Exploration Techniques

The Geothermal Institute
University of Auckland

Bridget Lynne

Santiago de Chile, 26-29 May 2014

GEOTHERMAL INSTITUTE

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Exploration Techniques

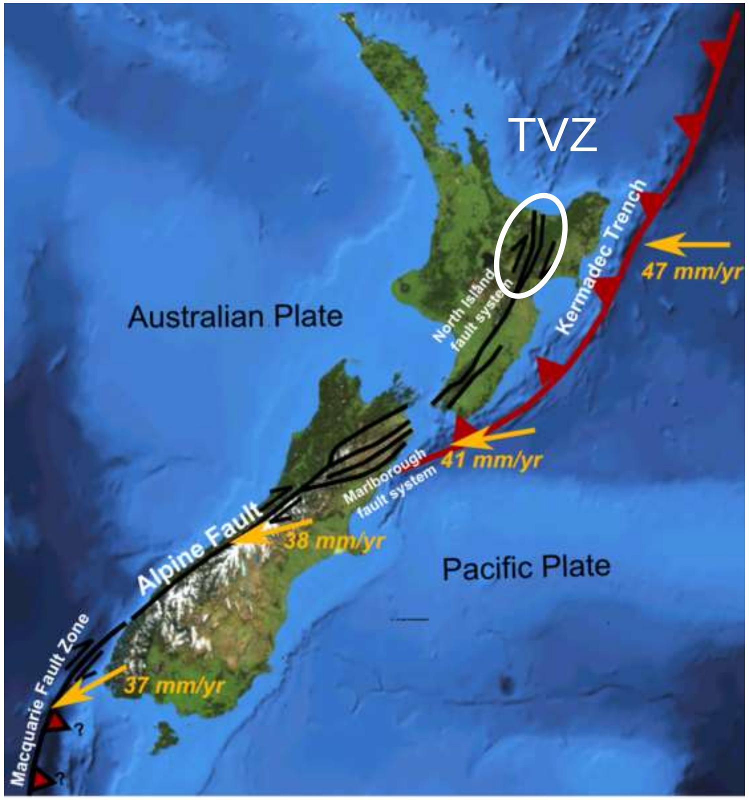
Bridget Y. Lynne

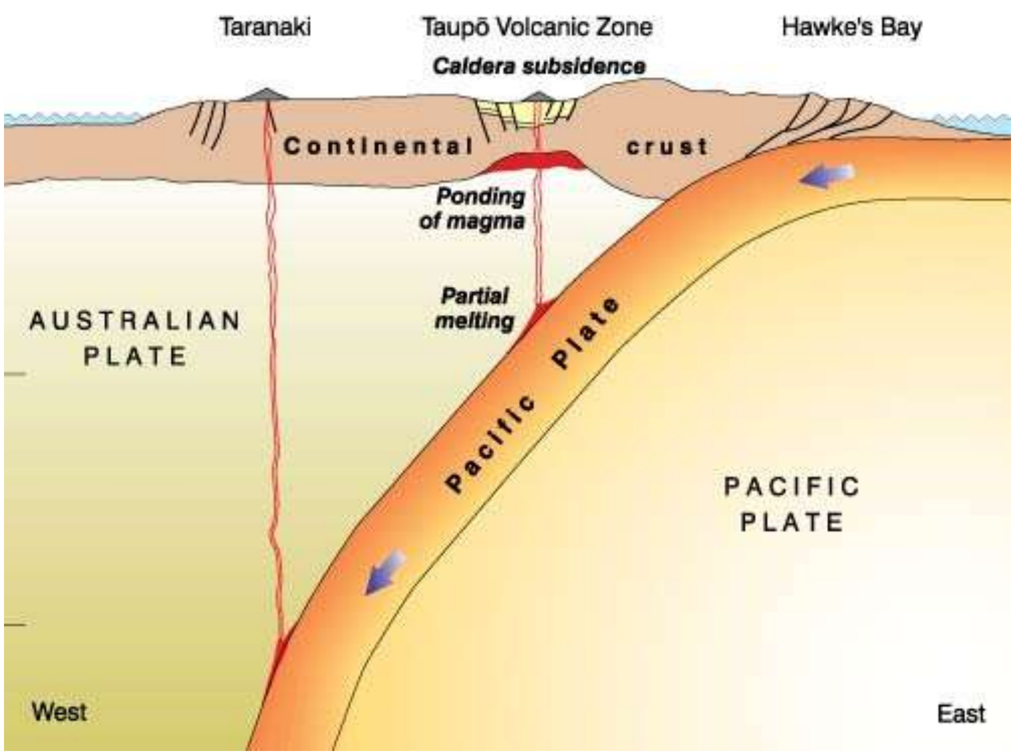
New techniques in geothermal exploration

NZ geological setting is favourable for geothermal activity

Pioneers in geothermal energy development

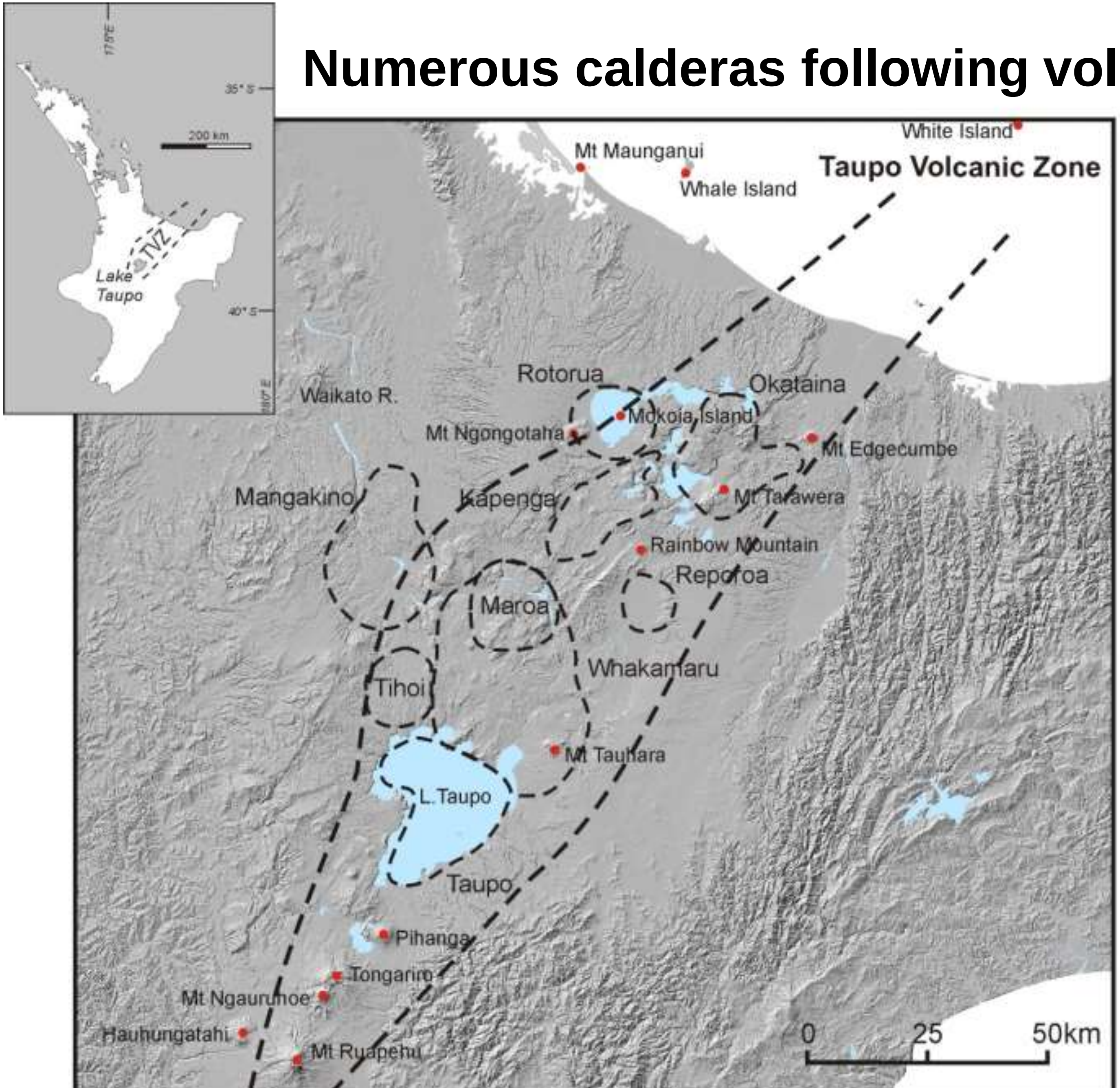
New Zealand situated on plate boundary = subduction → high heat flow areas active volcanism active faulting

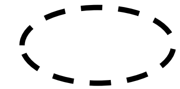




http://www.teara.govt.nz/en/volcanoes/2/2

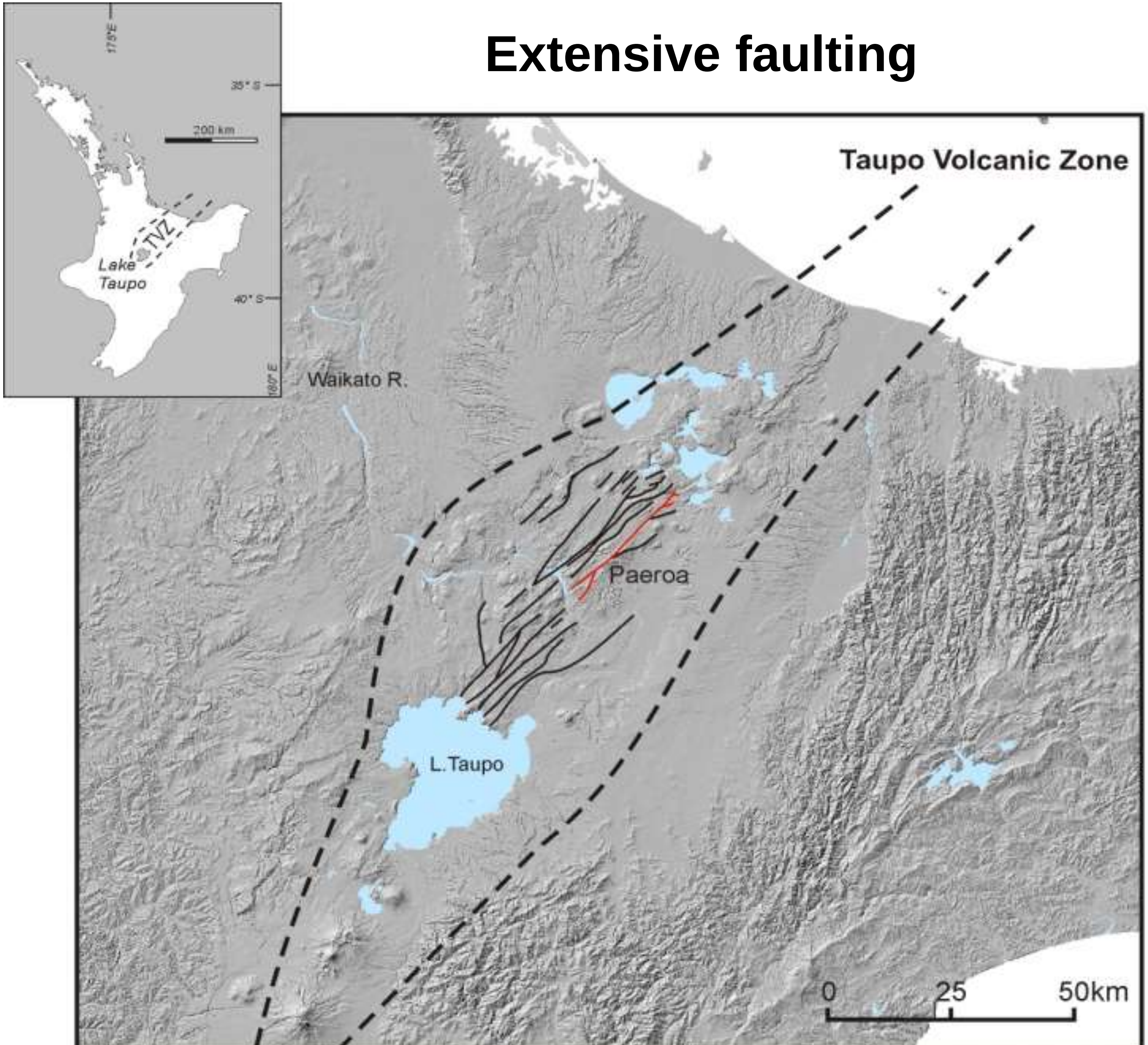
Numerous calderas following volcanism





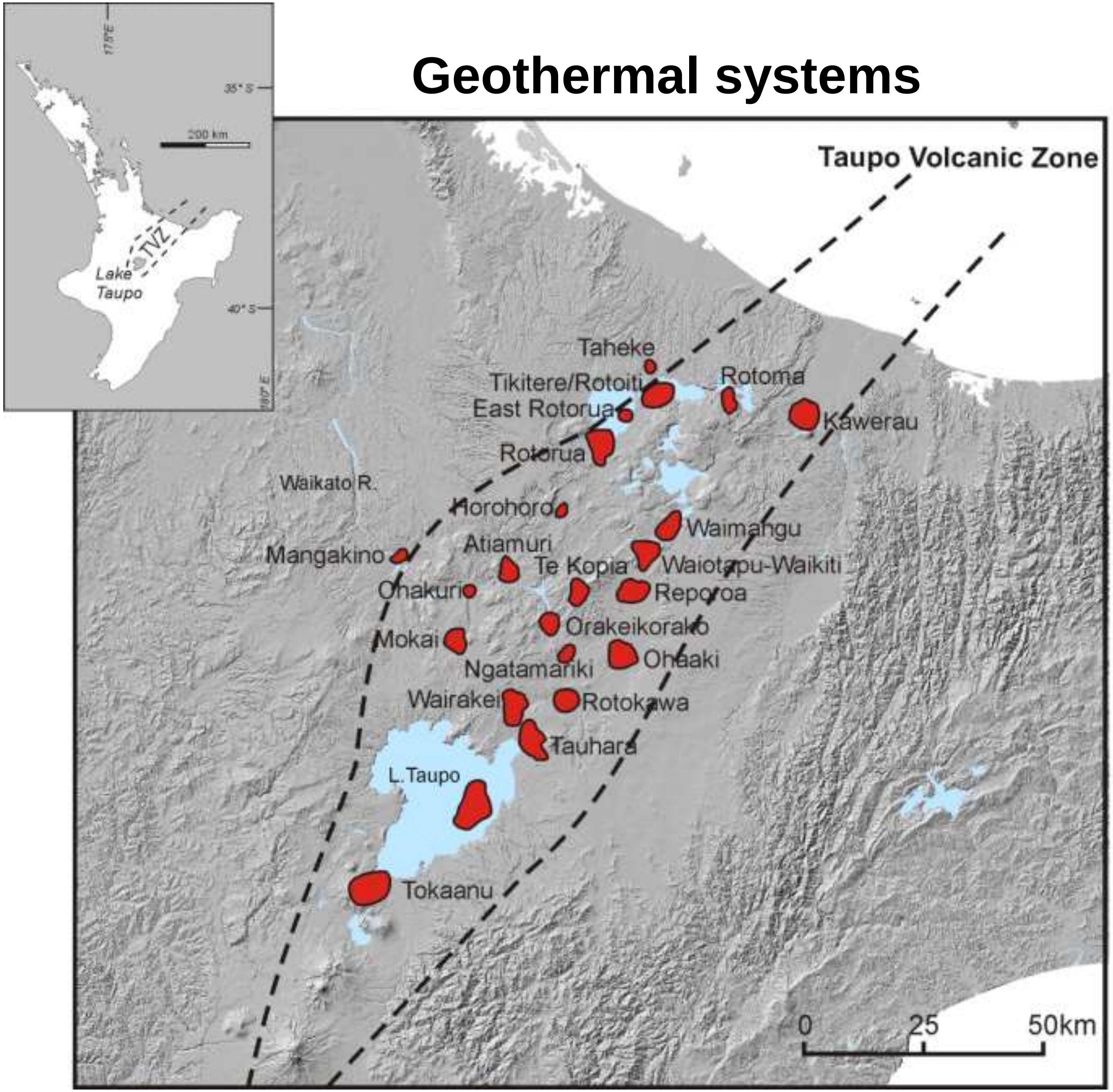
calderas

Extensive faulting



Faults

Geothermal systems



High heat flow

20 mid-high T systems

15 over 220 °C

750 Mw generated today

Wairakei 1950: Exploration Phase

1958: World's first production from a liquid dominated system

New Zealand has history of geothermal education

Geothermal Institute 1979-2002
(1 year full time course)

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Followed by **University of Auckland** short courses and the Masters of Energy Degree

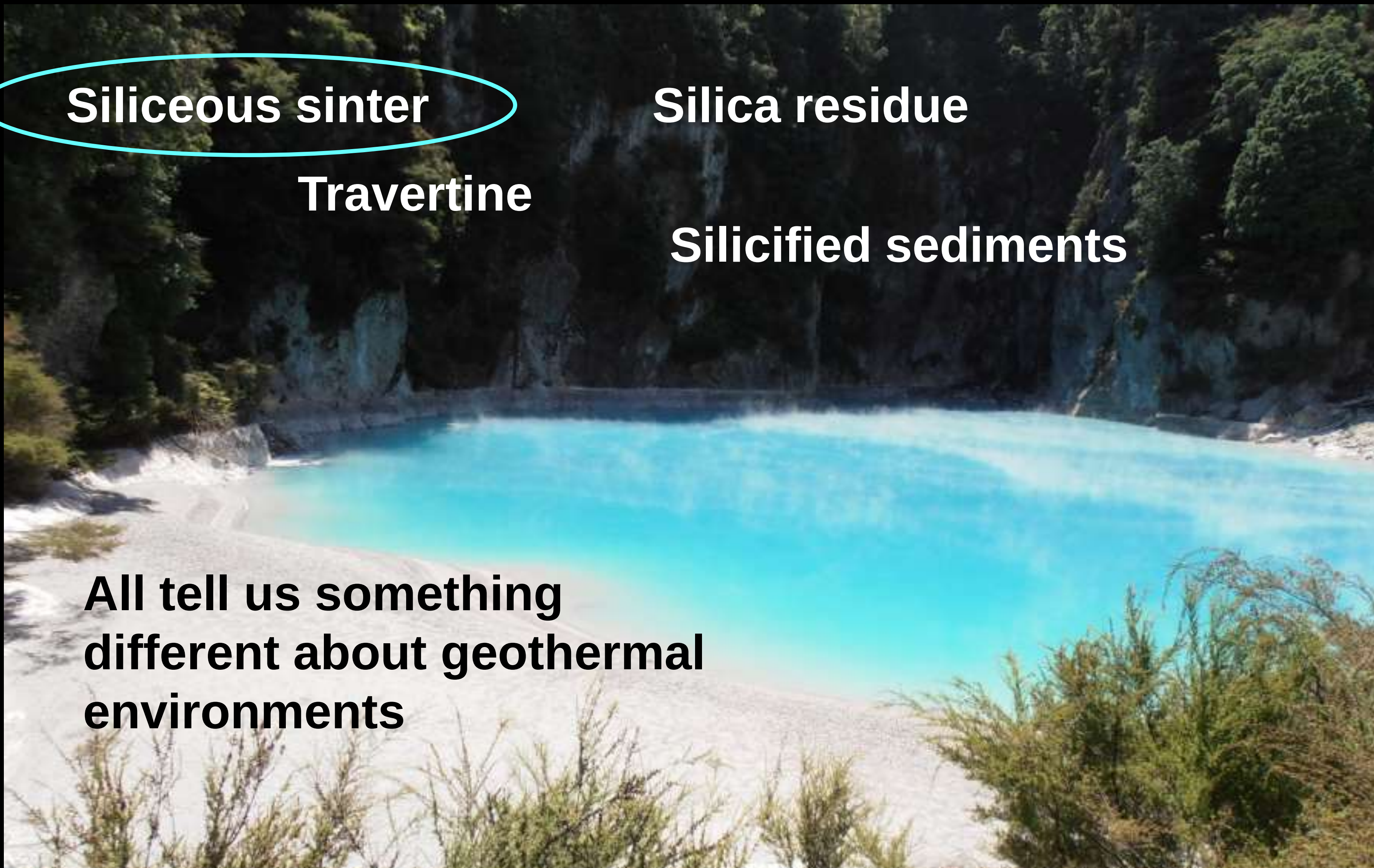

Where are we in 2012?
Most obvious geothermal sites known
Now need ways to find more obscure sites

New Geothermal Exploration Techniques

New Exploration Techniques

1. Hot spring rocks
2. Ground Penetrating Radar
3. Infrared imaging
4. Joint Geophysical Imaging
5. Downhole seismometers

Recognition and significance of hot spring rocks



Silicified sediments

Indicate thermal fluid flow but usually located a long way from the geothermal source or hot up flow zone

Least significant

Silica Residue

Dissolution of silica-rich country rock (ignimbrites)

Re-deposition of silica to form thin veneer

Not indicative of thermal water but do indicate heat

Travertine Deposits

Indicate cooler outflow zones (or CO_2 rich reservoir)

More useful now with improved technology that can use cooler fluids

How do sinters form?

Alkali chloride hot spring water discharges

↓

Cools to < 100°C

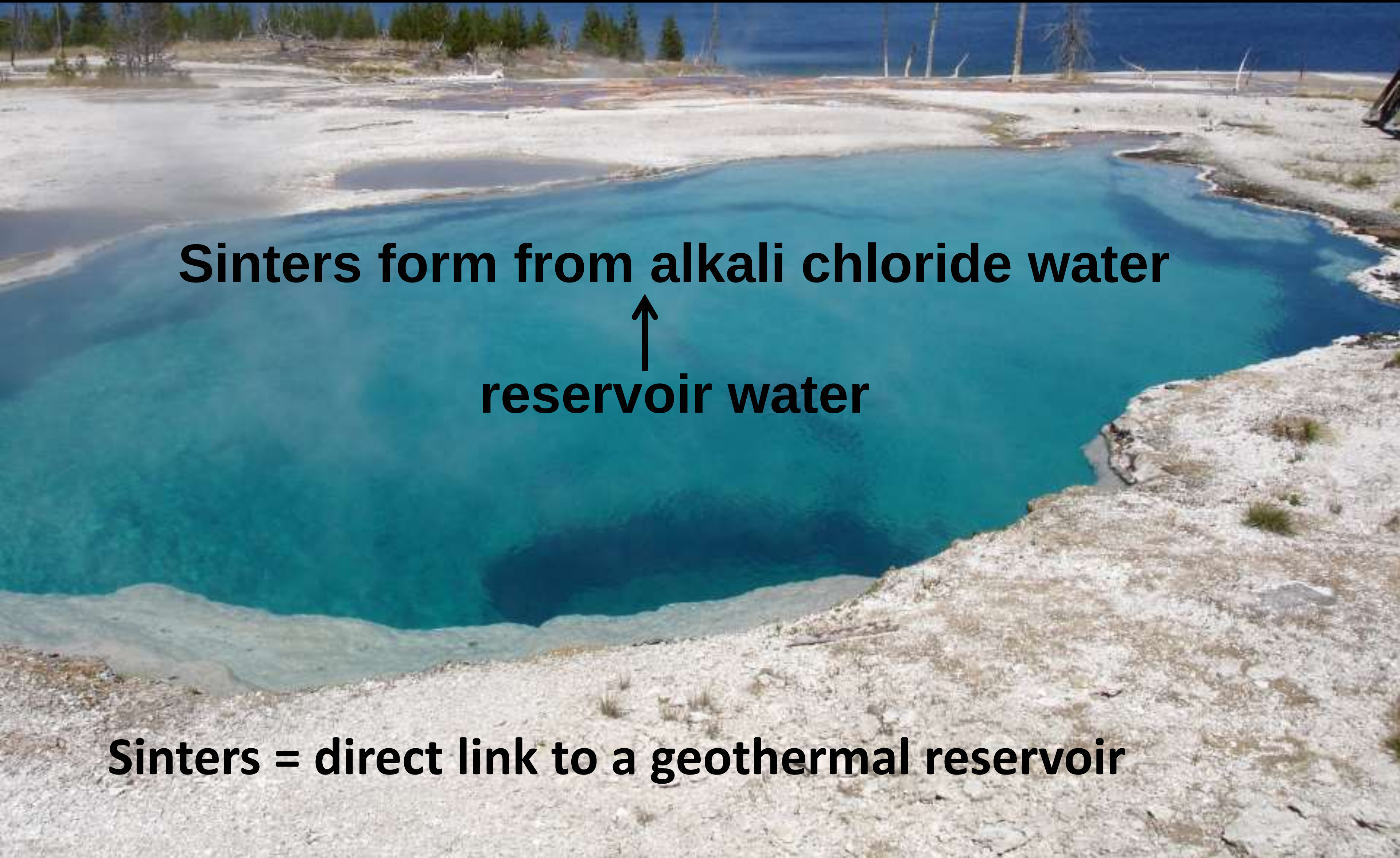
↓

Silica precipitates + accumulates

↓

sinter

WHY ARE SINTERS IMPORTANT?



Ancient sinters represent sites where there is now no surface discharge

There location provides a clue to a possible blind geothermal system

Example of:

No present-day hot springs but …

36 MW geothermal power plant

and extinct sinter deposit

1900 year old sinter outcrop preserved

Steamboat Springs, Nevada, USA
45 MW plant

How can we use sinter and associated textures for exploration?

By understanding the modern hot spring setting we can reconstruct paleo-flow conditions from historic sites

Temperature indicating microbes

Specific types of coloured microbial mats grow in different water temperatures

Silica precipitates from hot spring water

Initially silica deposits as opal-A silica

(amorphous silica)

coats

entombs

silicifies

preserves everything it deposits on

creating distinctive temperature indicating sinter textures

3 broad hot spring thermal gradients

Vent to mid-slope to distal apron

High temperature **>59 °C**
Vent/near-vent

Mid temperature **35 - 59°C**

Mid slope

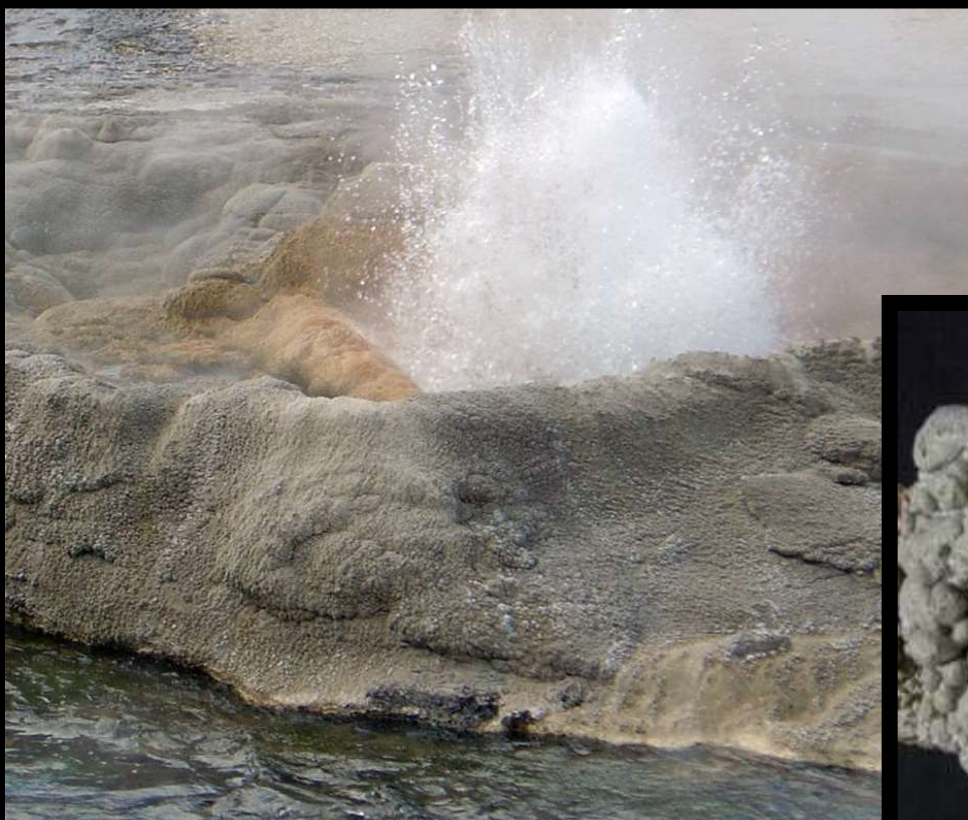
Low temperature **<35 °C**

Distal slope

From Cady and Farmer (1996)

High temperature environments (>59 °C)

Eruptive hot springs >90°C = geyserite textures



Form from intermittent wetting and drying in splash zone

Geyserite sinter textures

Abiotic Formation Process

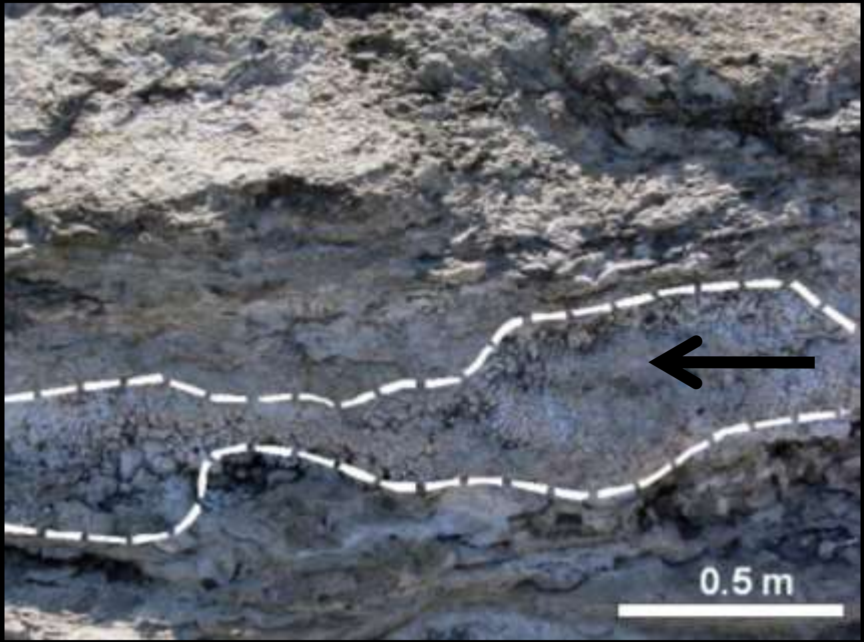
Multiple stacks of convex laminations

Geyserite texture in outcrop

Steamboat Springs, Nevada

Indicates historic discharge of high temperature alkali chloride fluids

Important for exploration



3 broad hot spring thermal gradients

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Vent/near-vent

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Mid slope

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Distal slope

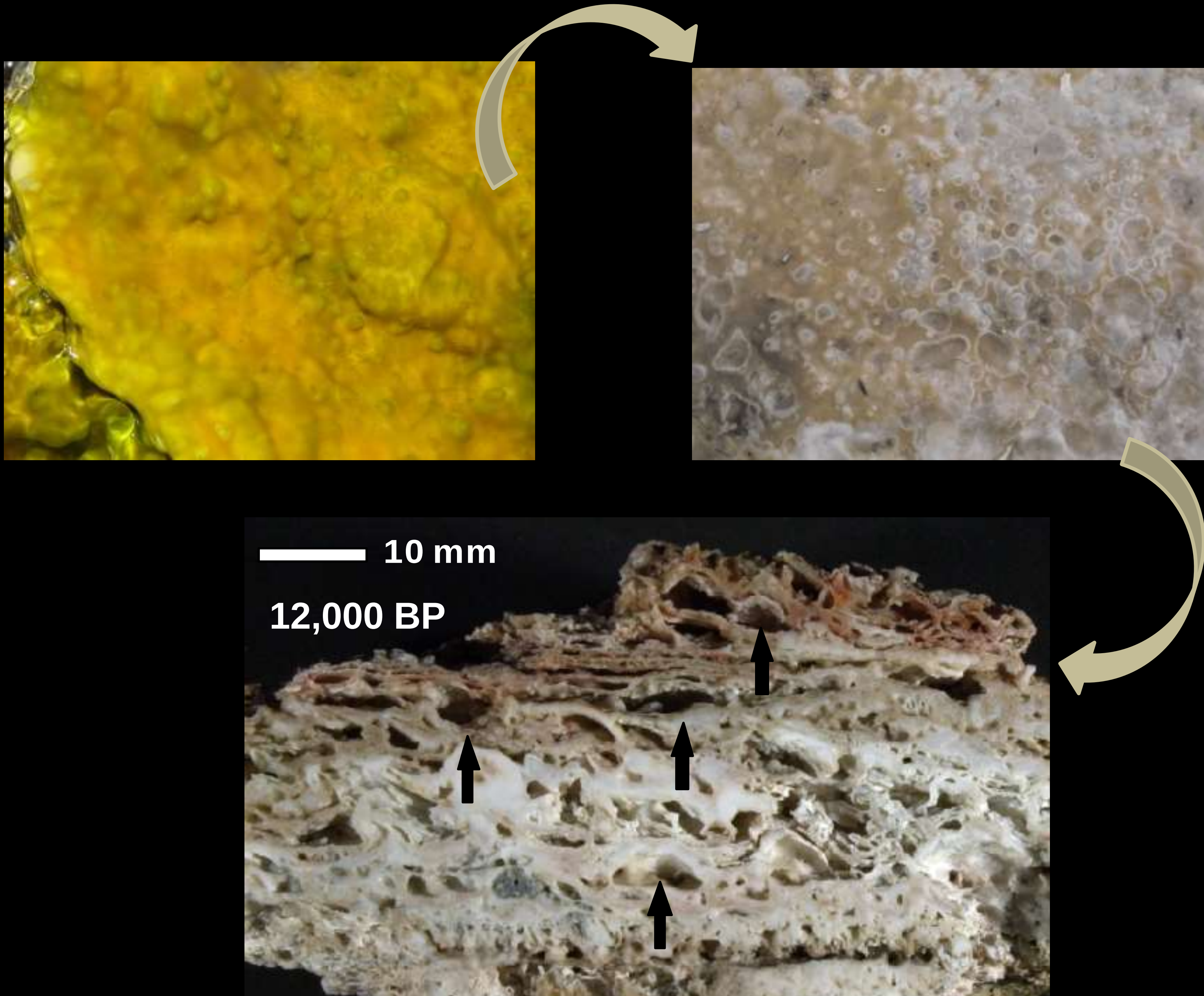
From Cady and Farmer (1996)

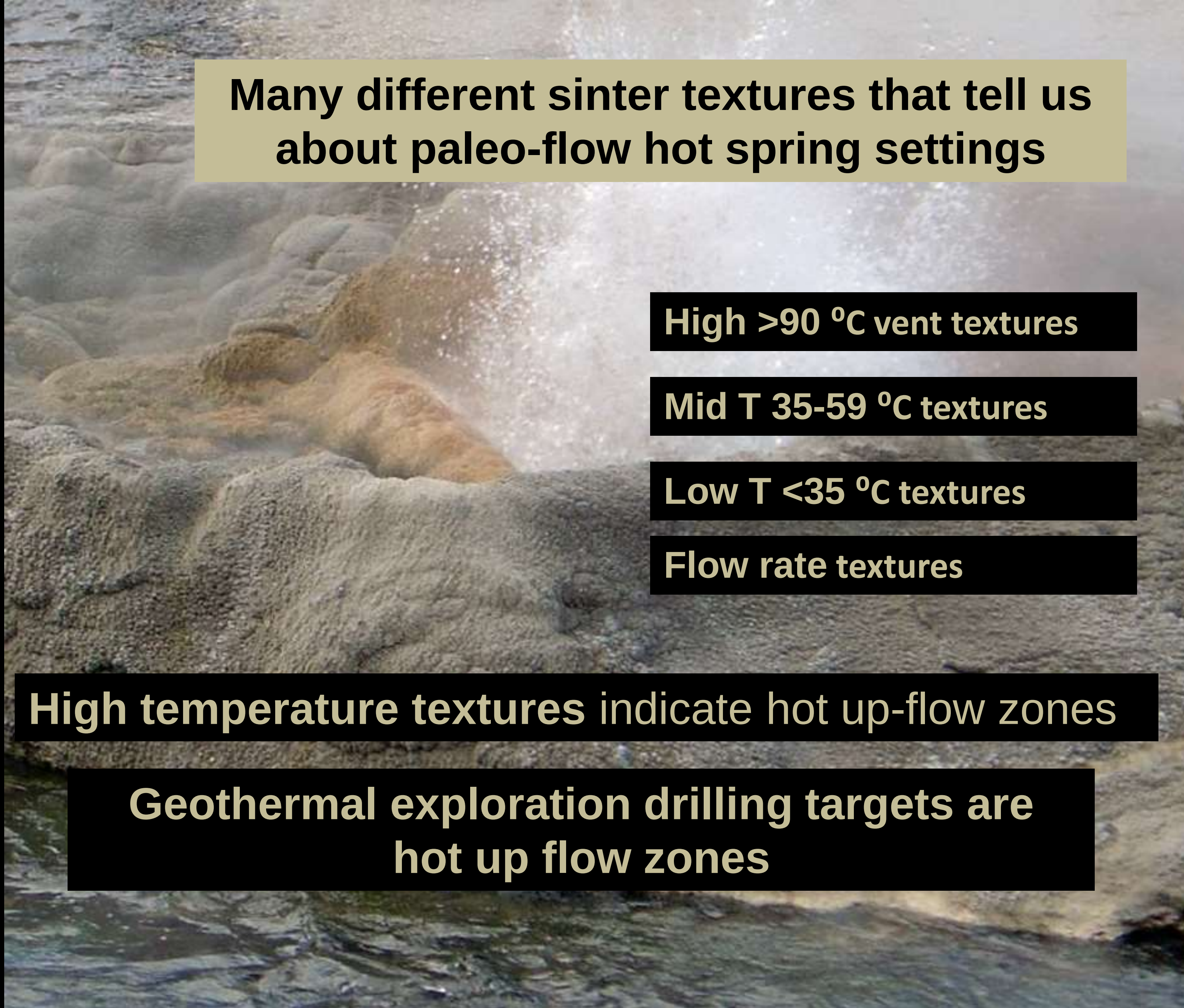
Mid-temperature environments (35-59 °C)

Mid-slope
pools and channels

Formation Process
Microbial silicification

Bubblemat texture


10 mm
12,000 BP



Many different sinter textures that tell us about paleo-flow hot spring settings

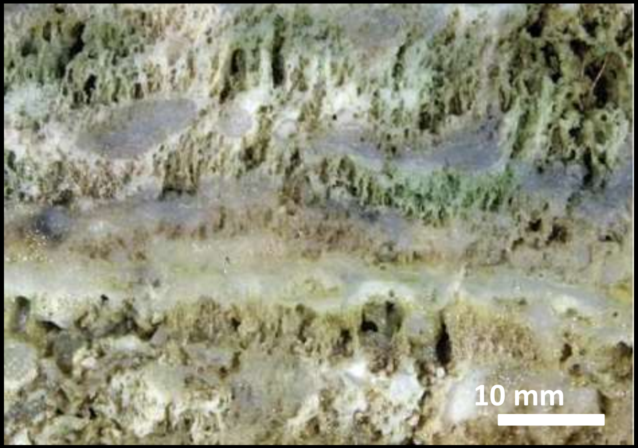
- **High >90 ^{o}C vent textures**
- **Mid T 35-59 ^{o}C textures**
- **Low T <35 ^{o}C textures**
- **Flow rate textures**

High temperature textures indicate hot up-flow zones

Geothermal exploration drilling targets are hot up flow zones

Would you recognise these textures in the field...

… and understand their significance ?



SINTER DATING - Regional Overview

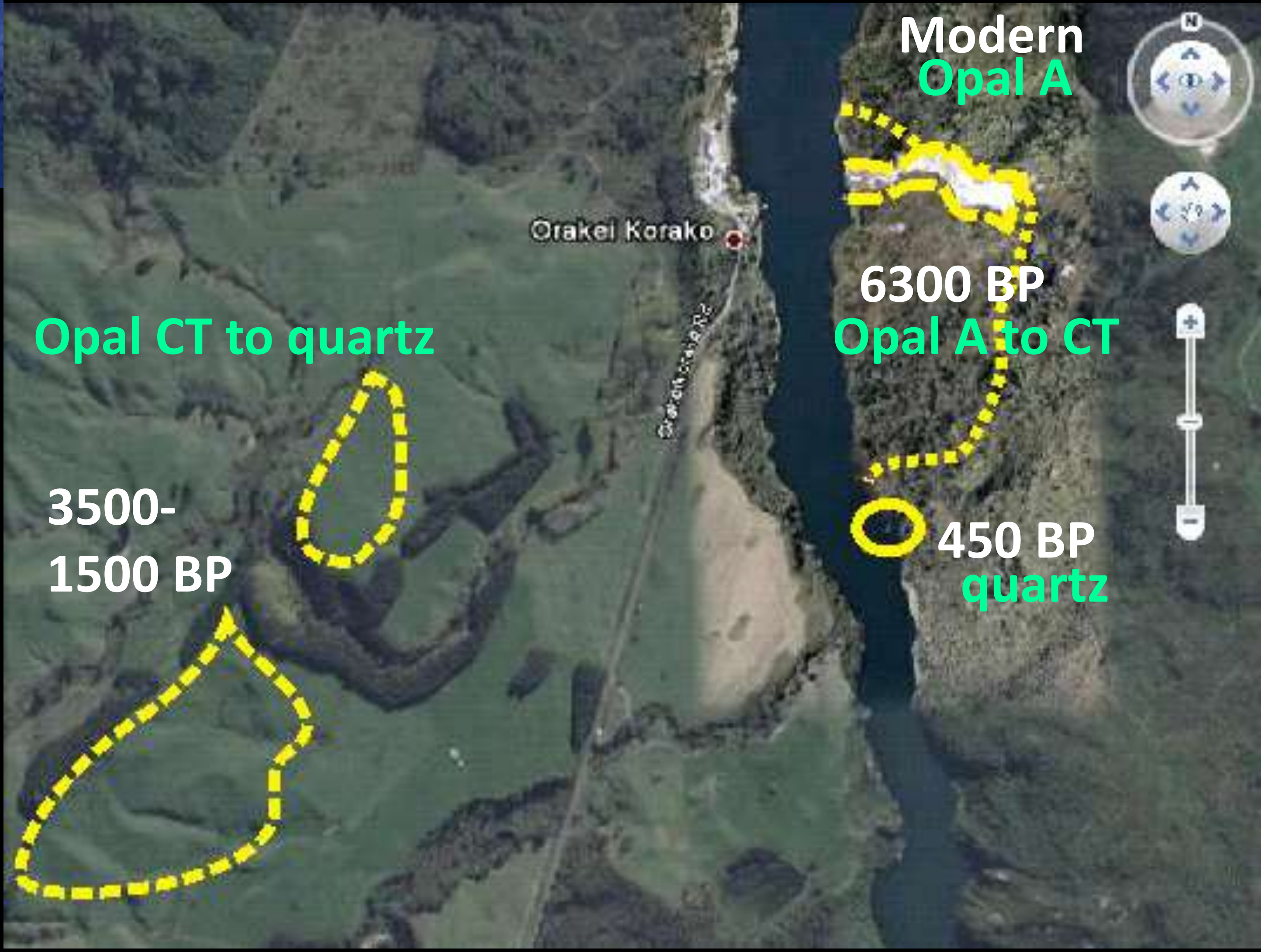
- AMS ^{14}C dating of sinters
  - **Maps the timing of discharging alkali chloride water on a REGIONAL SCALE**
- Establishes fluid flow migration trends

  (i.e., north to south etc)
- **Mineralogical maturity ≠ age**

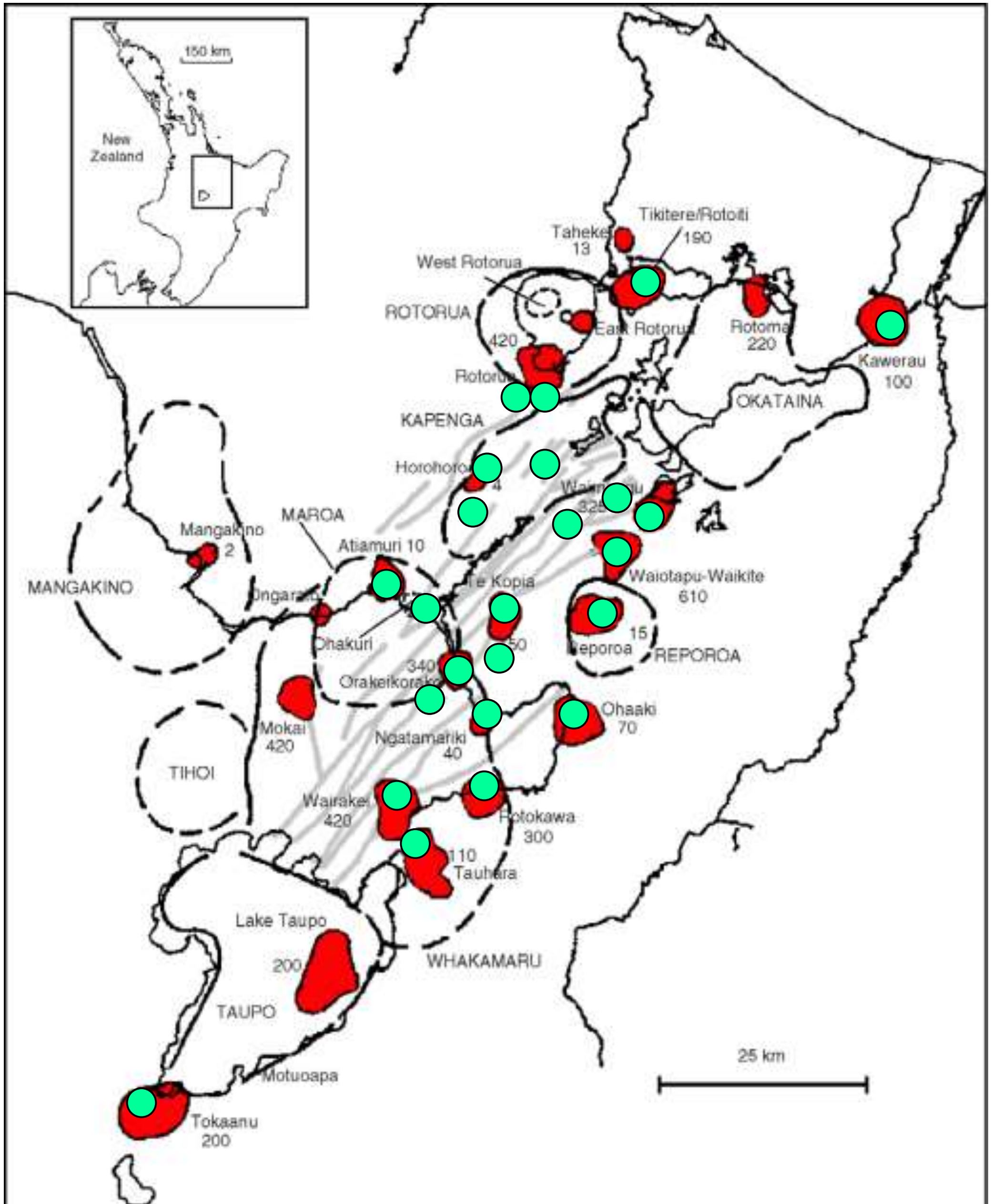
Opal-A → Opal-A/CT → Opal-CT → Opal-C → Quartz

Newly deposited — *diagensis* →

Fluid flow to surface can shift over time



Don't assume quartzose sinters = old



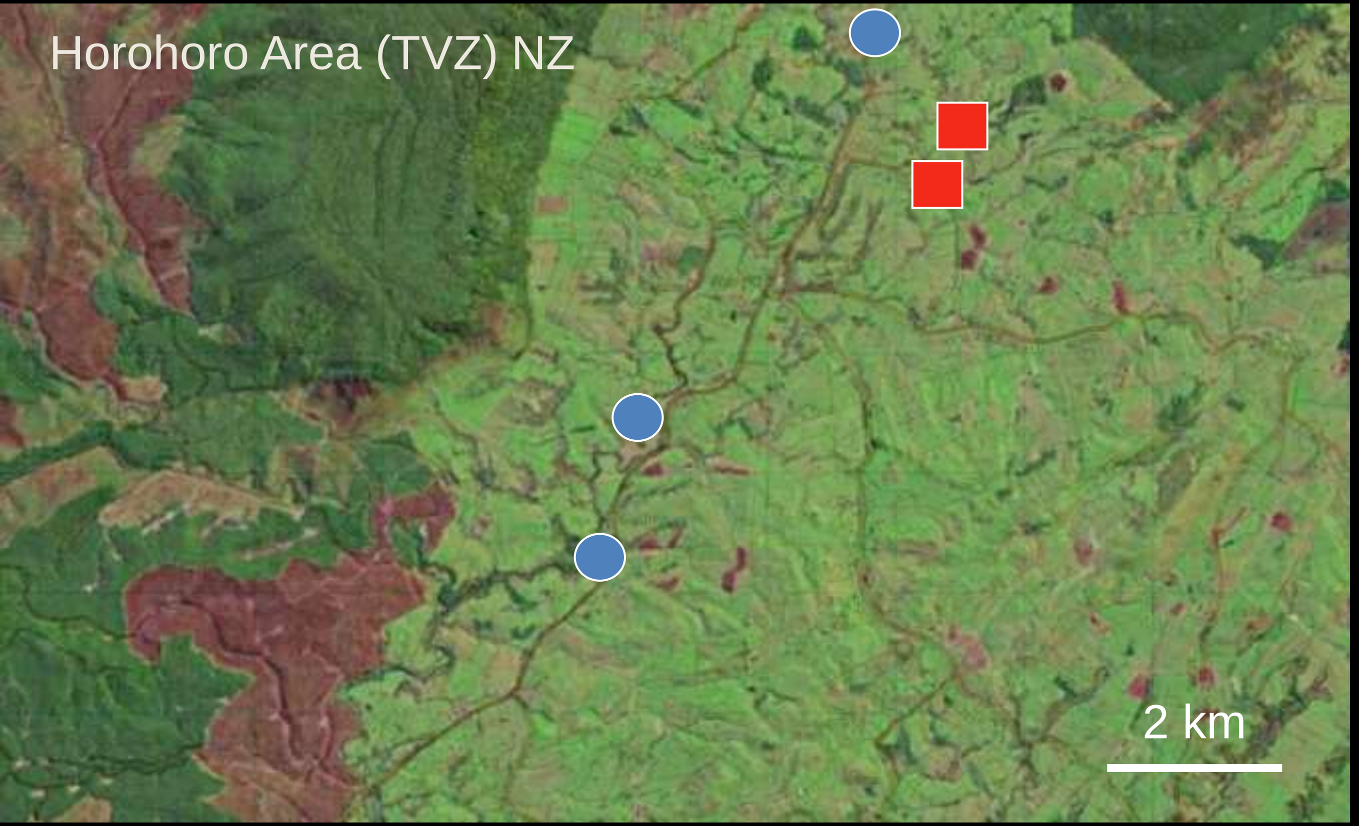
Map showing high heat flow areas
(Kissling & Weir, 2005)

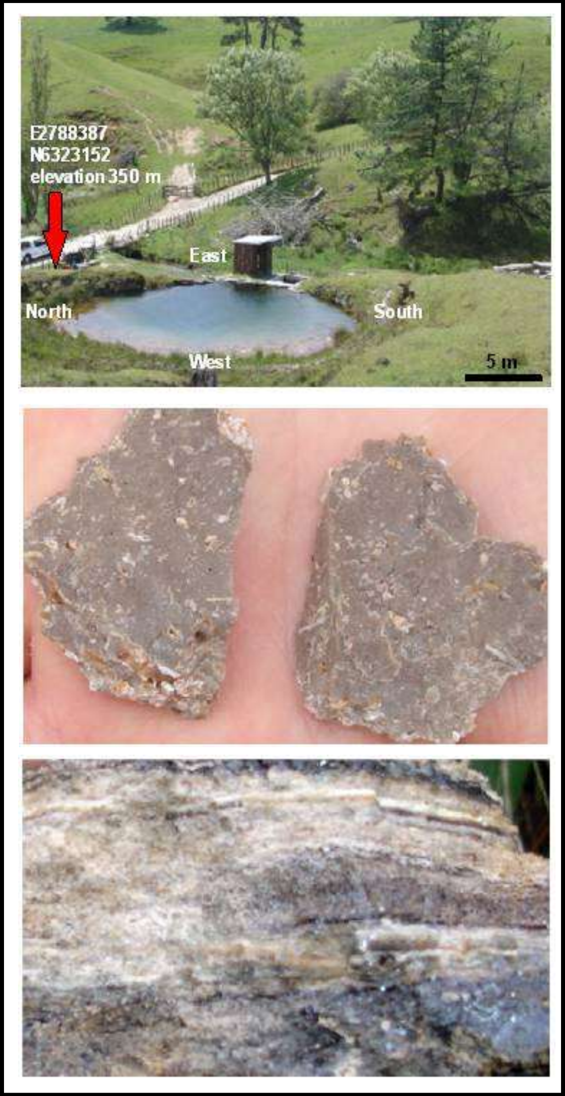
Documented sinters

(Campbell et al., 2004)

Not all sinters are mapped

Many undiscovered sinters, often away from present day hot springs



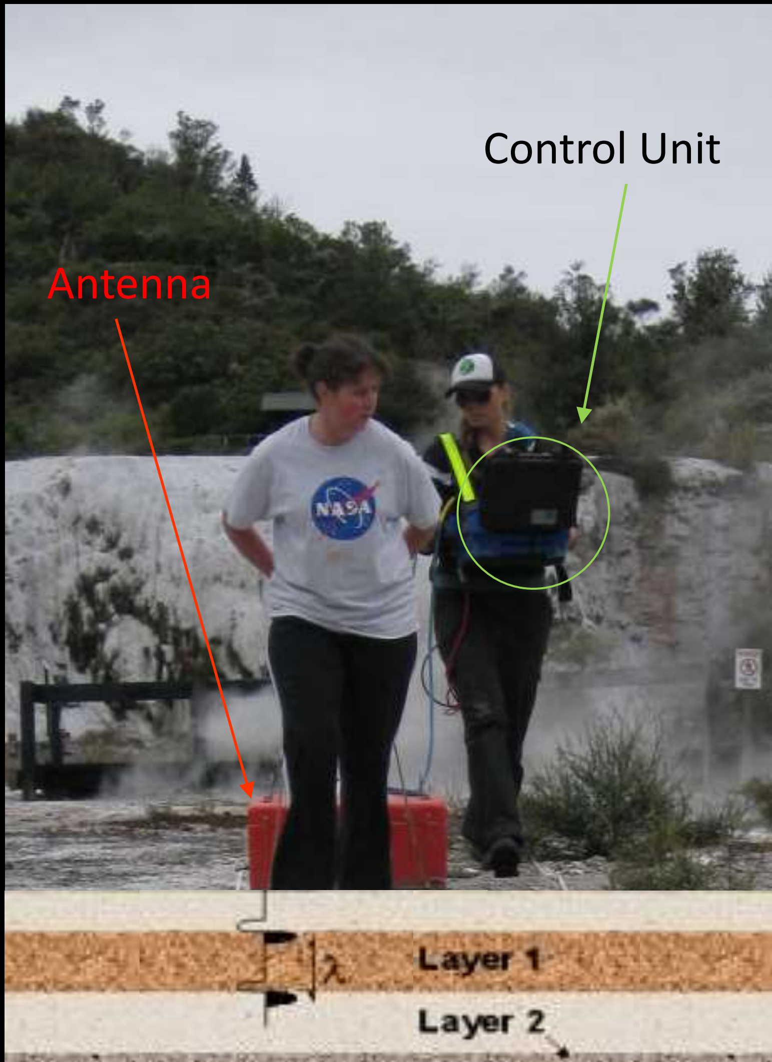


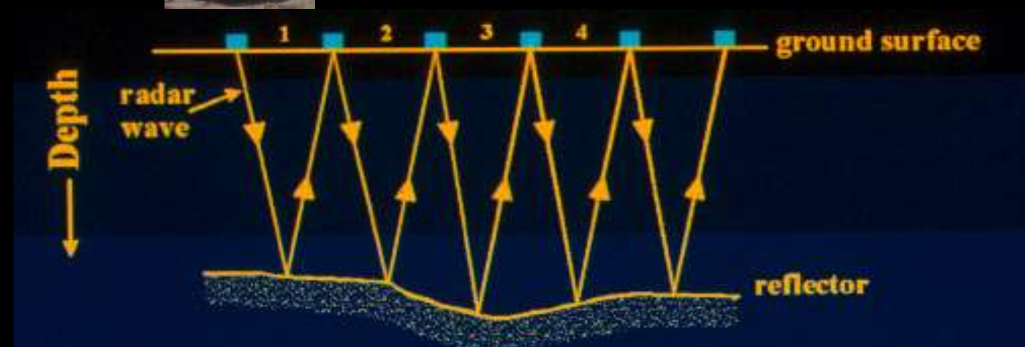
Undocumented sinters

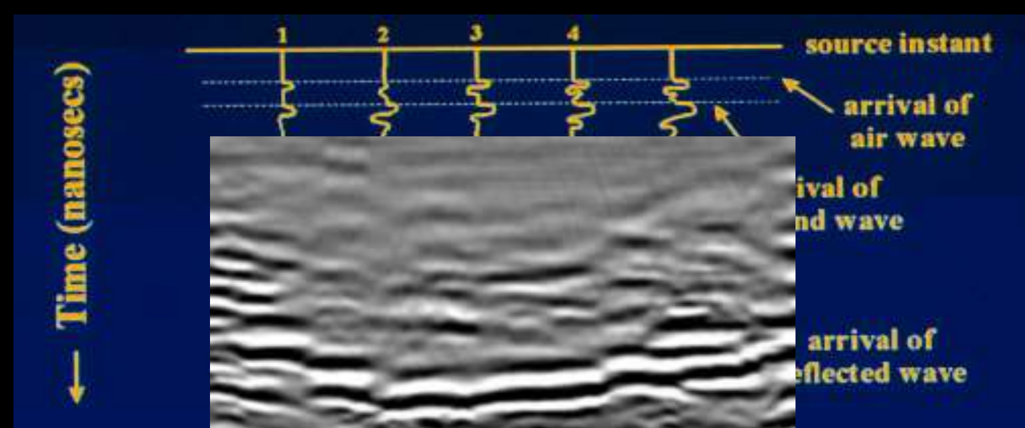
Hot springs


Problem:
Sinter exploration work is limited to outcrops
and many sinters are buried
Can GPR help extend our ability to find sinters?

GPR (GSSI-SIR 2000)
200MHz Antenna
Range 100-300ns



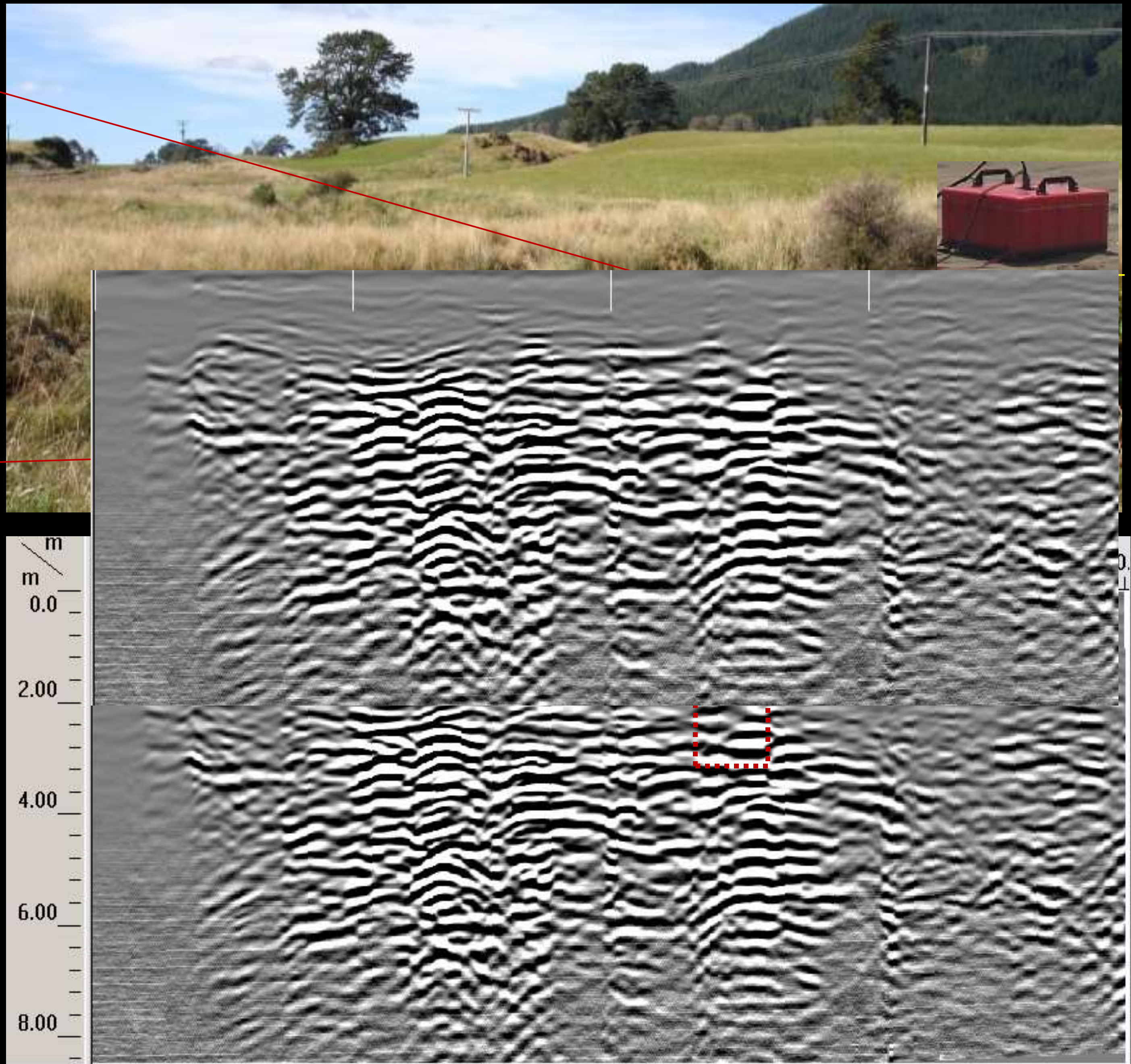


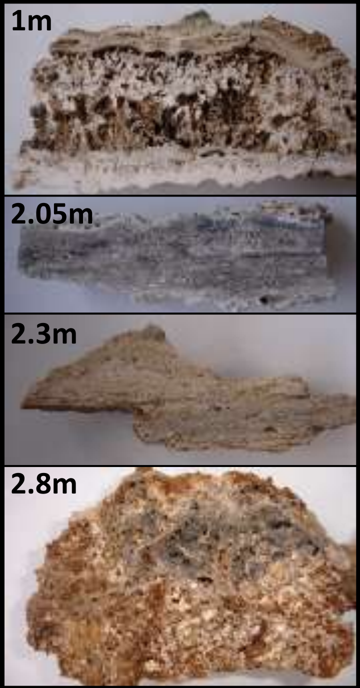


Jol and Smith, 1992

Partially buried sinter

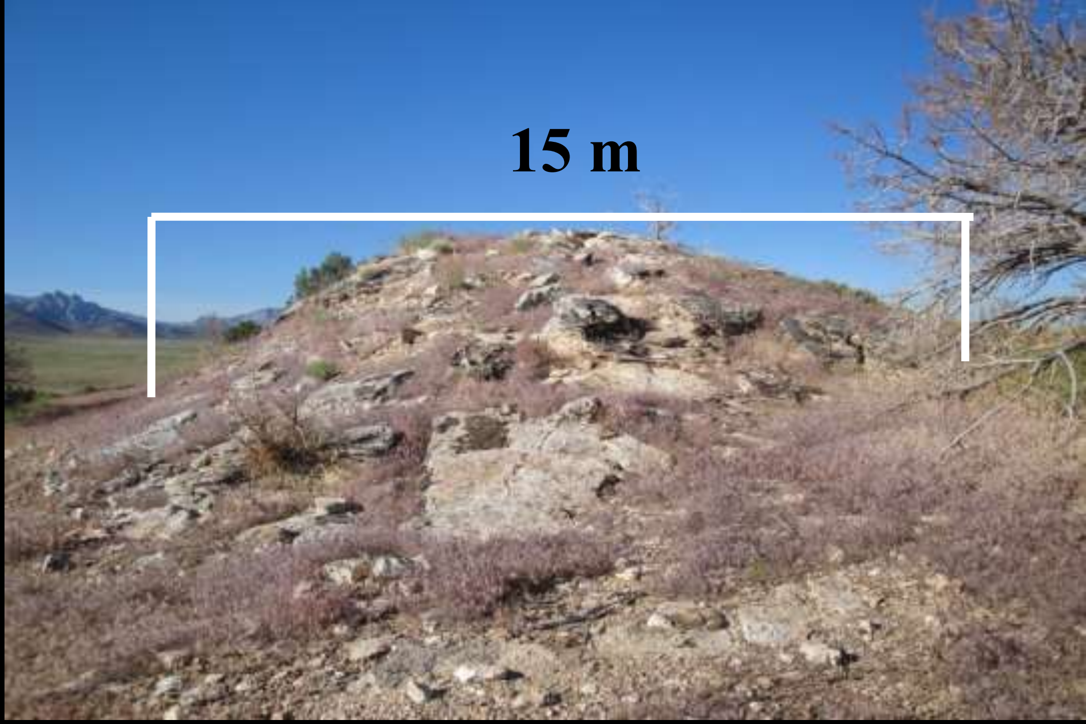
- Horohoro (Opal-A)



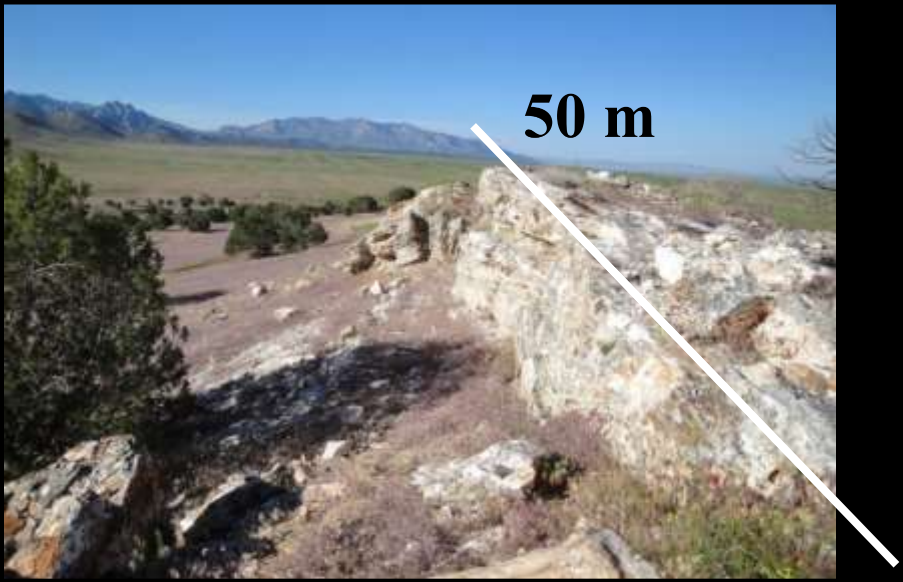


GPR gives a better estimate of fluid flow to surface than previously available.

No longer limited to outcrops

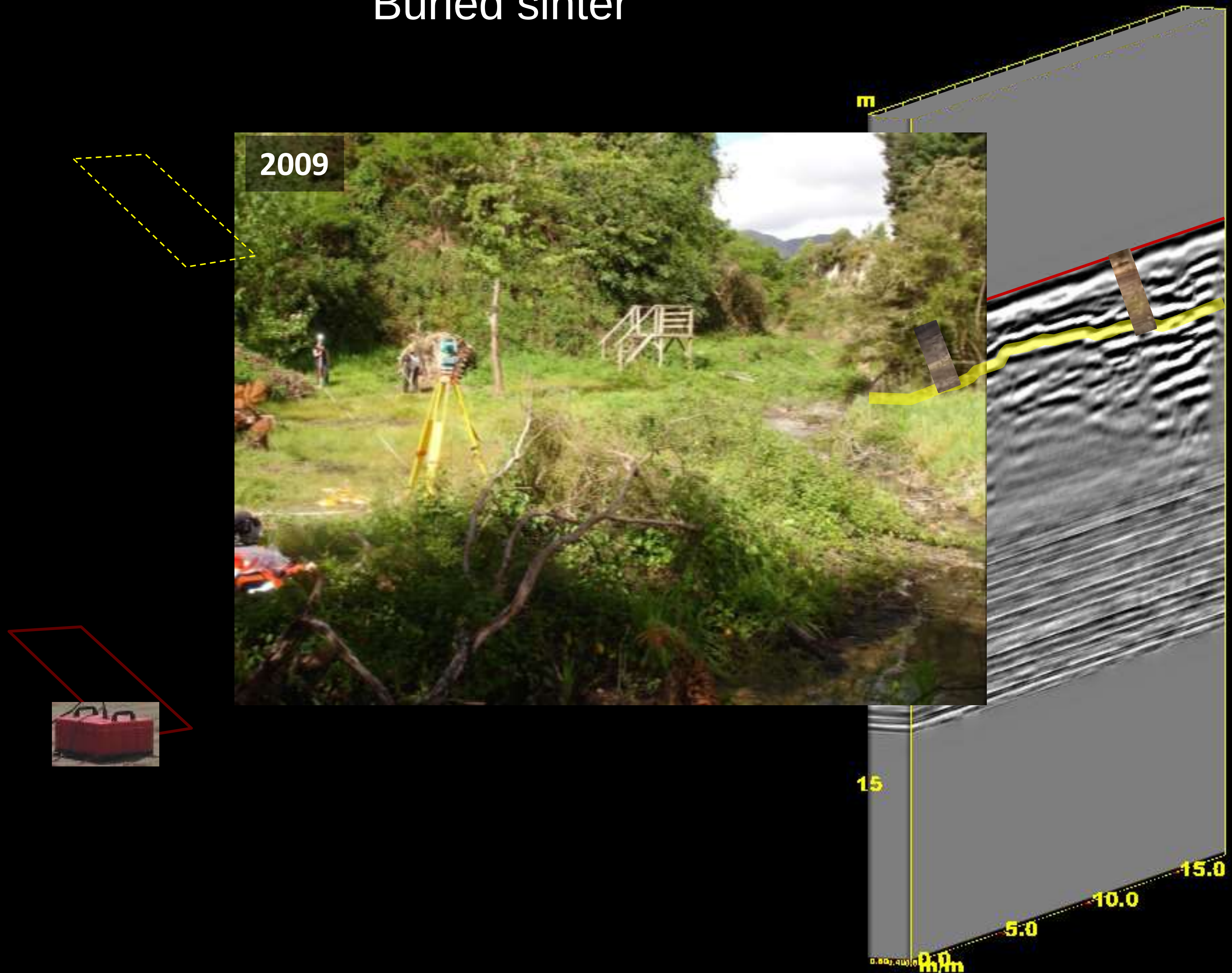


Visual extent
15 x 50 = 750 m² sinter
Thickness 2 m = 1500 m³

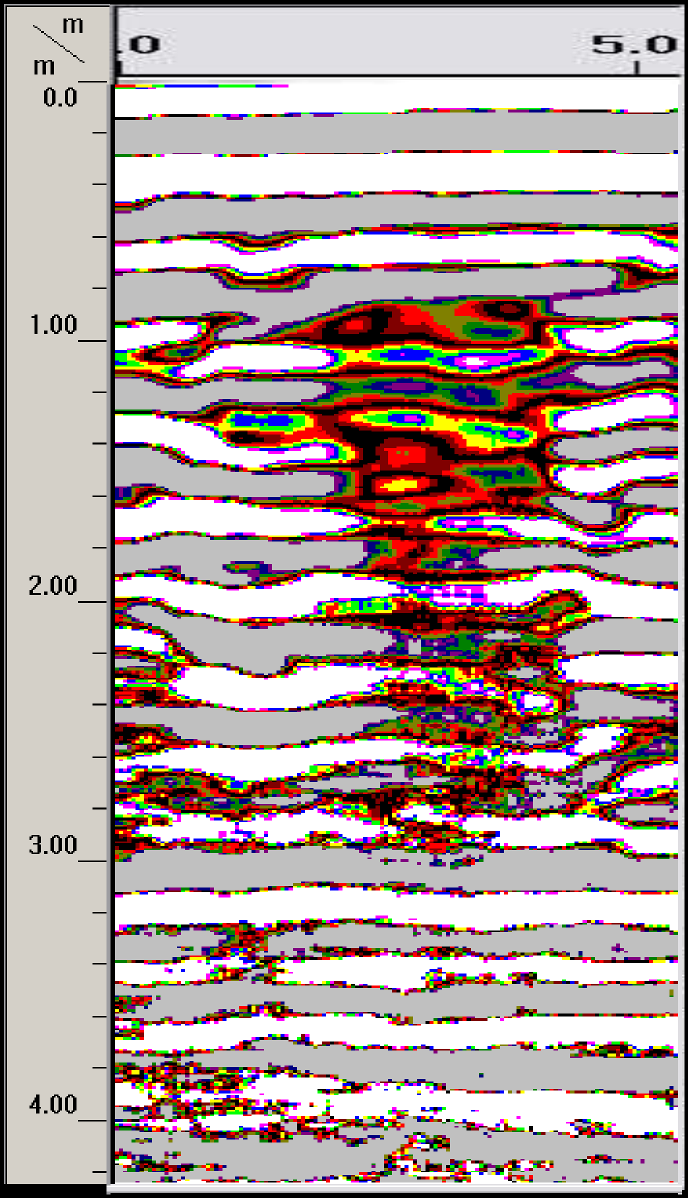


GPR extent
>50 x >100 = >5000 m² sinter
Thickness >10 m = >50,000 m³

Buried sinter

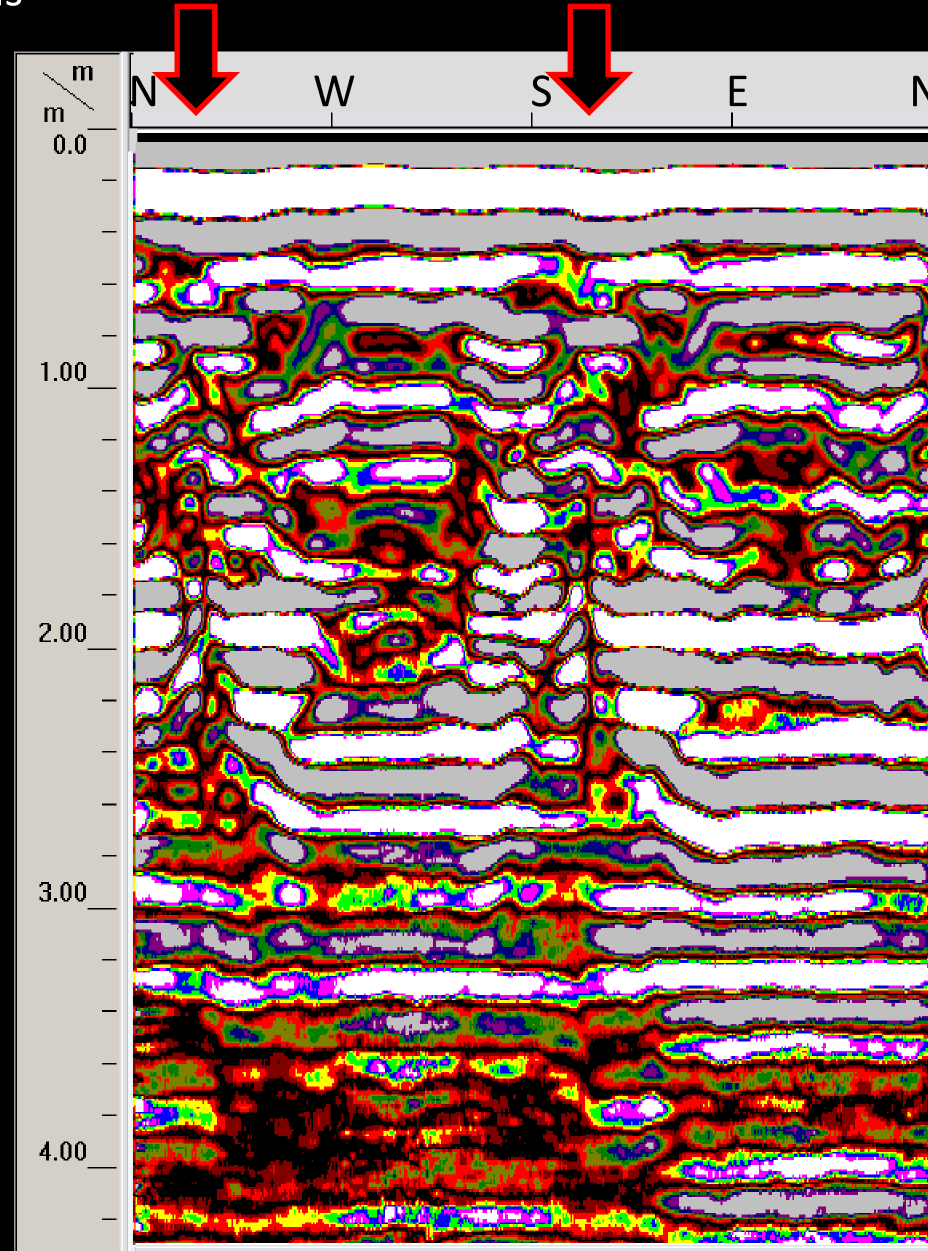


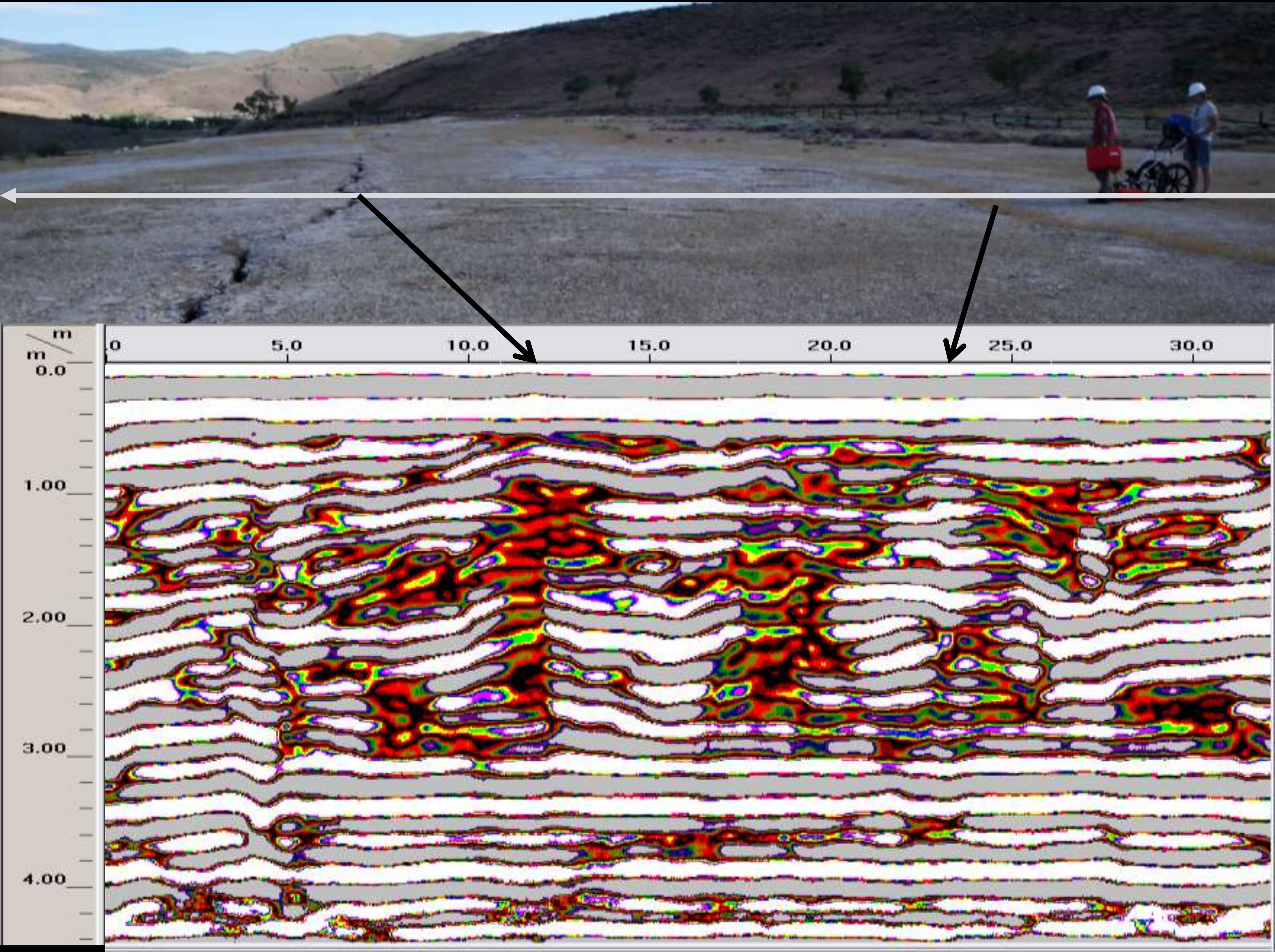
•Steamboat Springs Low Terrace (Opal-A)



•Vent Directionality – Regional structural trends

Around Vent

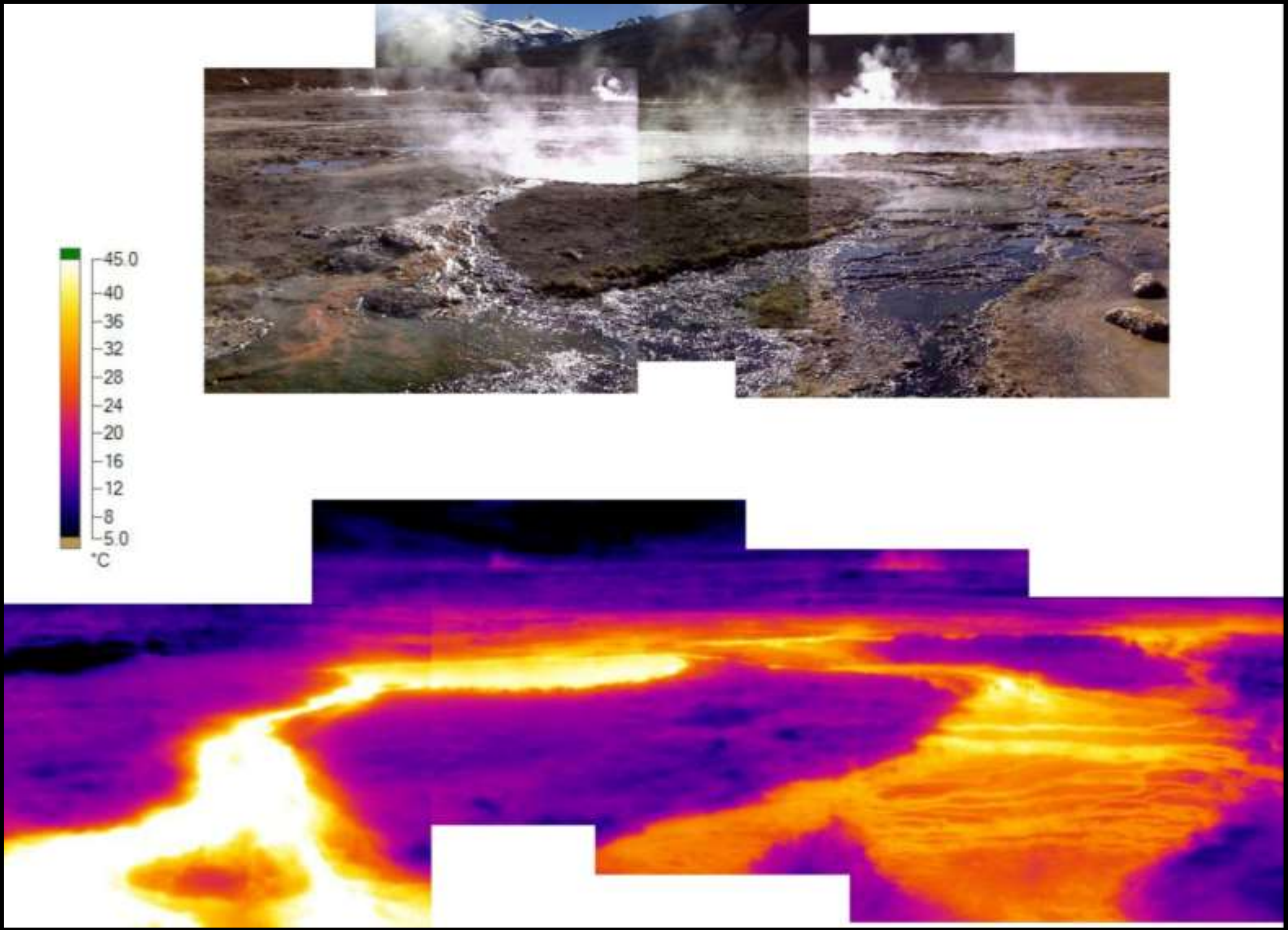


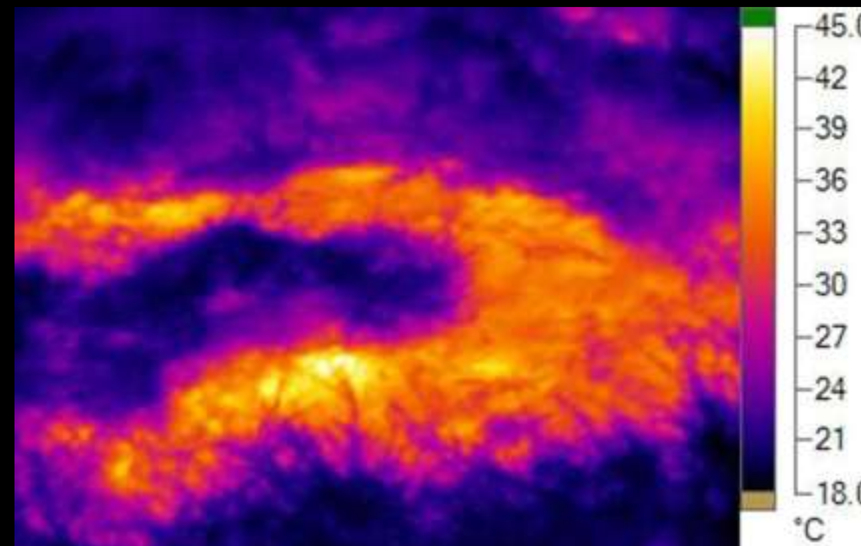

m
m
.0
5.0
10.0
15.0
20.0
25.0
30.0
0.0
1.00
2.00
3.00
4.00

Heat and mass flow

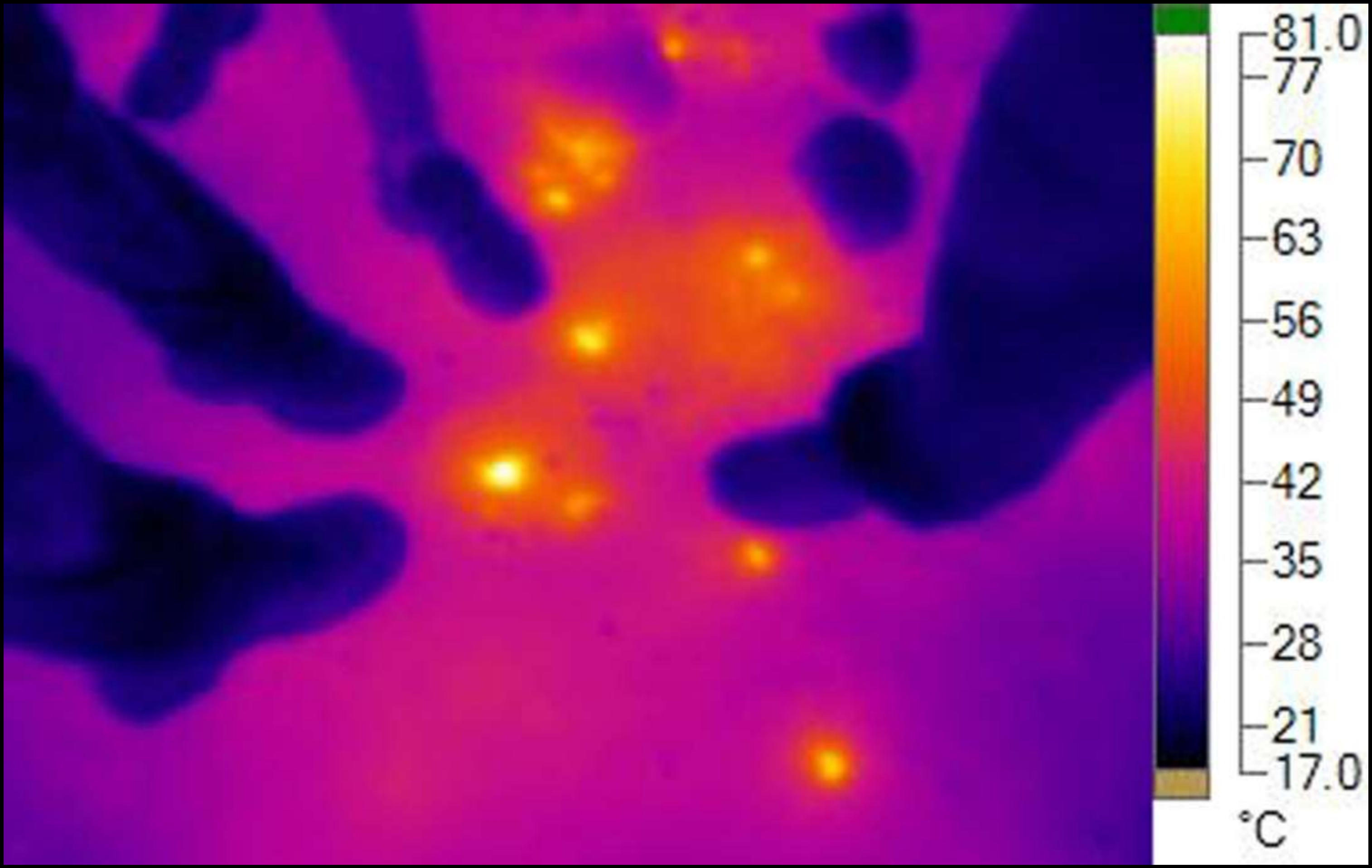
First order exploration technique

Infrared imagery compliments standard heat flow data collection



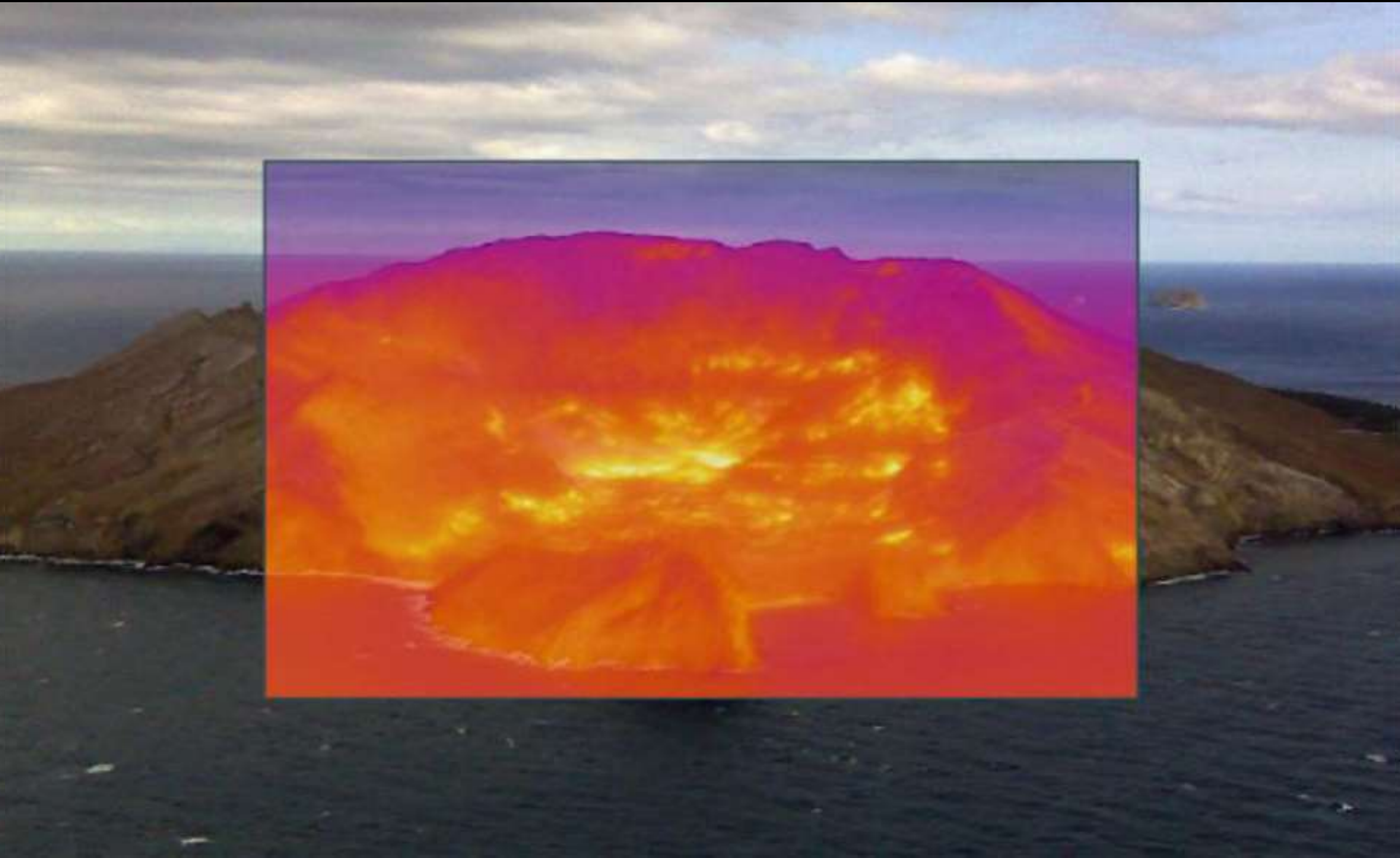


Easy to map areas with elevated temperature profile



Vent orientation and alignment

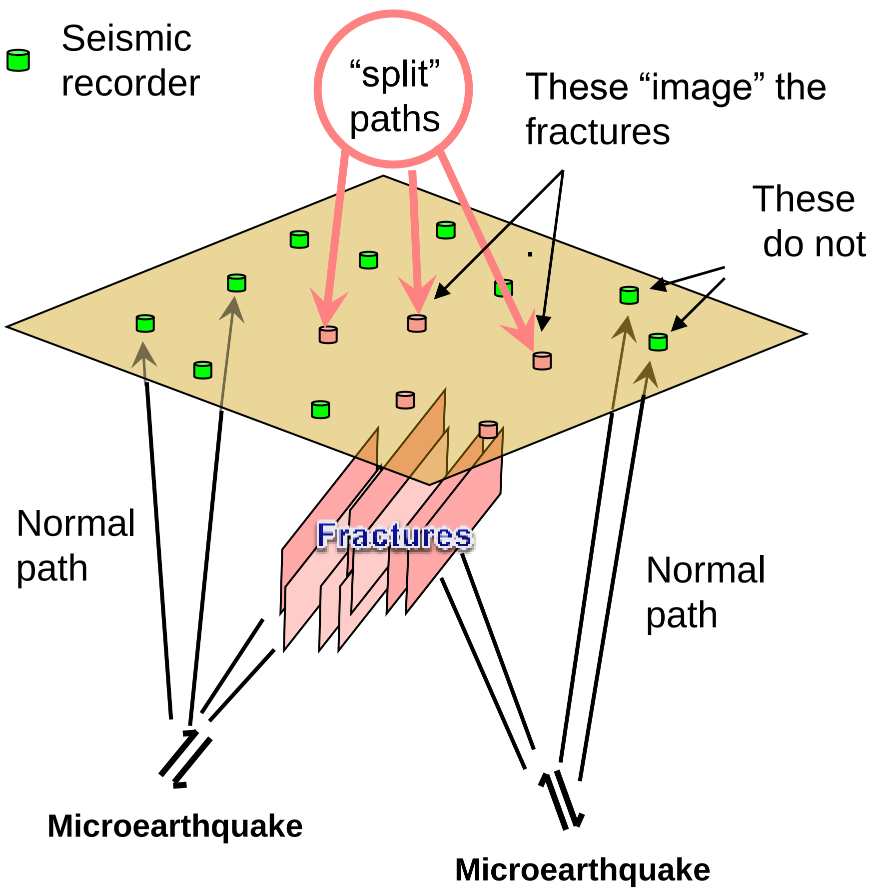
Imaging from a safe distance
IR provides guide to heat flow



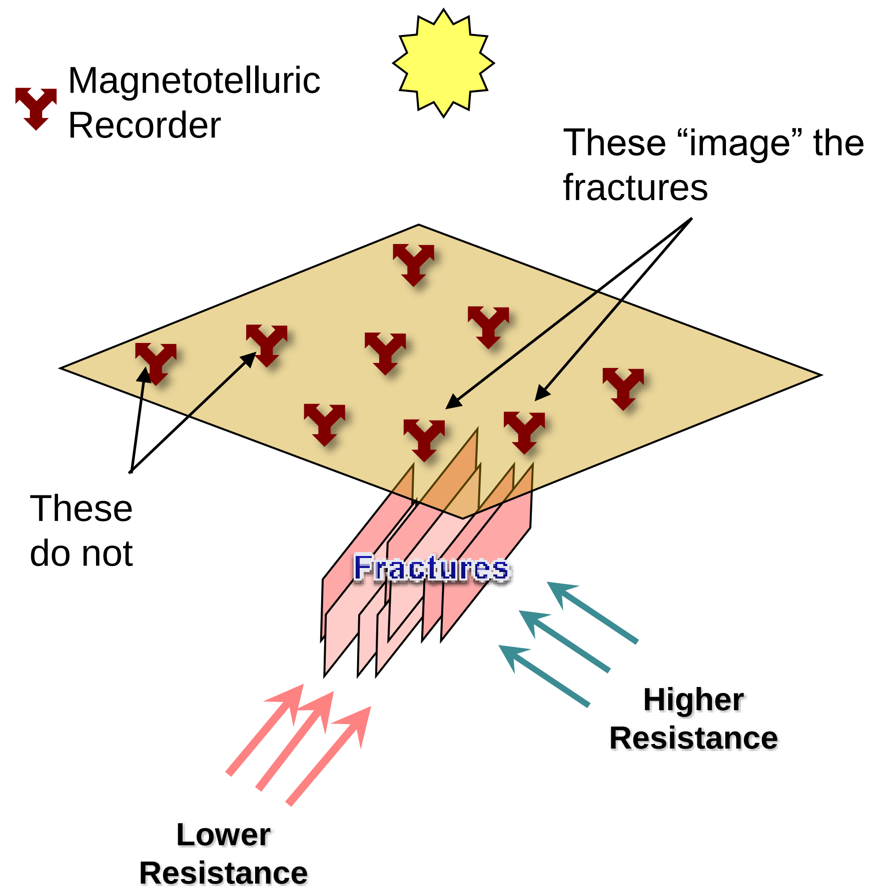

Geophysical Imaging
New Exploration Techniques
Joint Geophysical Imaging (JGI)

JGI (Combination of techniques)

Microearthquake (MEQ) S-splitting mapping

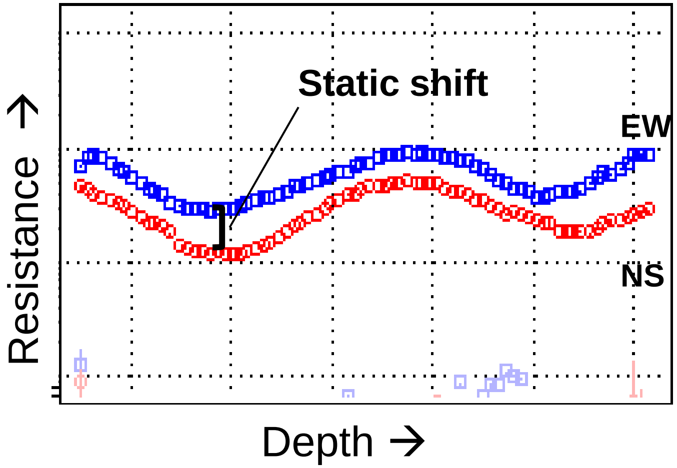


Magnetotelluric (MT) Polarization mapping

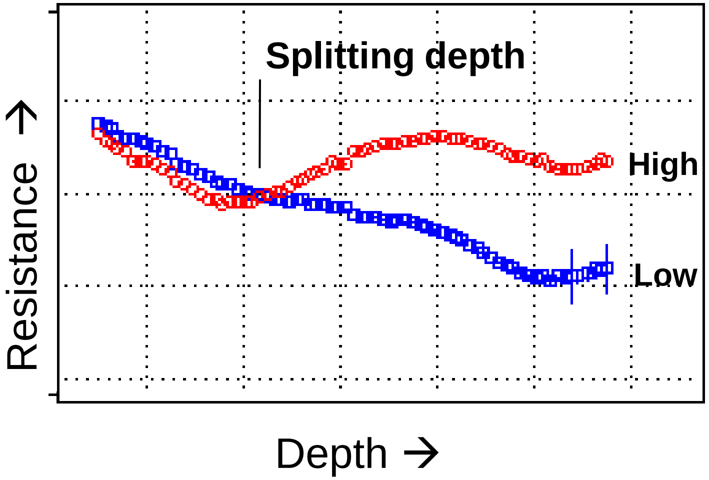


Example of MT data profiles

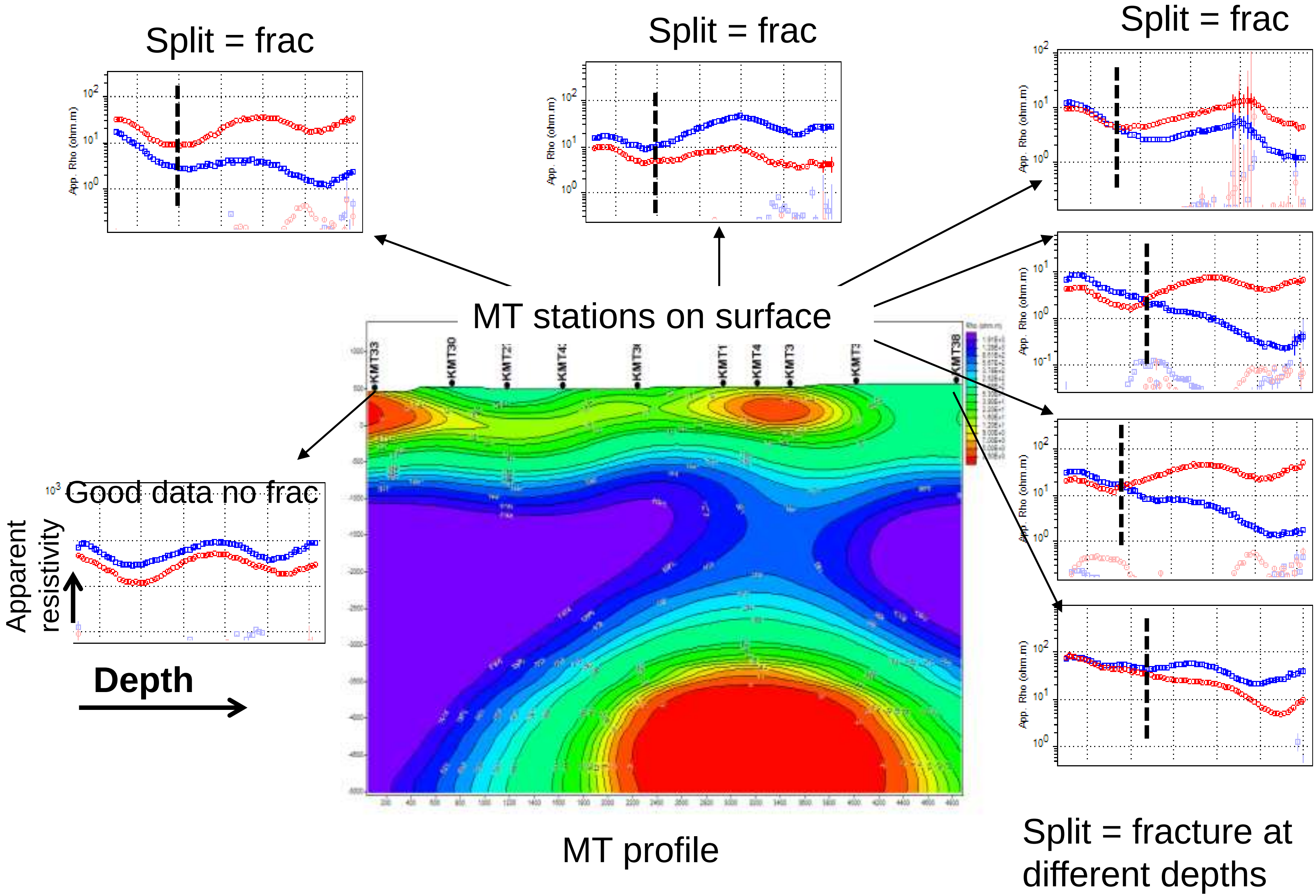
Common data
No fracture



Uncommon data
Fractures



JGI - MT shear wave splitting



Why JGI?

- Reduced risk in exploration phase
  - Targeting permeable fracture zones
  - Helps with the “Go – No-go” decision making

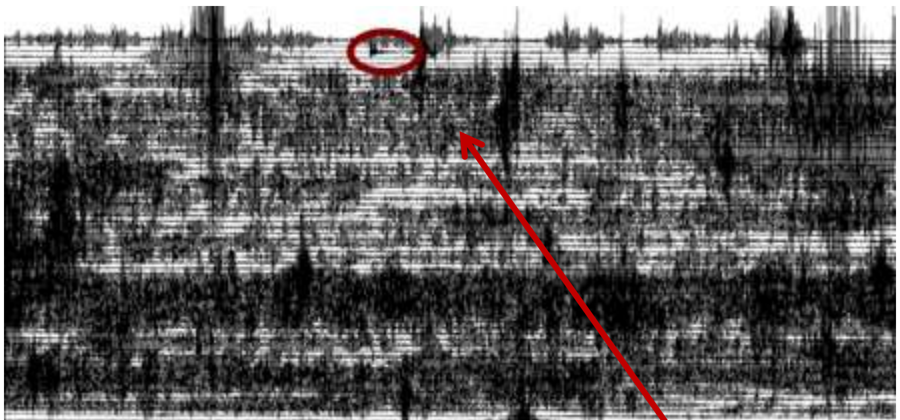
- Increases productivity
  - Fewer wells necessary or more production from wells drilled

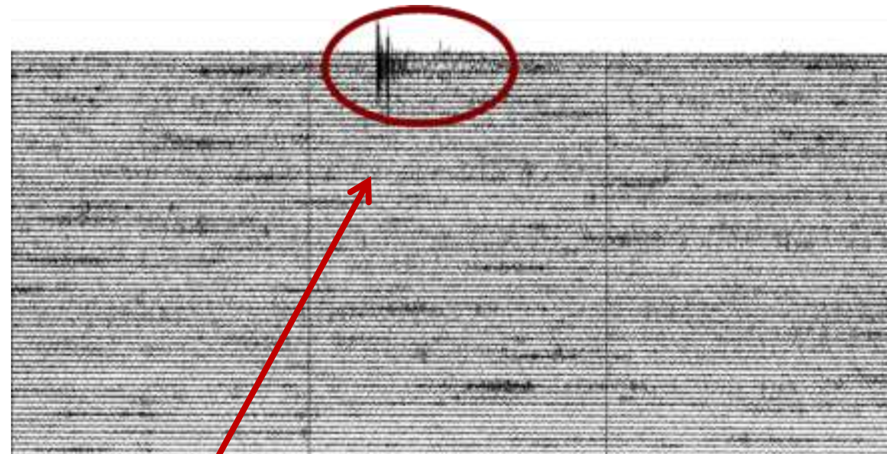

Downhole seismometers
New Exploration Techniques

BOREHOLE SEISMIC MONITORING

Advantage: Noise Reduction

Results of test station installed at Riverhead, NZ, depth of 245m





Same small event

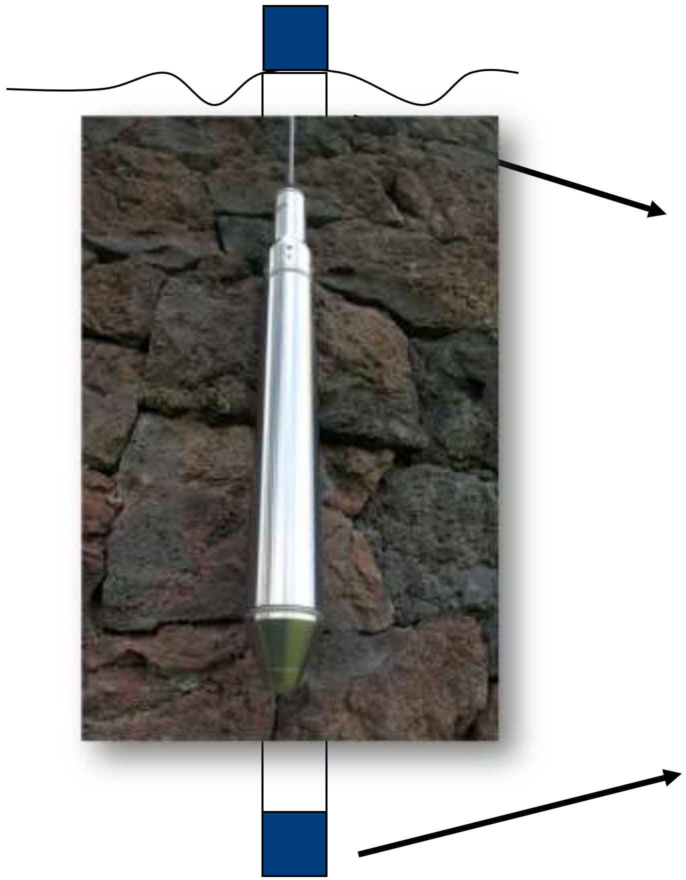
Surface seismic data

Borehole seismic data

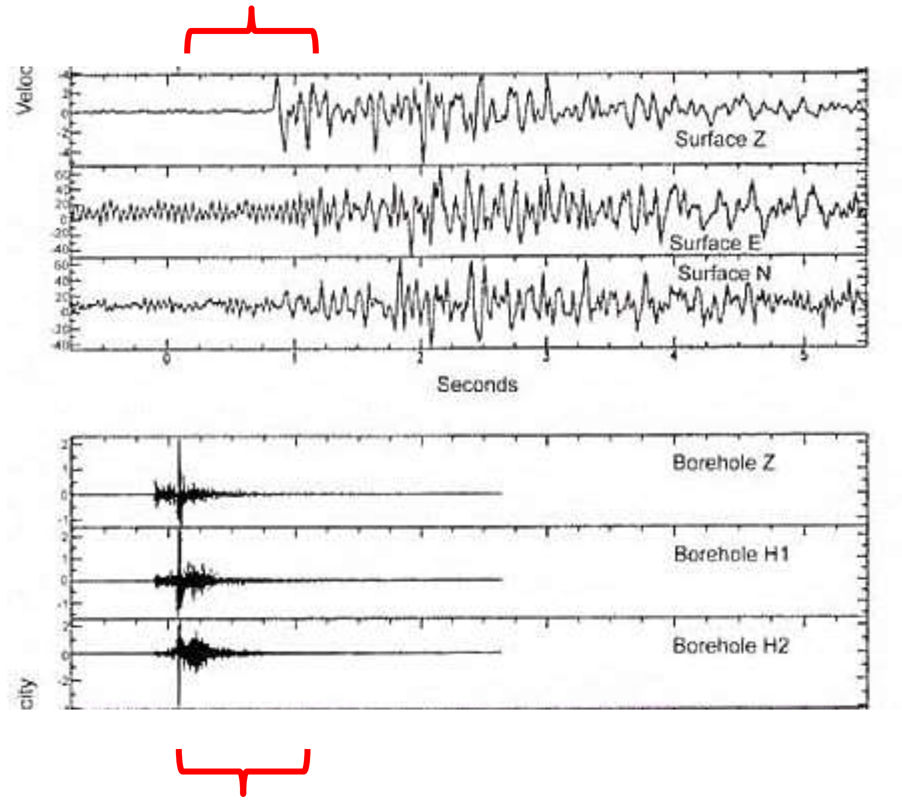
Reduction in scattering = obtain more information

Surface seismograph

M ~ 0.5 MEQ   Data from 3.3 km deep LVEW



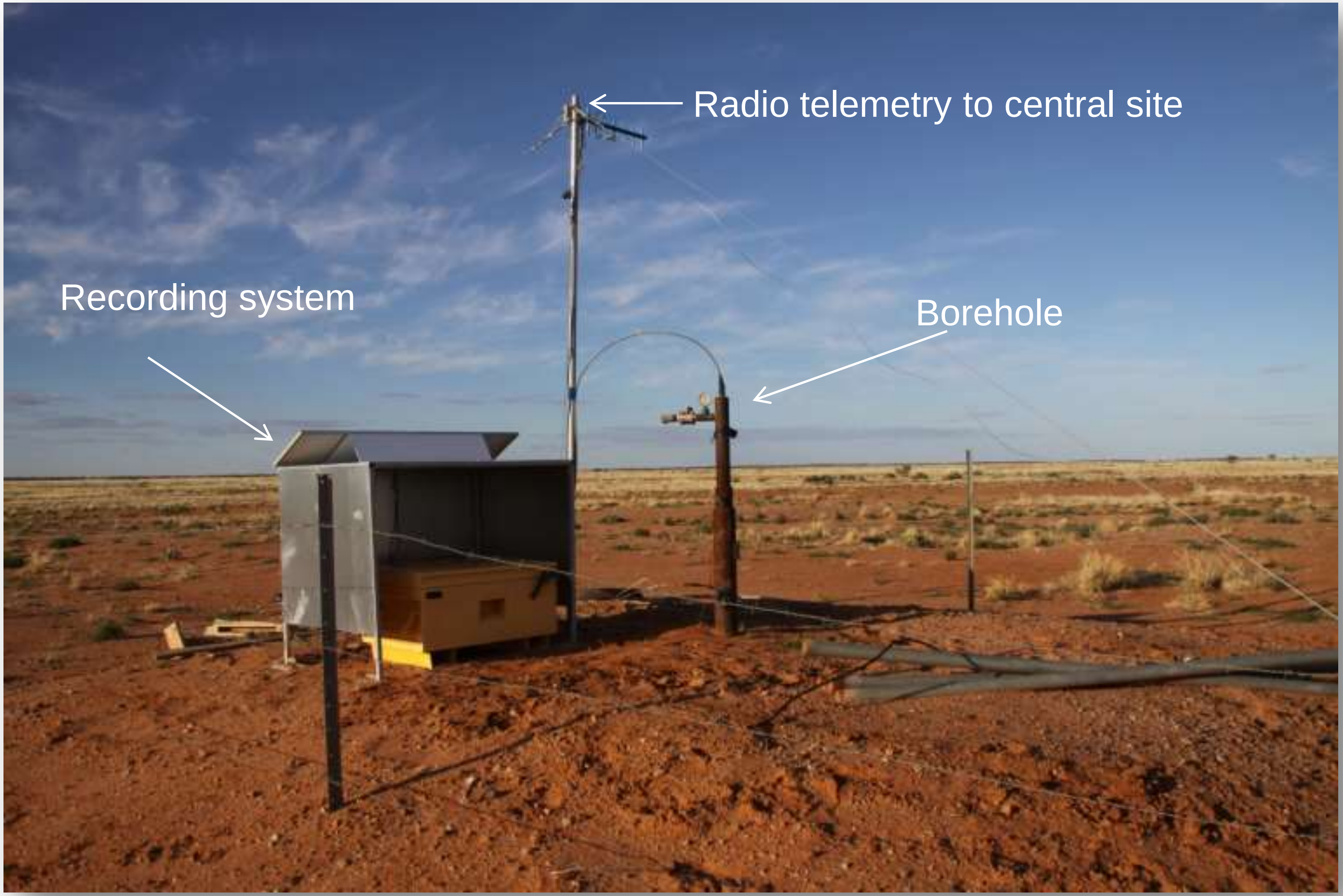
1 second



1 second

Borehole seismograph

Typical borehole micro-earthquake station



Advantages of borehole micro-earthquake monitoring

1. More sensitive than surface arrays

2. Capture more earthquakes than surface arrays

3. High gain 24 bit digital recording

4. Stations telemetered via radios to Central recording site – real-time -

5. Used to monitor effects of extraction and reinjection of fluids

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In summary

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Geothermal Exploration is multi-disciplinary science

All New Techniques help to target production wells