shallow subsurface temperature measurements


A
Heat Survey Point
B
Waikato River
Artist Palette
Rainbow Fault
Golden Fleece Fault
0.5m
Low (<35)
Medium (35-60)
High (>60)
C
Waikato River
Artist Palette
1.0m
Low (<35)
Medium (35-60)
High (>60)
D
Waikato River
Artist Palette
1.5m
Low (<35)
Medium (35-60)
High (>60)
Low T <35 ˚C
Mid T 35-60 ˚C
High T <60 ˚C

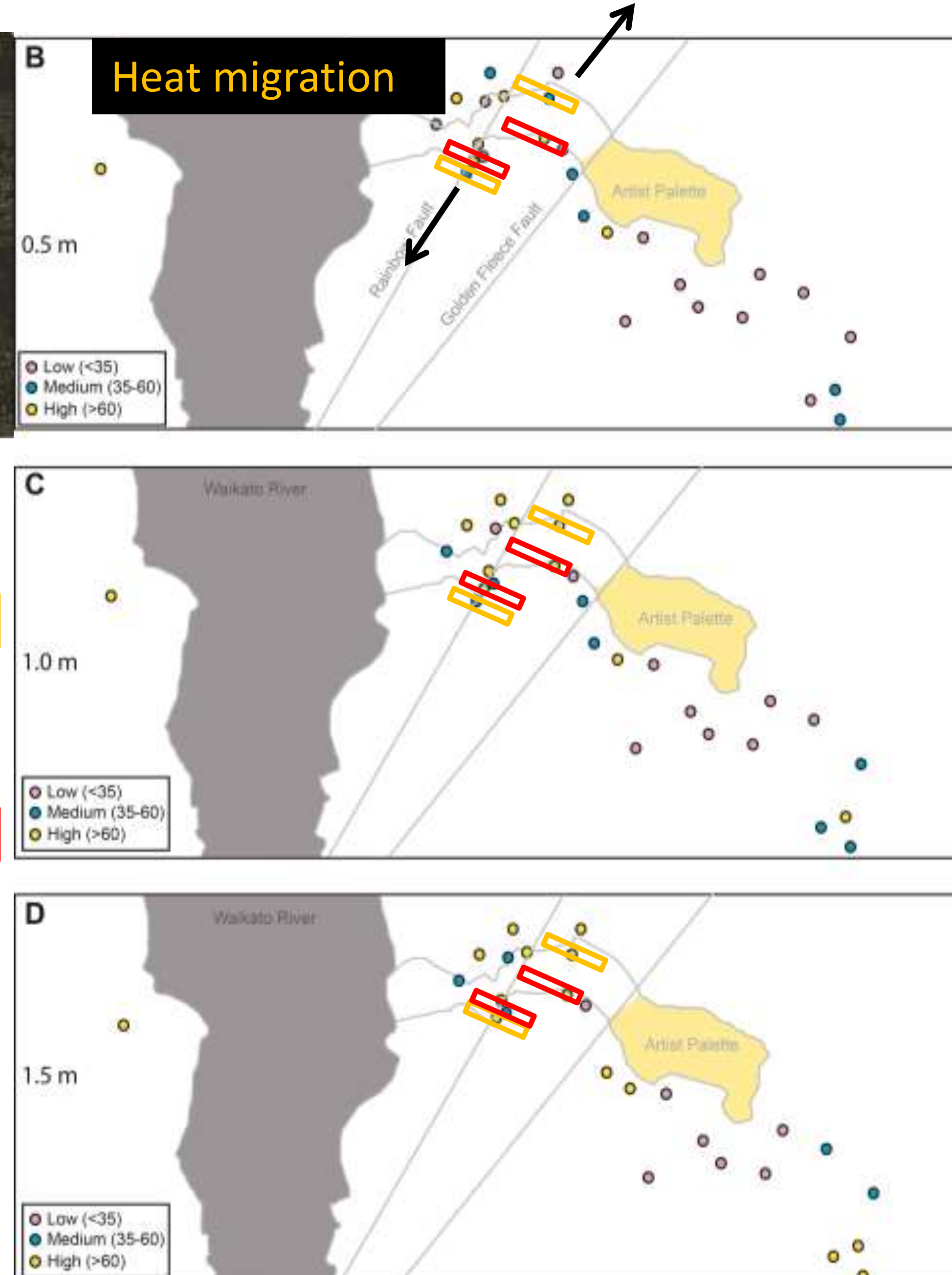

A
Heat Survey Point
B
Waikato River
Artist Palette
Rainbow Fault
Golden Fleece Fault
0.5m
Low (<35)
Medium (35-60)
High (>60)
C
Waikato River
Artist Palette
1.0m
Low (<35)
Medium (35-60)
High (>60)
D
Waikato River
Artist Palette
1.5m
Low (<35)
Medium (35-60)
High (>60)
Low T <35 ˚C
Mid T 35-60 ˚C
High T >60 ˚C


A
Heat Survey Point
B
Waikato River
Artist Palette
Rainbow Fault
Golden Fleece Fault
0.5m
Low (<35)
Medium (35-60)
High (>60)
C
Waikato River
Artist Palette
1.0m
Low (<35)
Medium (35-60)
High (>60)
D
Waikato River
Artist Palette
1.5m
Low (<35)
Medium (35-60)
High (>60)
Low T <35 ˚C
Mid T 35-60 ˚C
High T >60 ˚C



A
Heat Survey Point
B
Waikato River
Artist Palette
Rainbow Fault
Golden Fleece Fault
0.5m
Low (<35)
Medium (35-60)
High (>60)
C
Waikato River
Artist Palette
1.0m
Low (<35)
Medium (35-60)
High (>60)
D
Waikato River
Artist Palette
1.5m
Low (<35)
Medium (35-60)
High (>60)
Low T <35 ˚C
Mid T 35-60 ˚C
High T>60 ˚C

Location Data			Temperature (°C)			
Location #	Nearest Feature	GPS Coordinates (NZMG)	</= 0.5m depth	at 1.0m depth	at 1.5m depth	
1	Diamond geyser	E2784618 N6298506	51.8	N/A	N/A	
2	Hydrothermal eruption crater	E2784637 N6298544	23.2	37.2	46.9	
3	Map of Africa	E2784686 N6298563	20.8	33.1	36.6	
4	Lookout (North)	E2784654 N6298565	68.6	74.4	73.8	
5	Lookout mudpool	E2784688 N6298589	55.3	76.8	86.6	
6	Devils throat	E2784697 N6298563	66.7	74.3	77.1	
7	End of eastern boardwalk	E2784737 N6298584	24.8	62.2	69.6	
8	Western side Fred and Maggies	E2784734 N6298561	38.5	69.5	92.1	2
9	West boardwalk - fossilised outcrop	E2784731 N6298521	100	N/A	N/A	3
10	VPWG	E2784743 N6298514	30.1	32	34.5	
11	Elephant rock	E2784752 N6298489	41.2	44.2	N/A	
12	EW steaming ground area	E2784769 N6298474	58	59	N/A	
13	1655 - Opposite mudpool	E2784786 N6298438	96.5	99.3	99.2	
14	Lookout over artists palette	E2784820 N6298431	24.1	28.1	31.2	
15	Turutu signal	E2784804 N6298343	13.6	18.7	30	
16	Turutu signal 2	E2784859 N6298394	16	17.9	19.7	
17	Lookout bend	E2784872 N6298367	15.1	19	21	
18	Palm tree curve to the left	E2784911 N6298351	13.3	15	16.4	
19	Before mud pool	E2784963 N6298280	33.2	48.8	62.9	
20	Apex mud pool	E2784993 N6298266	46.2	59.7	73.3	
21	East of mud pool	E2784985 N6298300	54.3	79.6	94.2	
22	Corner 90° curve to the left	E2785009 N6298325	25.3	36.2	43	
23	Ponga signal	E2784972 N6298385	20	28.3	37	
24	Between ponga and bridge	E2784933 N6298401	19.1	26.2	29.6	
25	Before soda fountain	E2784676 N6298502	99.4	99.2	99.7	
26	Before soda fountain	E2784674 N6298512	29.5	43	53.3	
27	Before soda fountain	E2784667 N6298499	72.9	75	80.1	4
28	Soda fountain	E2784661 N6298488	45	51.7	N/A	1
29	In front of reception grounds	E2784329 N6298480	100	100	100	



NEWLY-HEATED GROUND
Ground heating up but not hot enough for sustained period of time as no sinter alteration yet

SUSTAINED HEAT
In subsurface + sinter alteration

Low T <35 ˚C

Mid T 35-60 ˚C

High T >60 ˚C

This method would also show if localised areas were cooling down

If so, we would expect …

GPR = highly altered subsurface

SEM/XRD = heat-affected sinter

IR = cold ground surface

1 m deep T measurements = cold ground

Useful for the following:

- Map sites of shallow heat flow (past and present)
- Map system boundaries
- Track migration of heat flow in shallow subsurface
- Identify if shallow subsurface is heating up or cooling down over time
- Identify potential future locations that may have issues due to ground heating up
  e.g., farmland, housing areas
- Good to do repeat surveys to see how extraction or reinjection of fluids is altering the shallow subsurface

Acknowledgements

FRST and SRF for funding these projects

Amy Dougherty
Gary Smith
Cheng Yii Sim
Ruben Yague
Isaac Smith