The Good, The Bad, The Ugly Fluids

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University of Auckland

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Santiago de Chile, 26-29 May 2014

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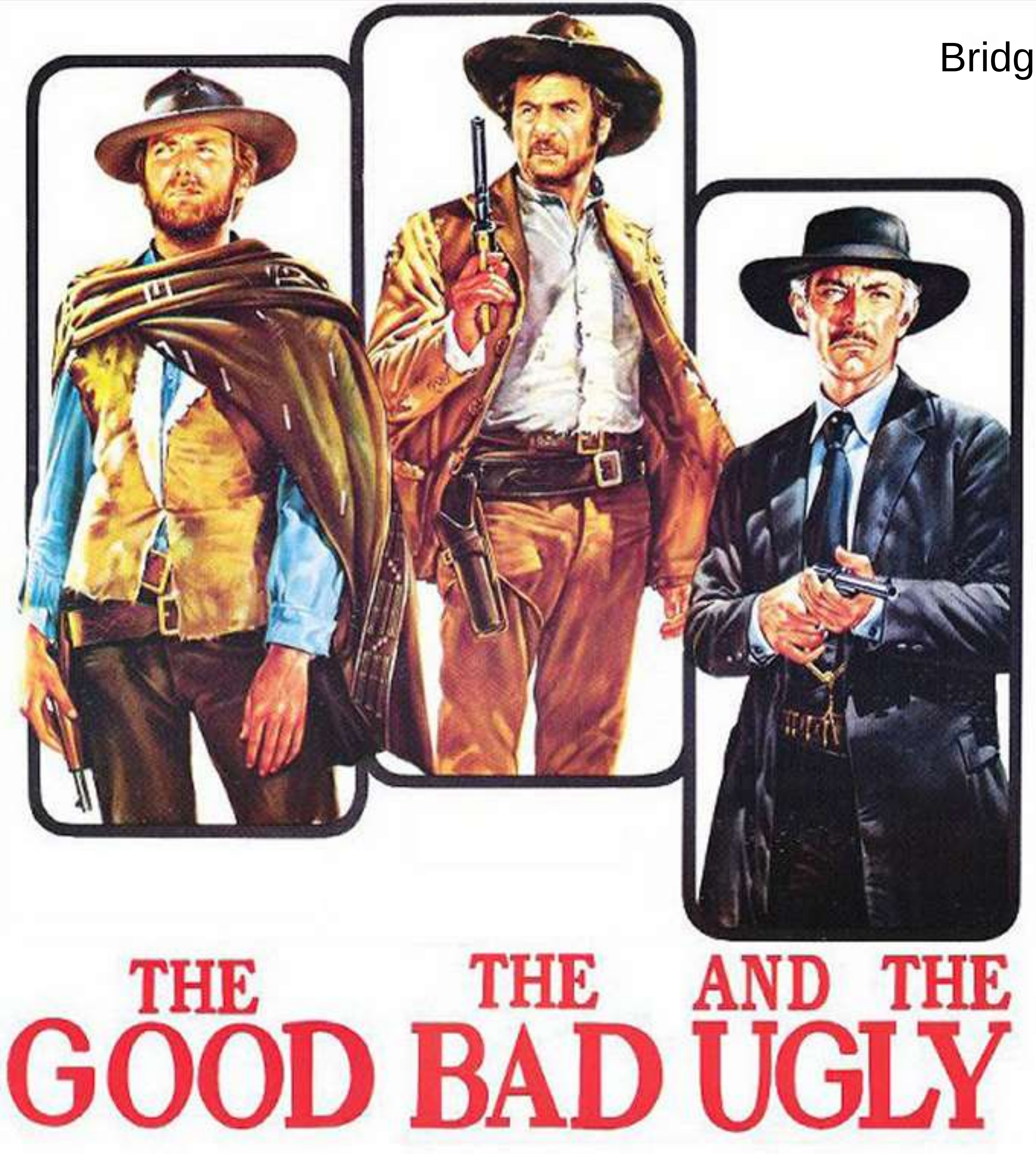
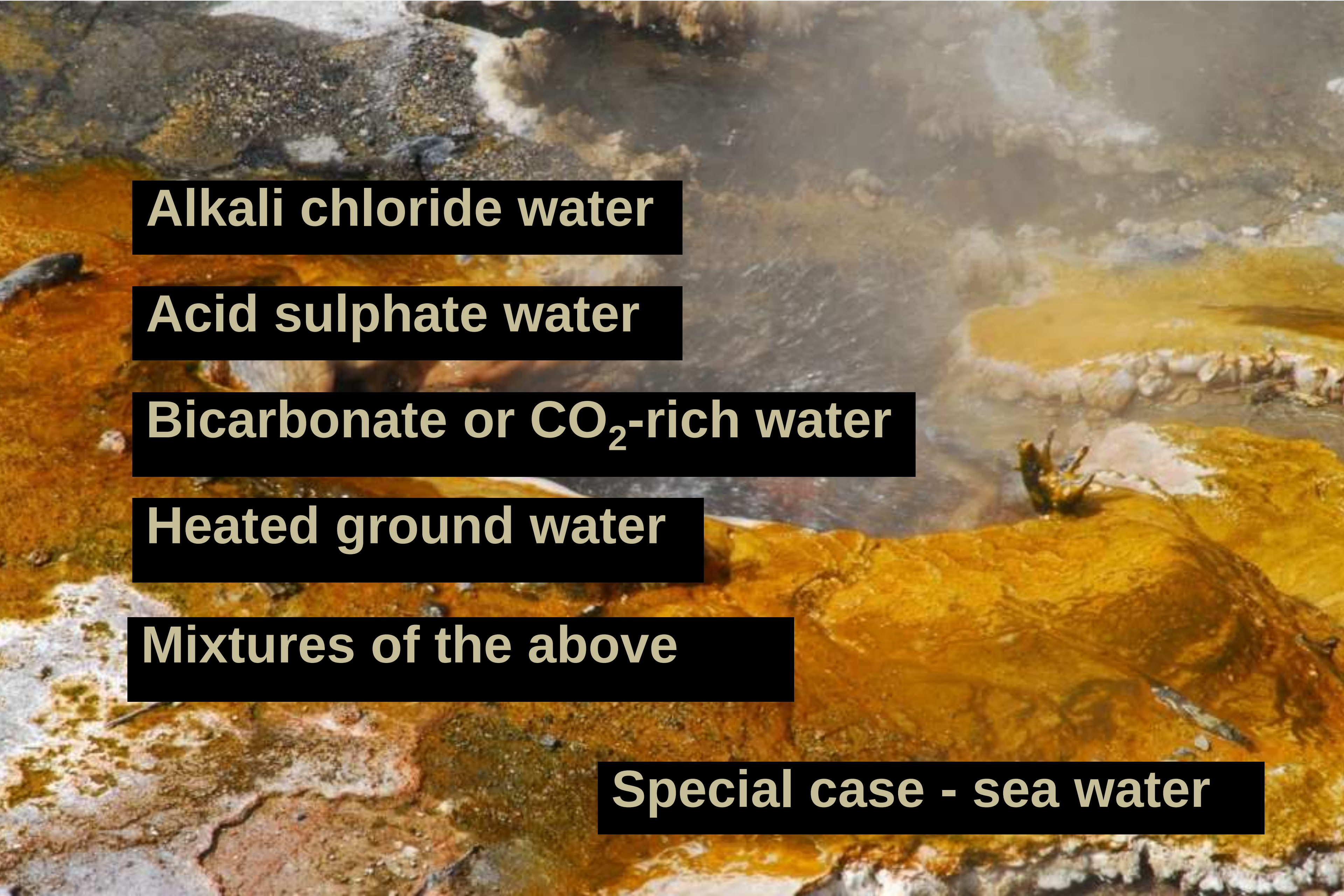


FLUIDS

Common fluid types in geothermal systems



Alkali chloride water

Acid sulphate water

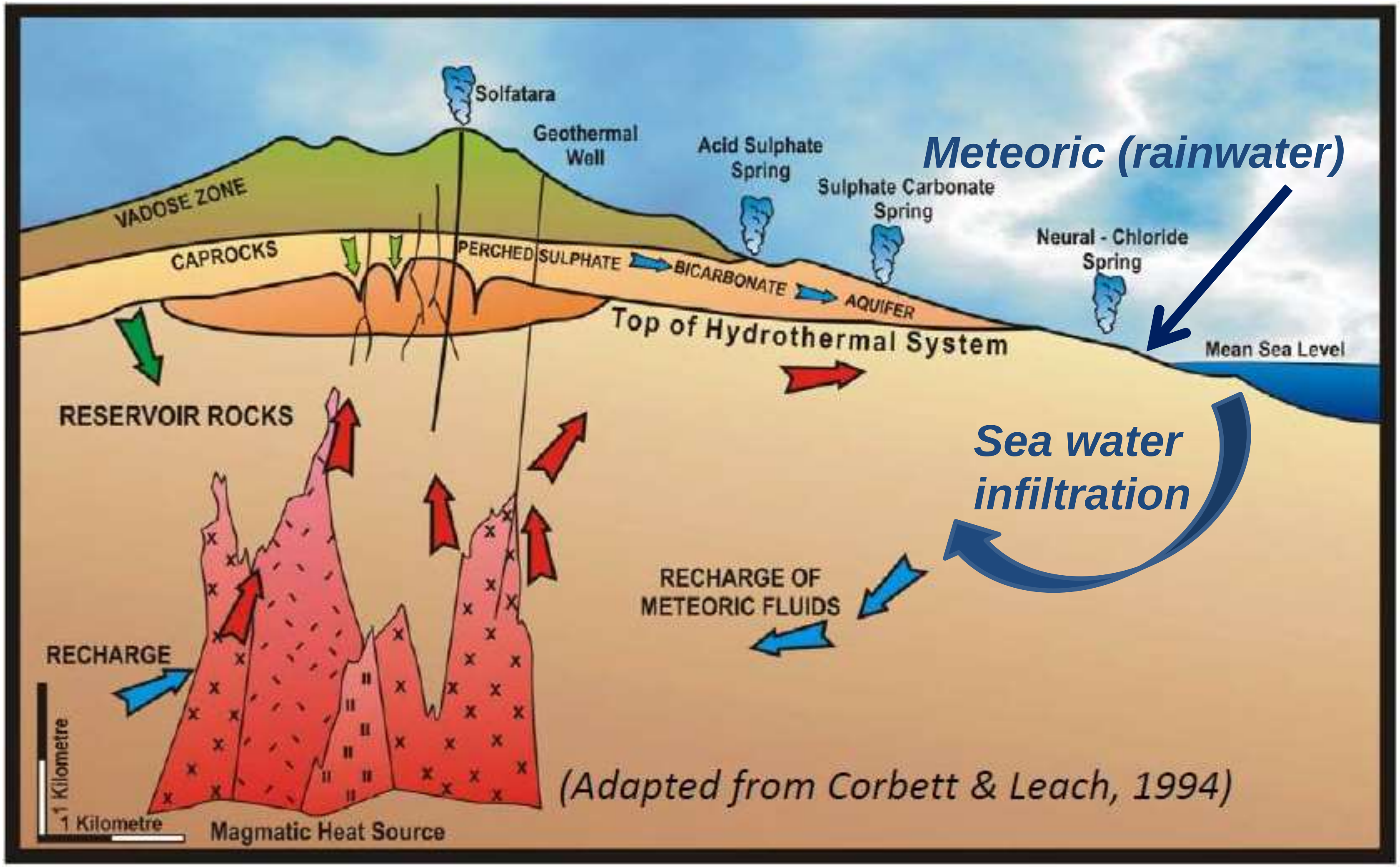
Bicarbonate or CO_2-rich water

Heated ground water

Mixtures of the above

Special case - sea water

Water origin influences reservoir water chemistry



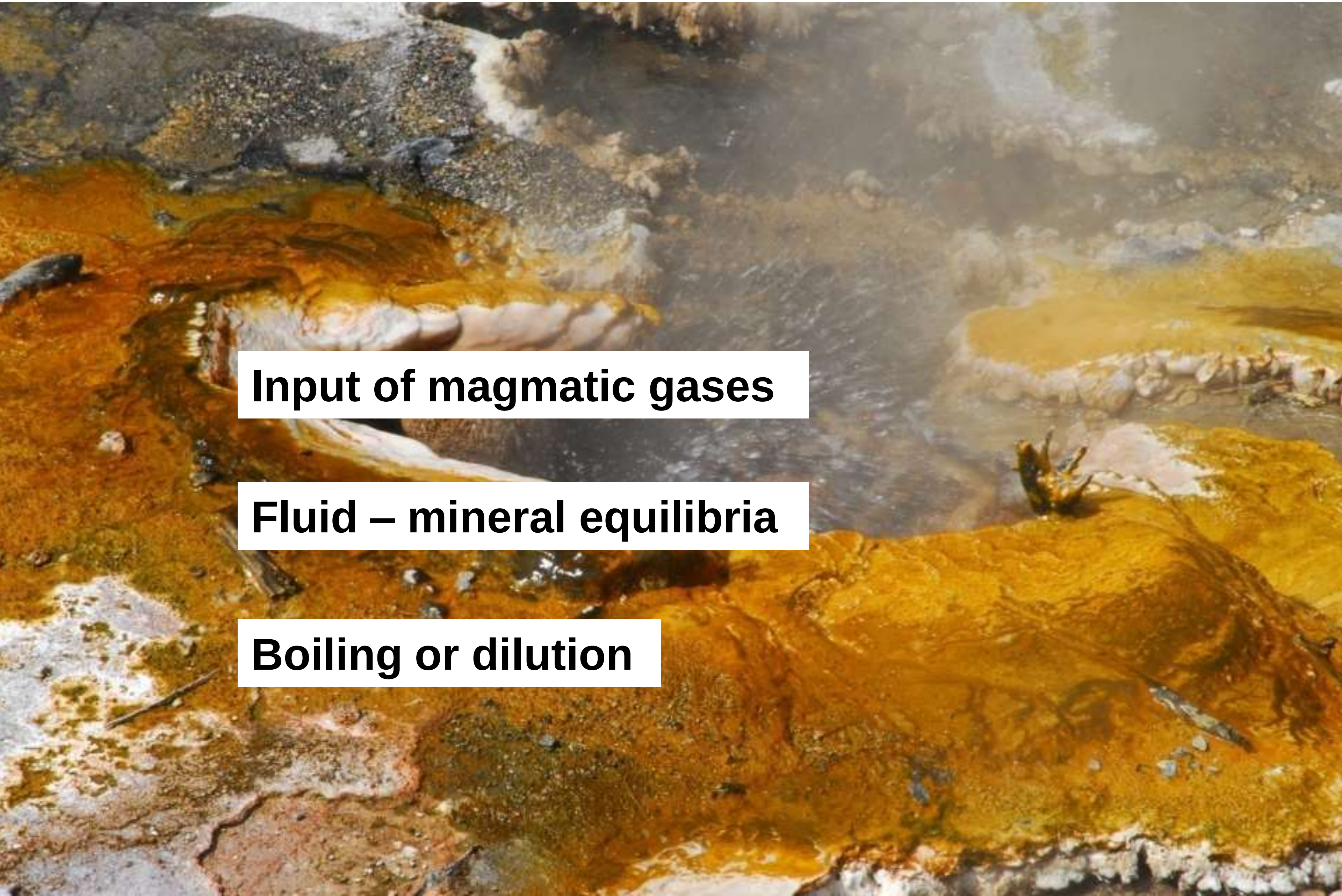
Meteoric (rainwater)

Sea water infiltration

(Adapted from Corbett & Leach, 1994)

Volcanic system geothermal model schematic

Factors influencing fluid chemistry

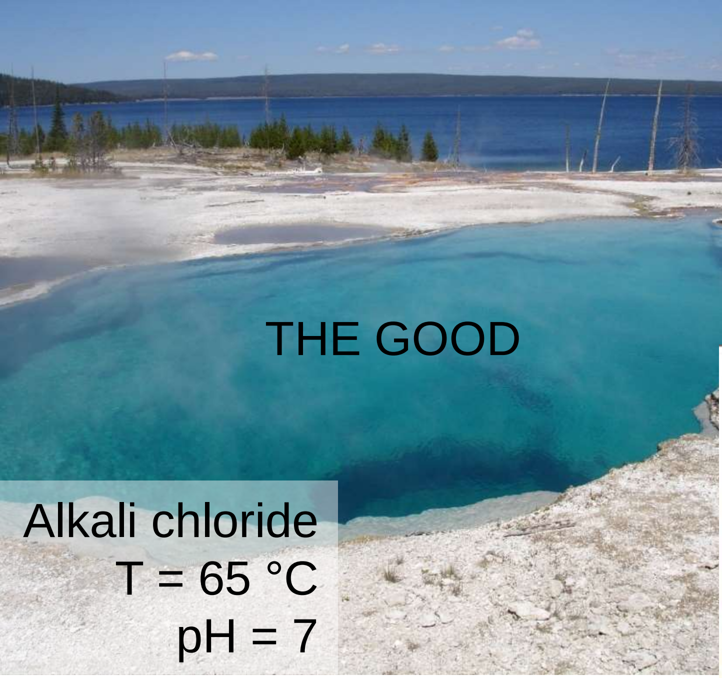


Input of magmatic gases

Fluid – mineral equilibria

Boiling or dilution

Different types of water



THE GOOD

Alkali chloride
T = 65 °C
pH = 7

THE BAD

Bicarbonate water
T = 88 °C
pH = 6

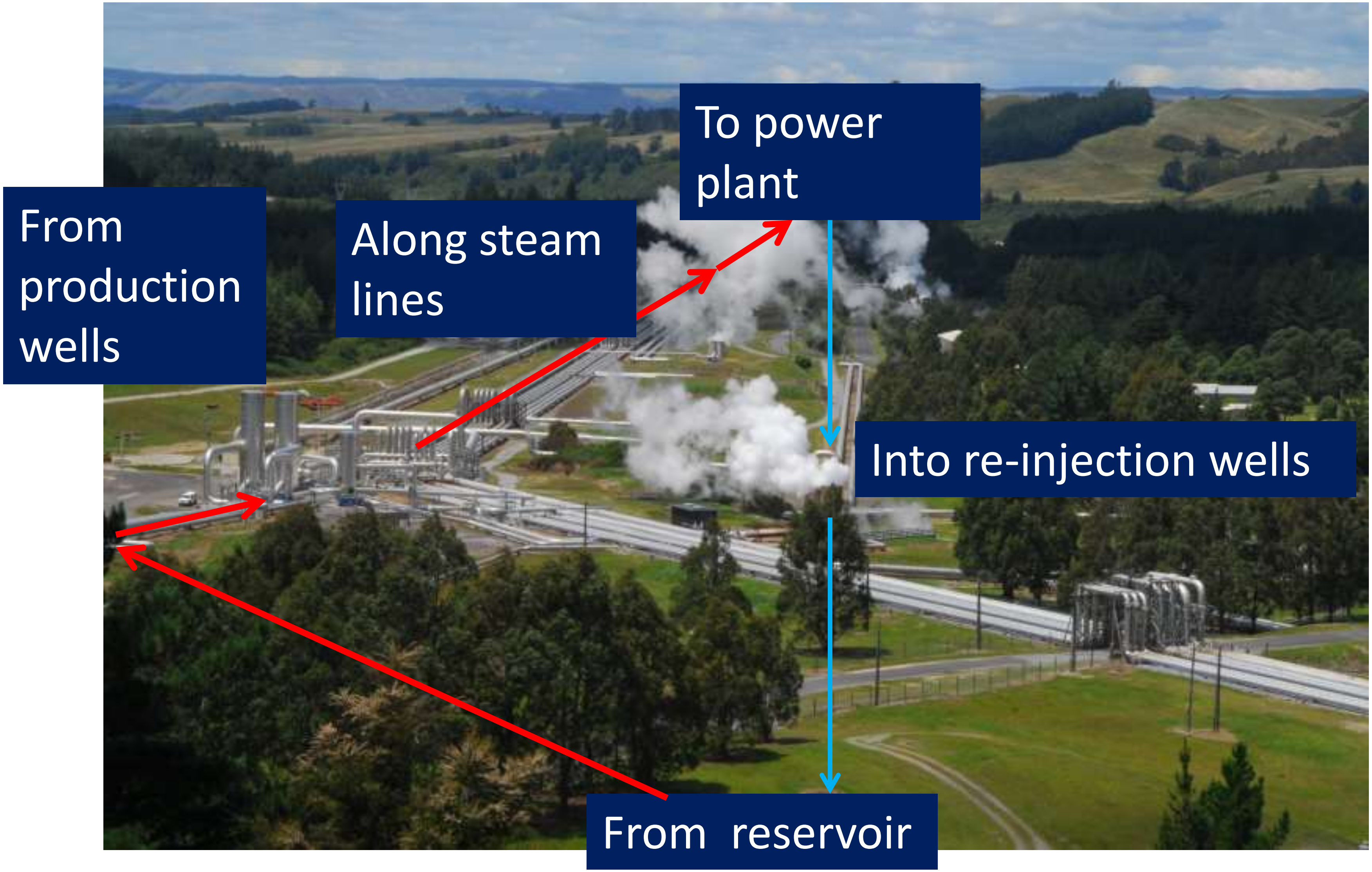
THE UGLY

Acid sulphate
T = 32 °C
pH = 3

Mixed water
T = 66 °C
pH = 4.5

THE UGLY

Water composition is important



From reservoir

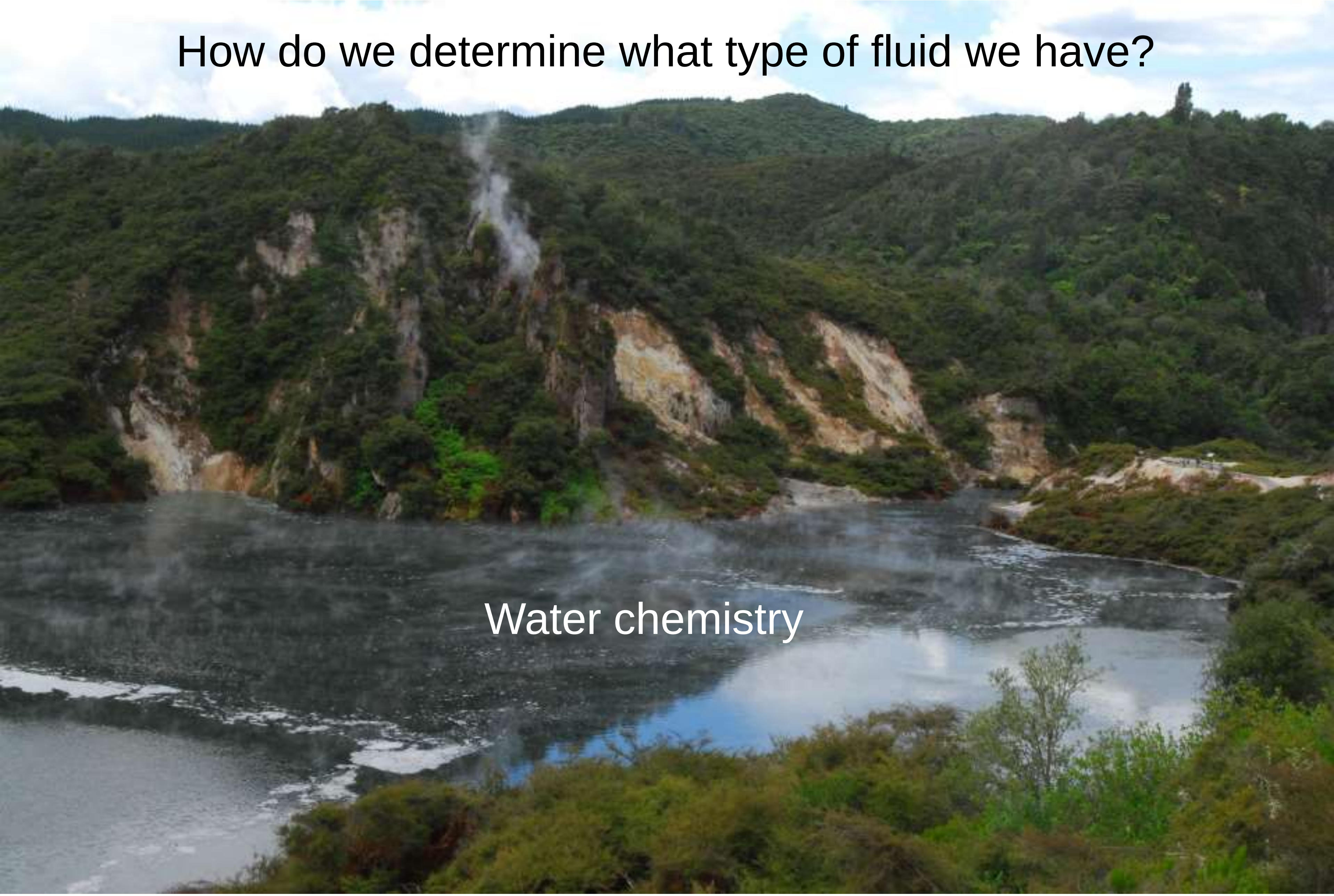
From production wells

Along steam lines

To power plant

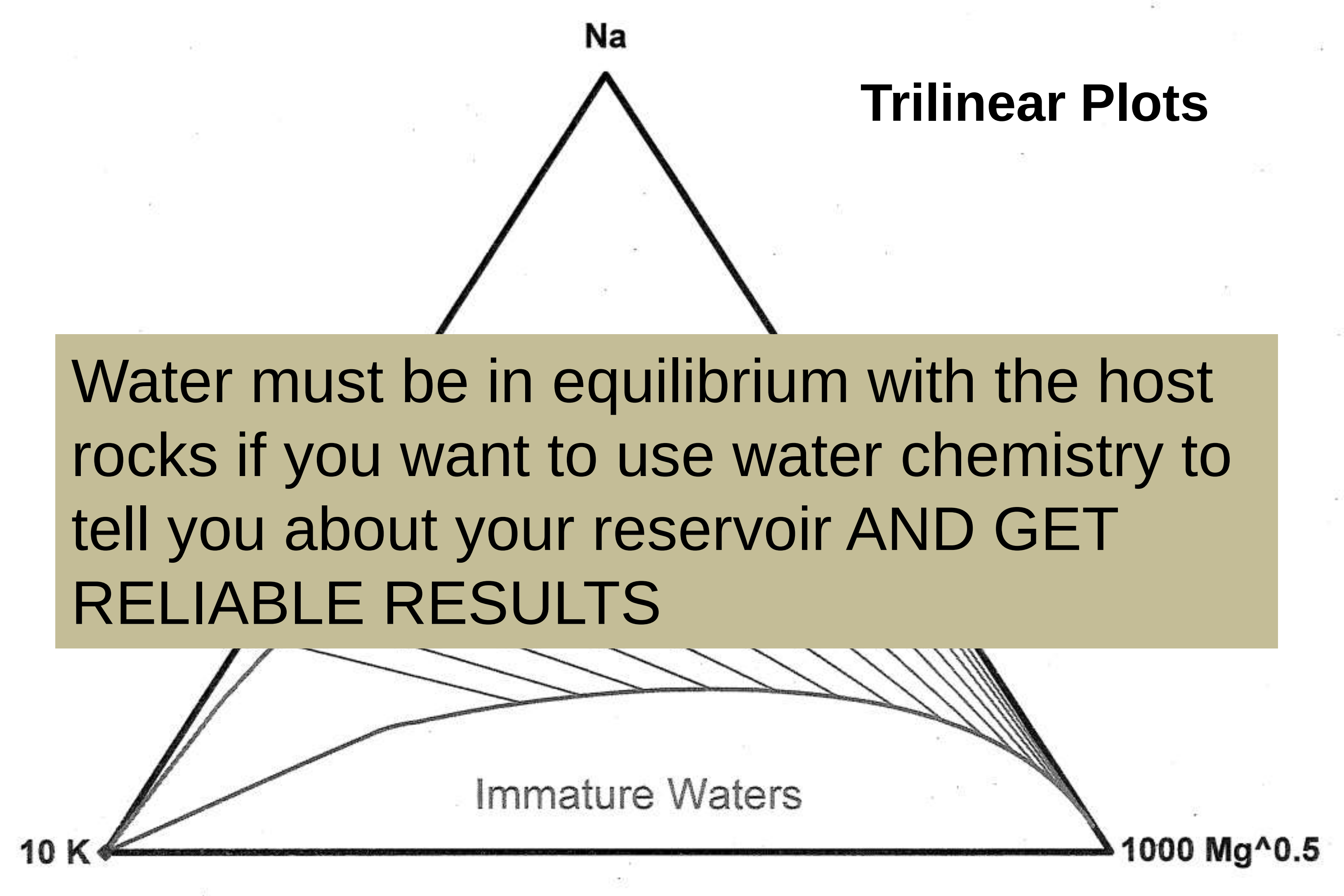
Into re-injection wells

How do we determine what type of fluid we have?



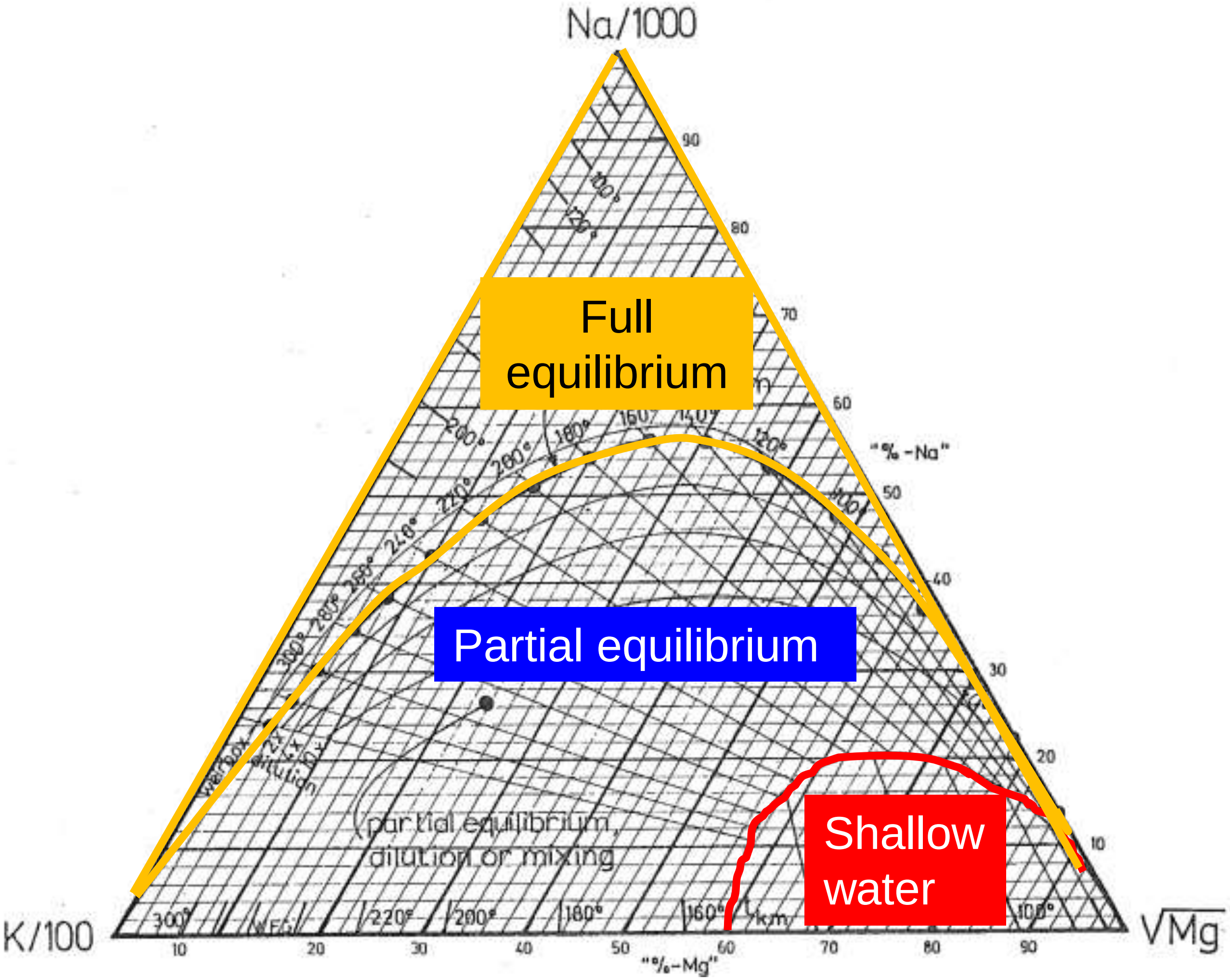
Water chemistry

Trilinear Plots



Water must be in equilibrium with the host rocks if you want to use water chemistry to tell you about your reservoir AND GET RELIABLE RESULTS

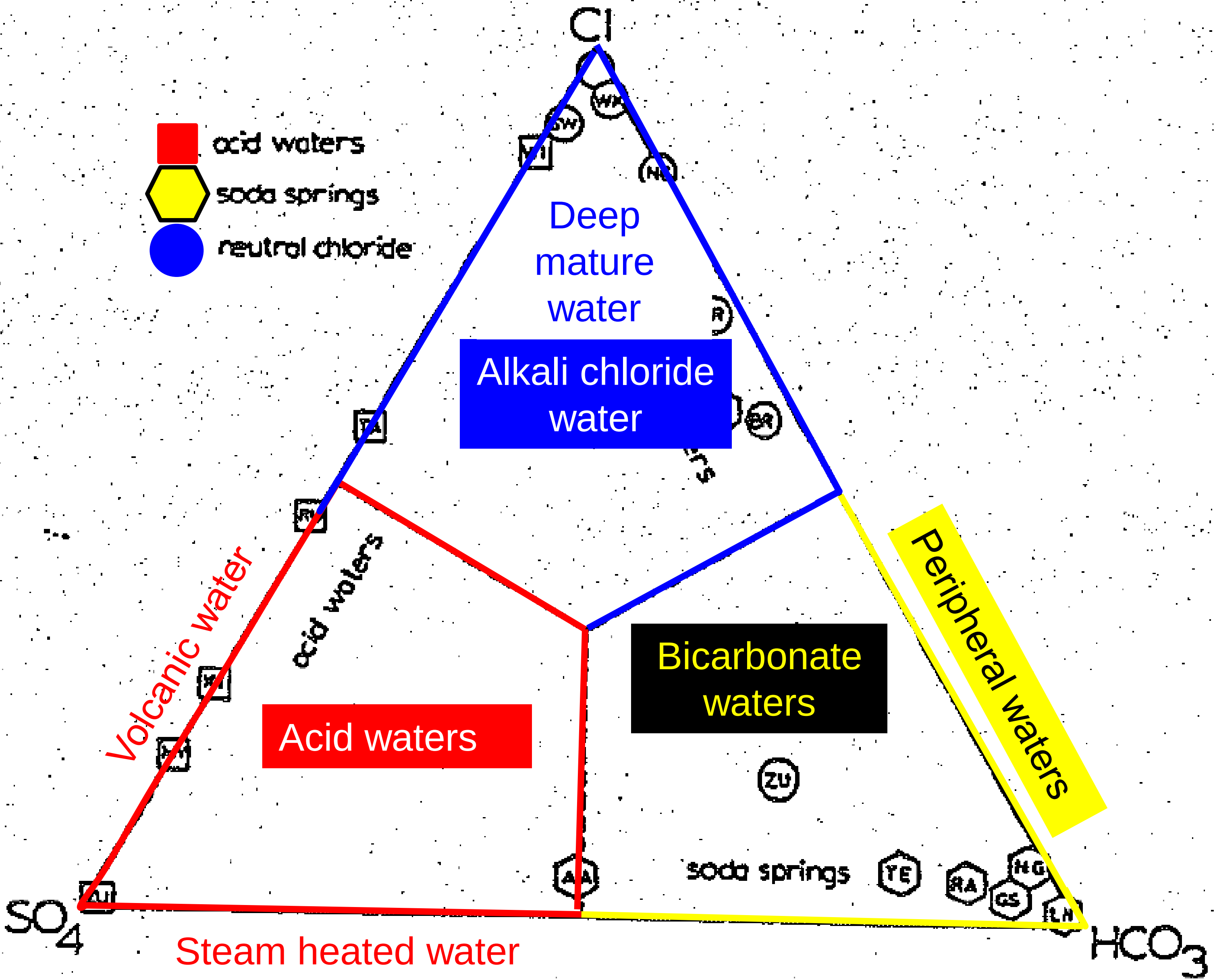
Geochemists use plots of the water composition to tell them information



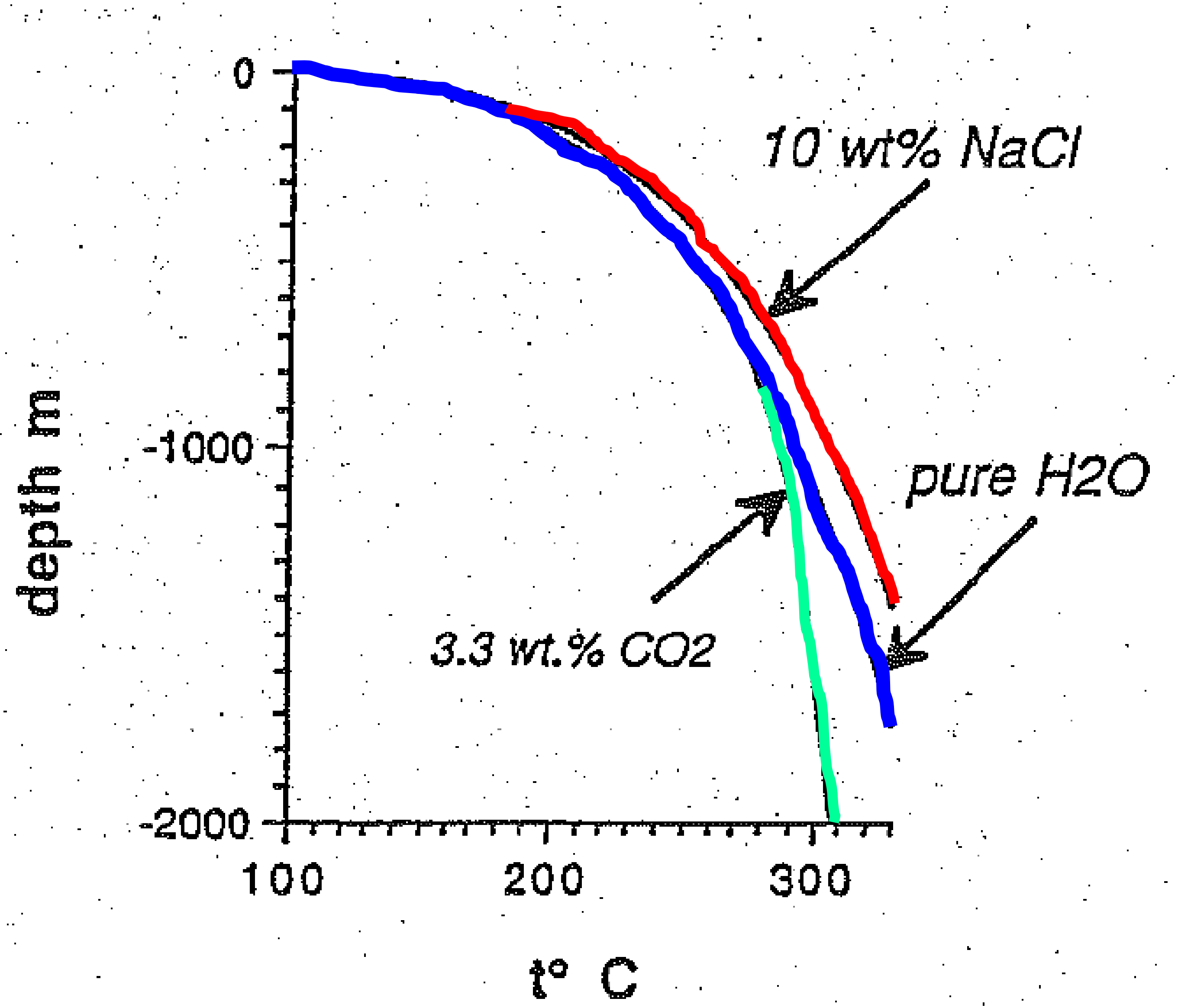
Full equilibrium

Partial equilibrium

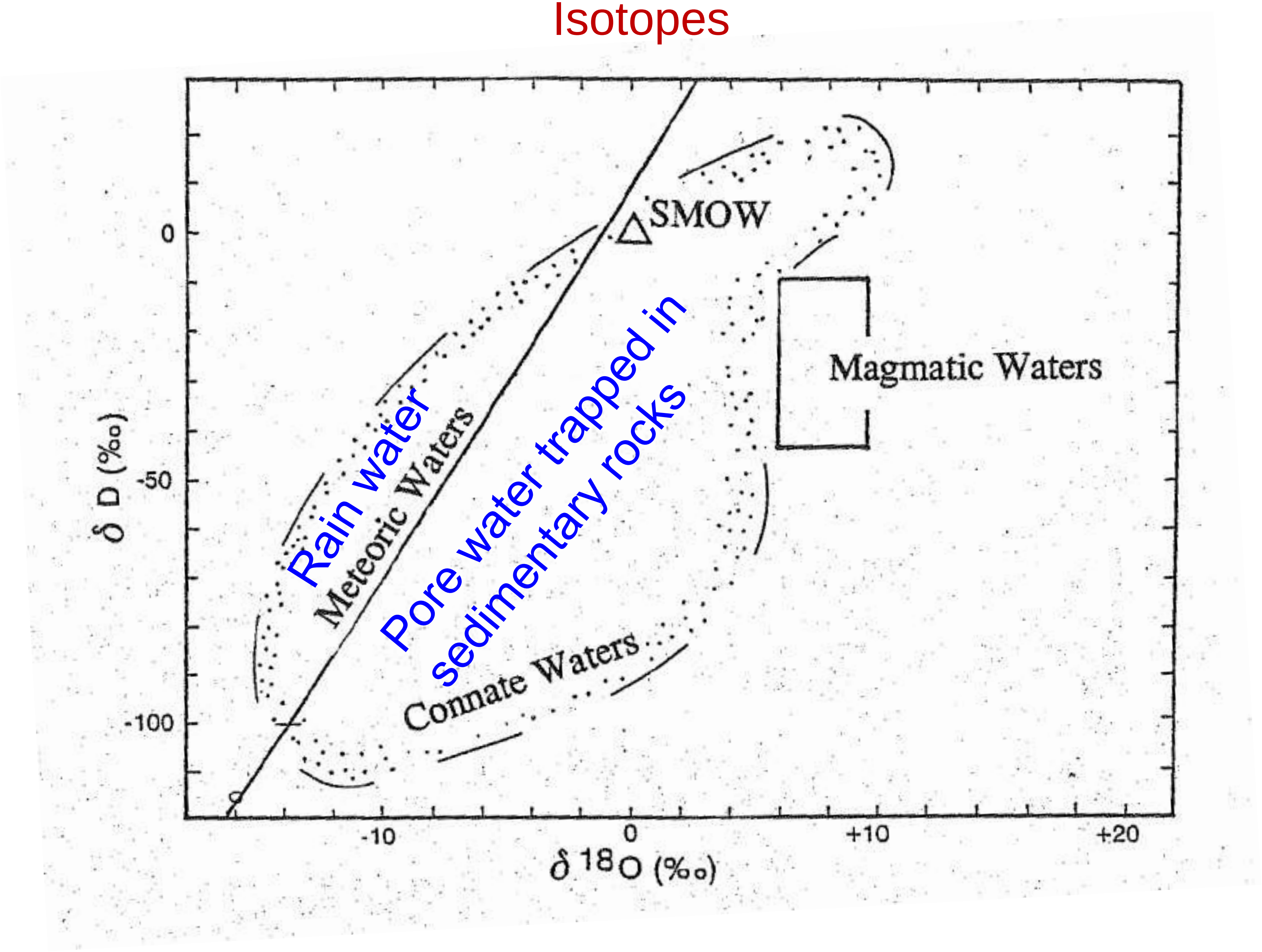
Shallow water


Cl
SO4
HCO3
acid waters
soda springs
neutral chloride
Deep mature water
Alkali chloride water
Volcanic water
acid waters
Acid waters
Bicarbonate waters
Peripheral waters
soda springs
Steam heated water
WK
SW
NG
BR
ZU
AA
YE
RA
HG
GS
LN

Boiling point with depth curves



Isotopes


SMOW
Magmatic Waters
Meteoric Waters
Rain water
Pore water trapped in sedimentary rocks
Connate Waters
δ D (‰)
0
-50
-100
δ 18O (‰)
-10
0
+10
+20

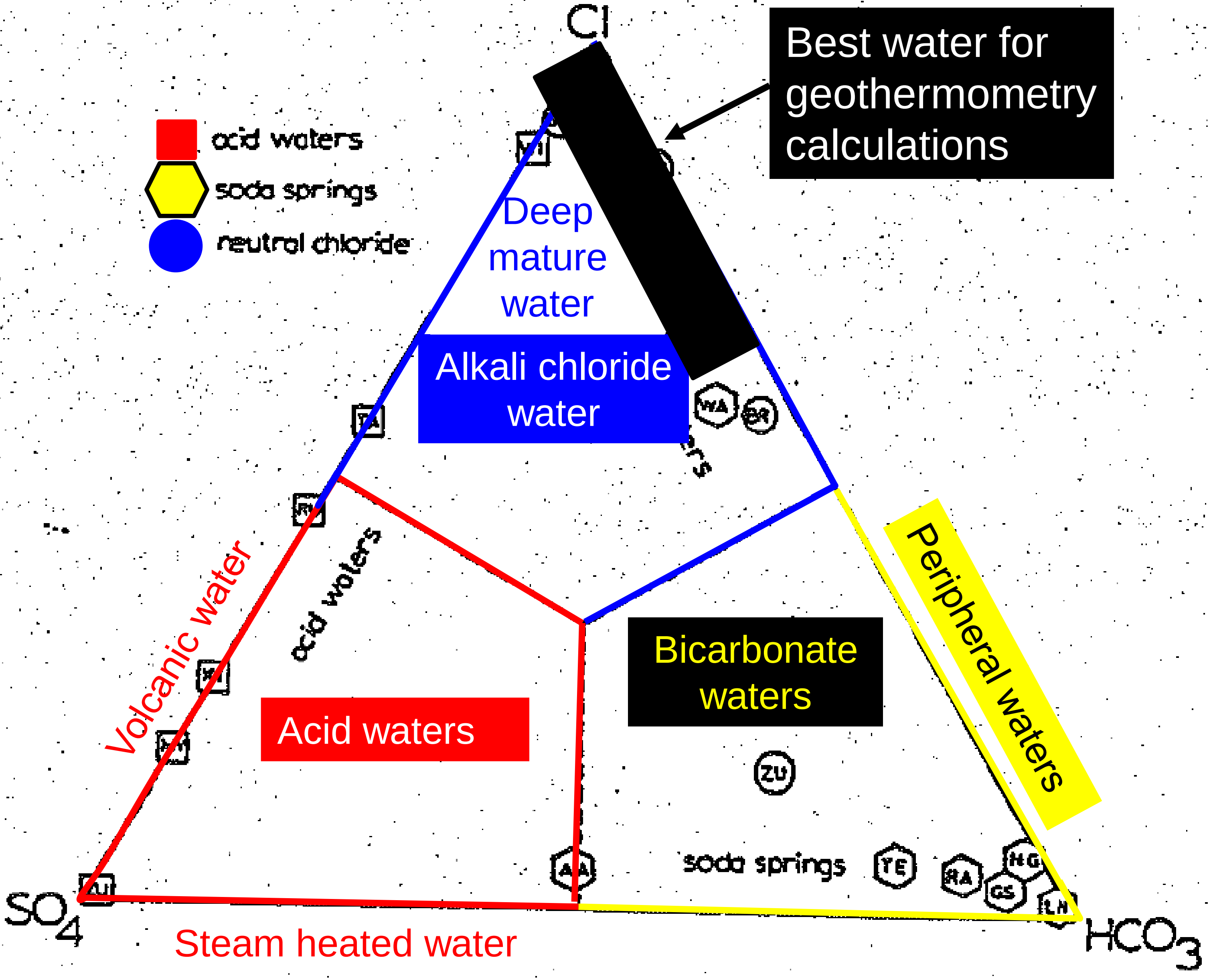
Geothermometry calculations

Using chemical equations based on the water chemistry to determine the deep reservoir temperatures

Many rules on where and when you can use geothermometry to get accurate results

1. Quartz-no steam loss	$t\ °C = \frac{1309}{5.19 - \log SiO_2} - 273$	t = 50-250° C
2. Quartz-max. steam loss	$t\ °C = \frac{1522}{5.75 - \log SiO_2} - 273$	t = 100-250° C
3. Chalcedony	$t\ °C = \frac{1032}{4.69 - \log SiO_2} - 273$	t = 50-250° C
4. Cristobalite	$t\ °C = \frac{1000}{4.78 - \log SiO_2} - 273$	t = 50-250° C
5. Opal CT	$t\ °C = \frac{781}{4.51 - \log SiO_2} - 273$	t = 50-250° C
6. Amorphous silica	$t\ °C = \frac{731}{4.52 - \log SiO_2} - 273$	t = 50-250° C
7. Na-K (Fournier)	$t\ °C = \frac{1217}{\log (Na/K) + 1.483} - 273$	t > 180° C
8. Na-K (Giggenbach)	$t\ °C = \frac{1390}{\log (Na/K) + 1.75} - 273$	t > 180° C
9. Na-K-Ca	$t\ °C = \frac{1647}{\log (Na/K) + \beta[\log (Ca^{1/2}/Na) + 2.06] + 2.47} - 273$	t > 120° C
10. K-Mg	$t\ °C = \frac{4410}{14.0 - \log (K^2/Mg)} - 273$	t = 50-300° C
11. $\Delta^{18}O\ (SO_4^{-2}-H_2O)$	$1000 \ln \alpha = 2.88\ (10^6/T^2) - 4.1$	

where $\alpha = \frac{1000+\delta^{18}O_{HSO4}}{1000+\delta^{18}O_{H2O}}$ and T in °K



Best water for geothermometry calculations

Deep mature water

Alkali chloride water

Volcanic water

Acid waters

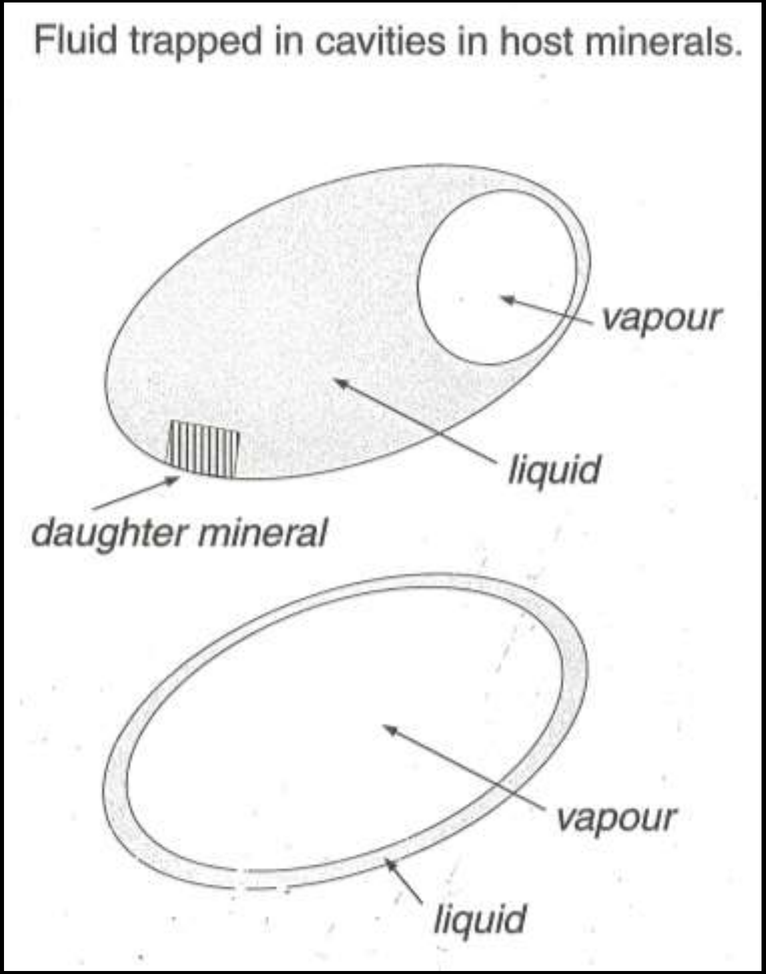
Bicarbonate waters

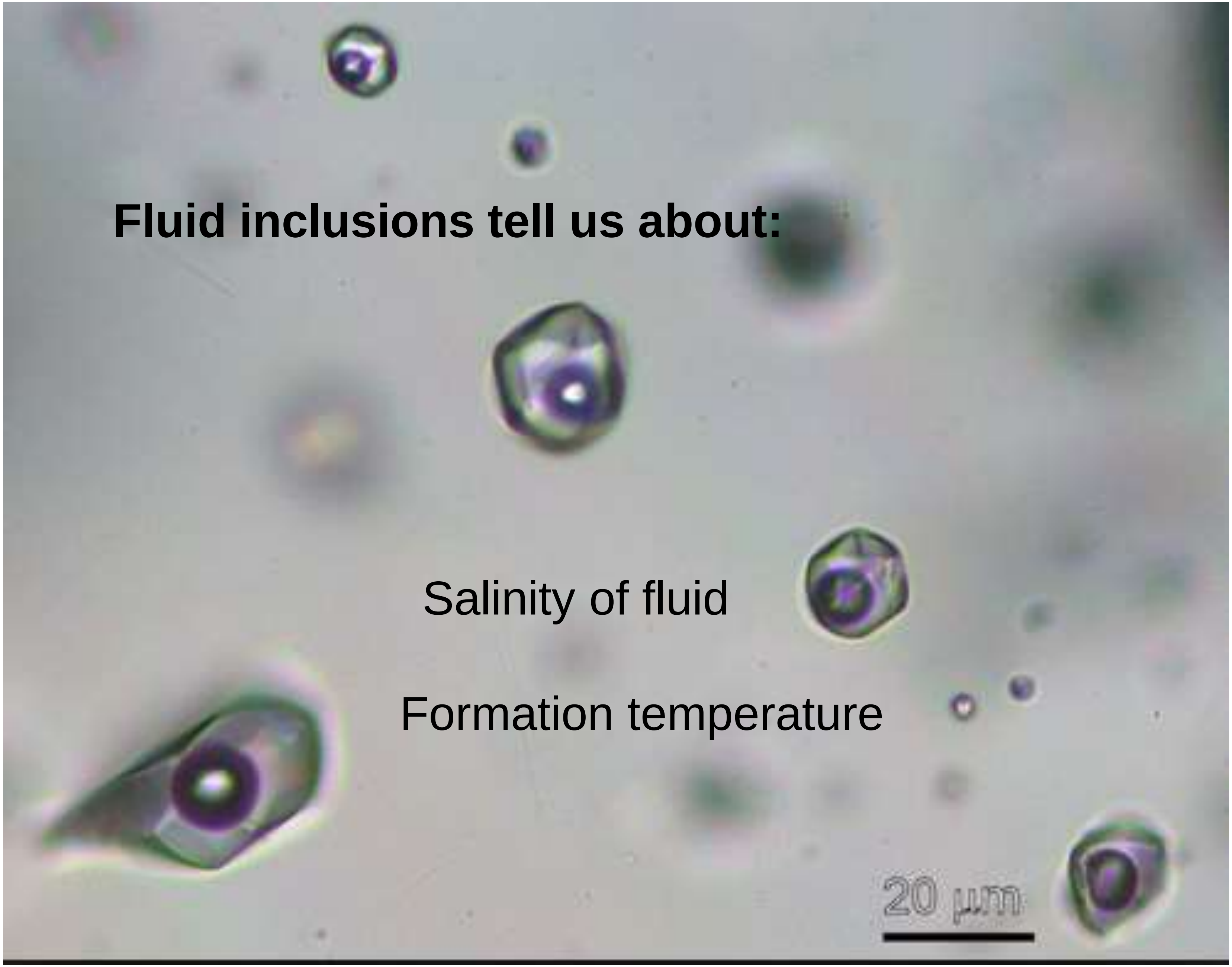
Peripheral waters

Steam heated water

Fluid inclusions also tell us about fluid type

2 phase inclusions

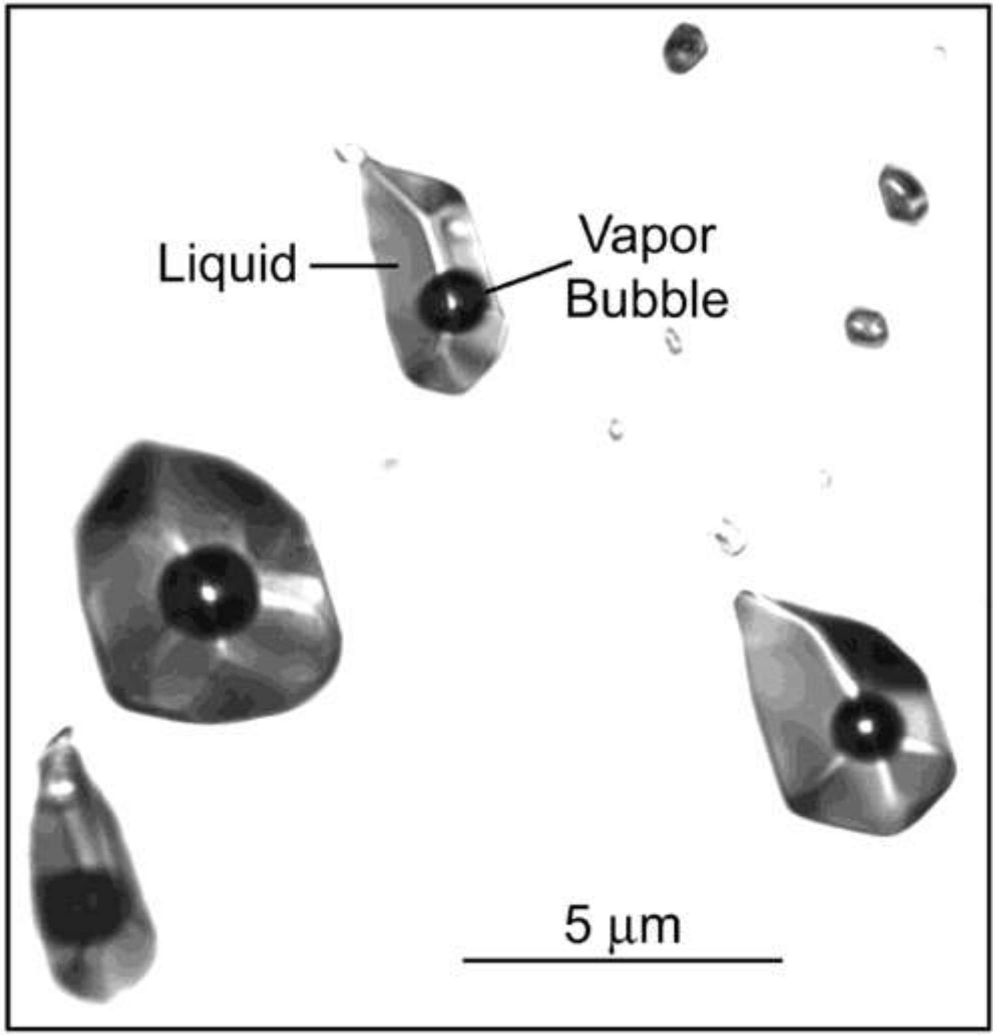

Fluid trapped in cavities in host minerals.



Fluid inclusions tell us about:

Salinity of fluid

Formation temperature

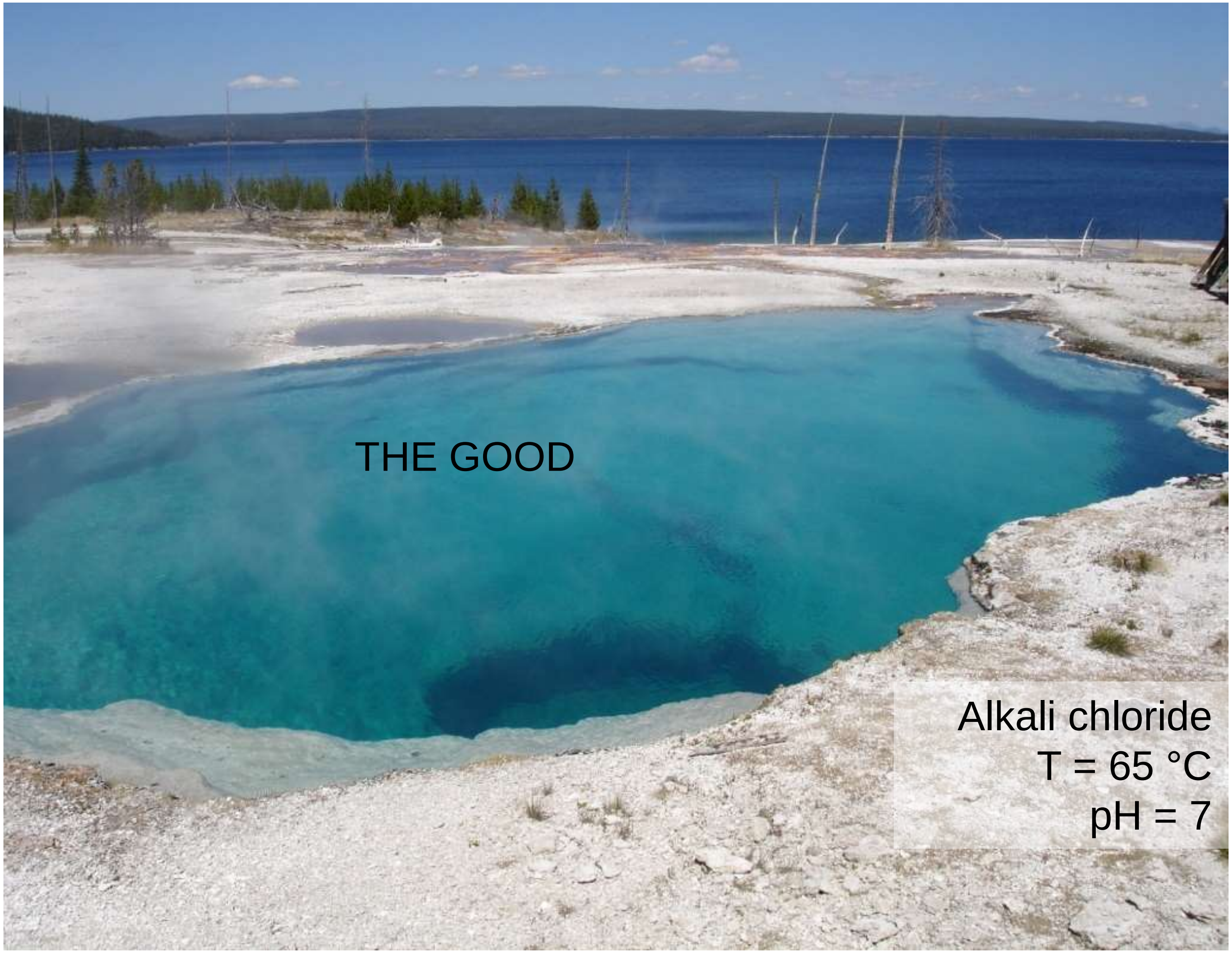


www.canmin.org

Best minerals for preserving fluid inclusions

Quartz
Calcite
Anhydrite

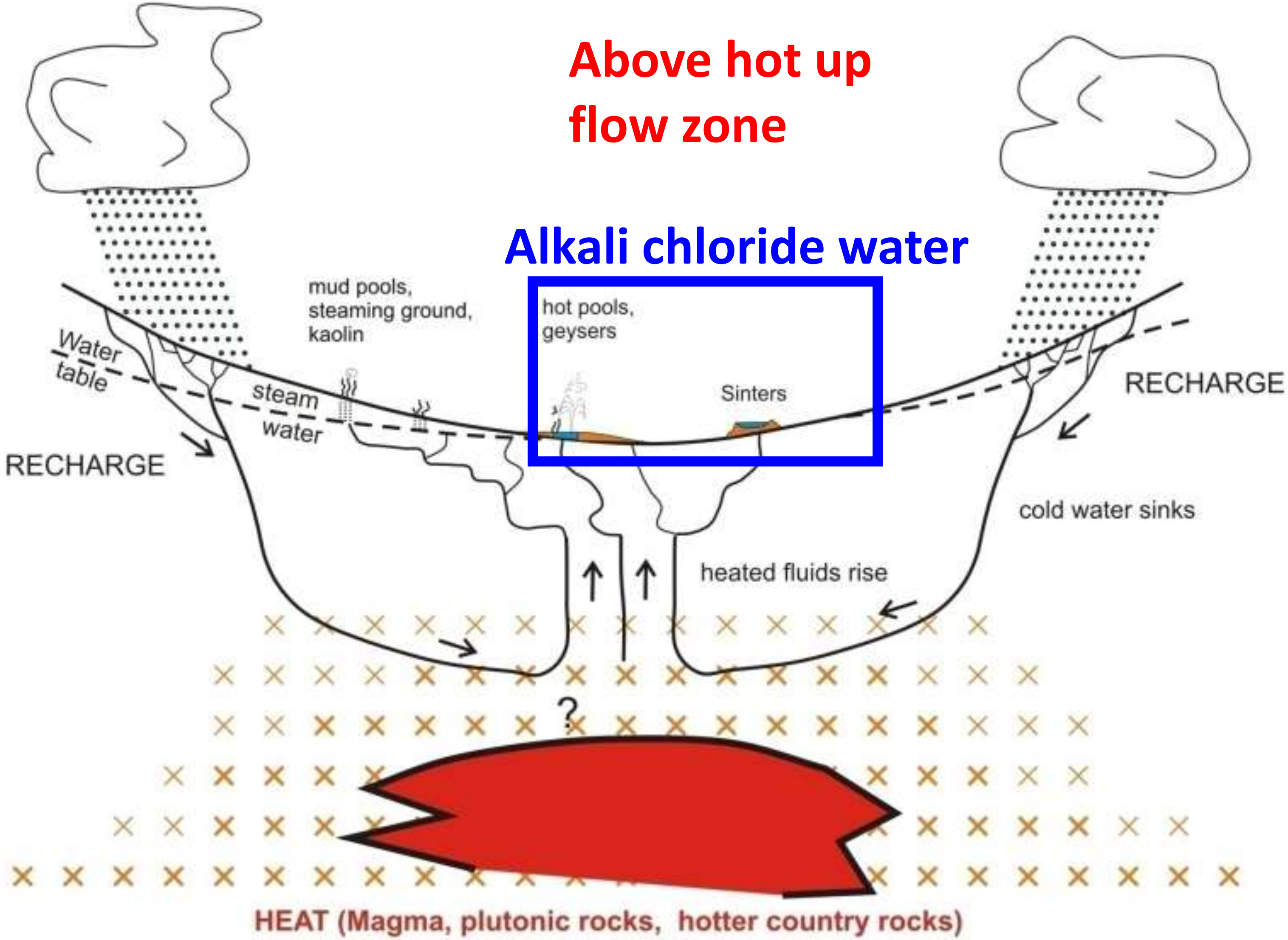
THE GOOD



THE GOOD

Alkali chloride
T = 65 °C
pH = 7

THE GOOD



Above hot up flow zone

Alkali chloride water

General concept of a geothermal system

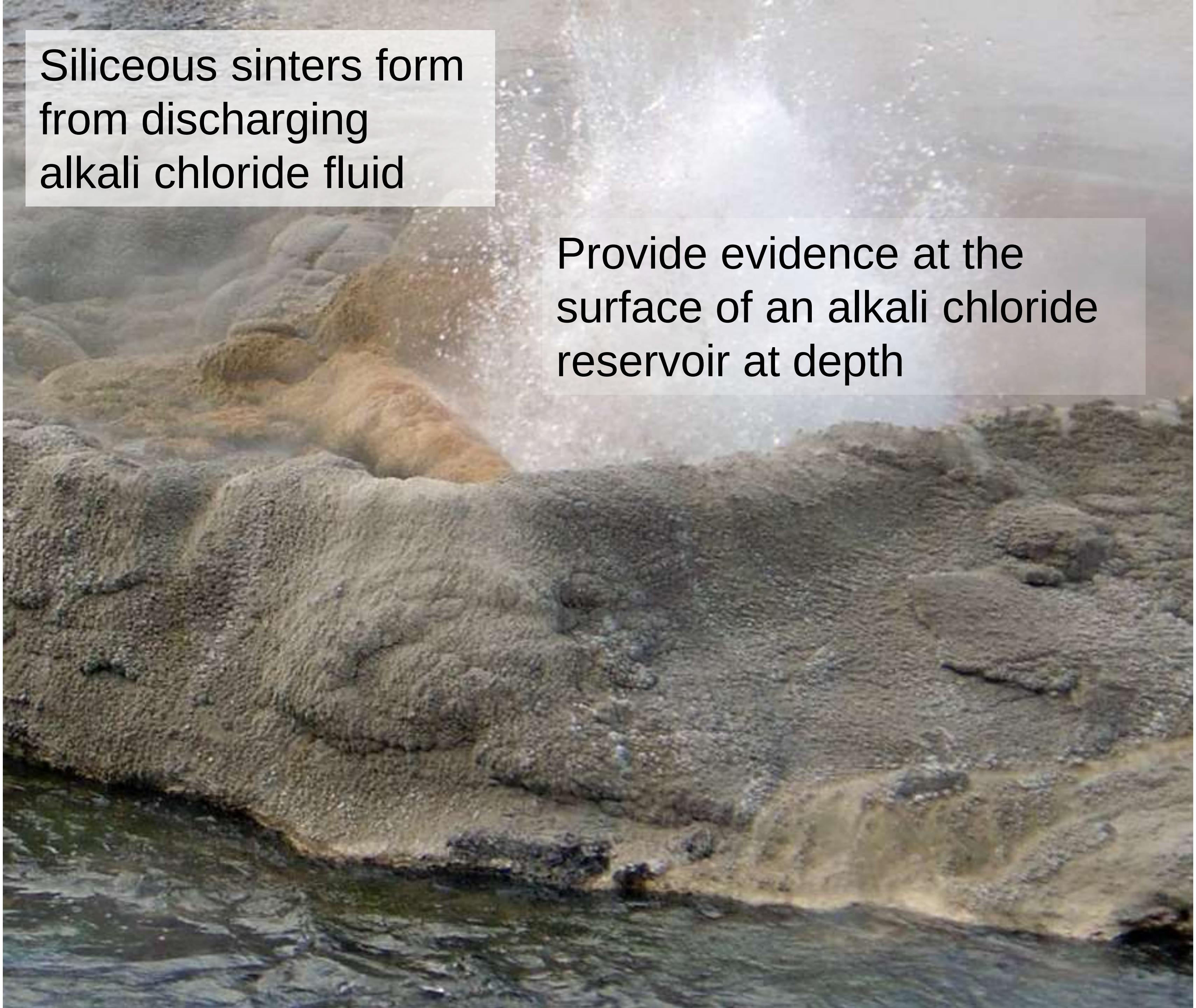
Alkali chloride water
for power generation

Properties of alkali chloride water

Near neutral pH 7-8
Clear blue water

High	Cl = 1500 ppm
	Na = 1000 ppm
	SiO_2 = 700 ppm
Low	SO_4 = 20 ppm
	HCO_3 = 20 ppm
	Mg = <1 ppm

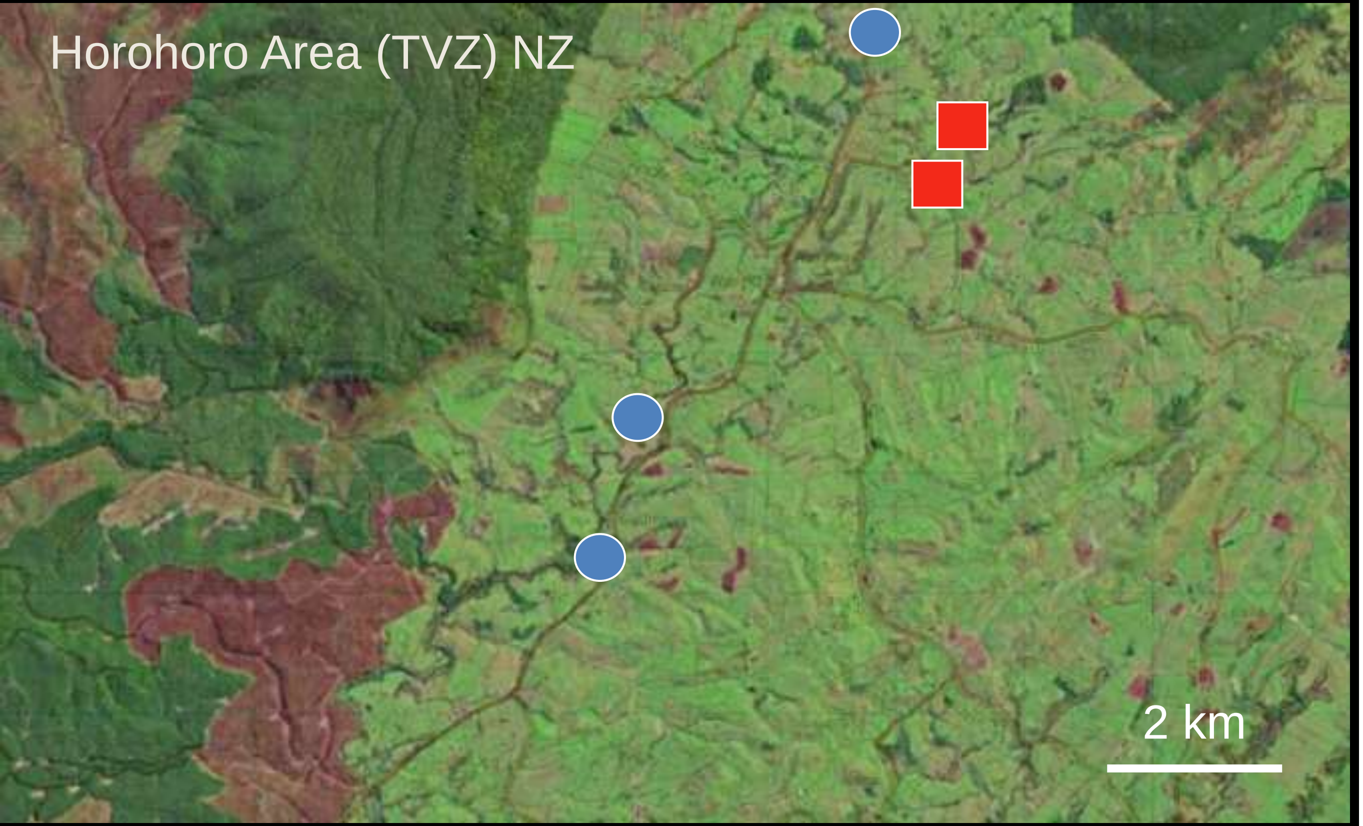
Each field differs but these are generalisations of good water chemistry



Siliceous sinters form from discharging alkali chloride fluid

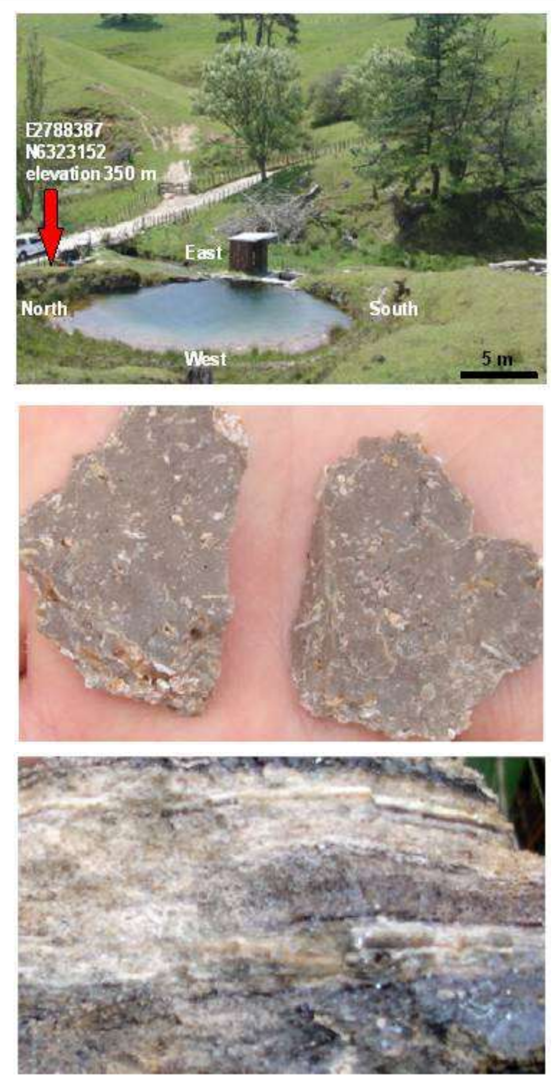
Provide evidence at the surface of an alkali chloride reservoir at depth

Many undiscovered sinters, often away from present day hot springs



● Undocumented sinters

🟥 Hot springs



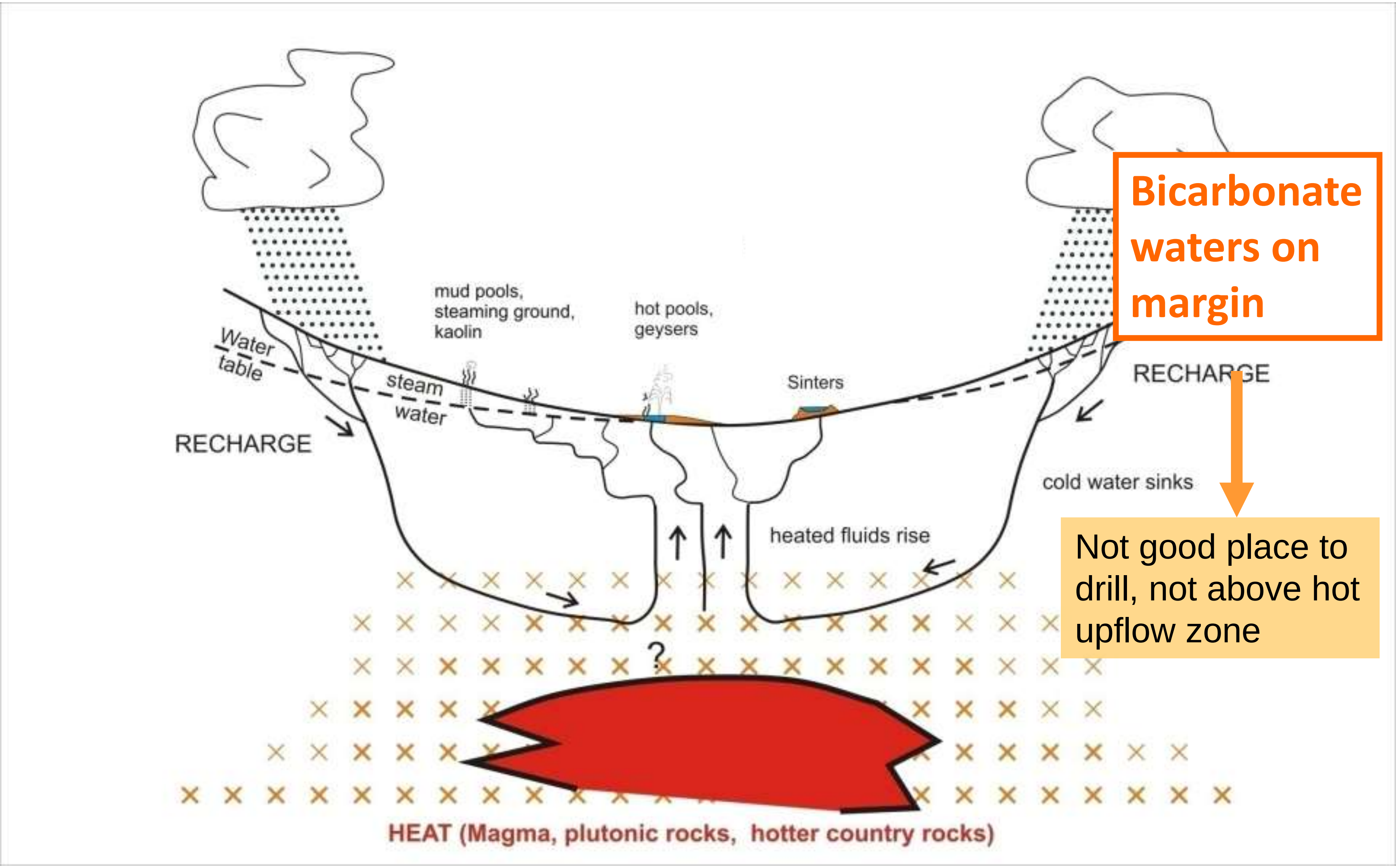
THE BAD

THE BAD

Bicarbonate water
T = 88 °C
pH = 6

THE BAD

CO_2-rich water



Bicarbonate waters on margin

Not good place to drill, not above hot upflow zone

General concept of a geothermal system

Pamukkale Hot Springs in Turkey
Travertine Deposits formed by bicarbonate water

Extensive travertine deposits worldwide

Look similar to siliceous sinter

Yellowstone, USA

Indicate cooler outflow zones (or CO_2 rich reservoir)

More useful now with improved technology that can use cooler fluids

Silicified sediments

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

Not a good place to drill

Scaling

One of the major issues in well casing and pipes

The scale story

Scaling is a problem that cannot be ignored

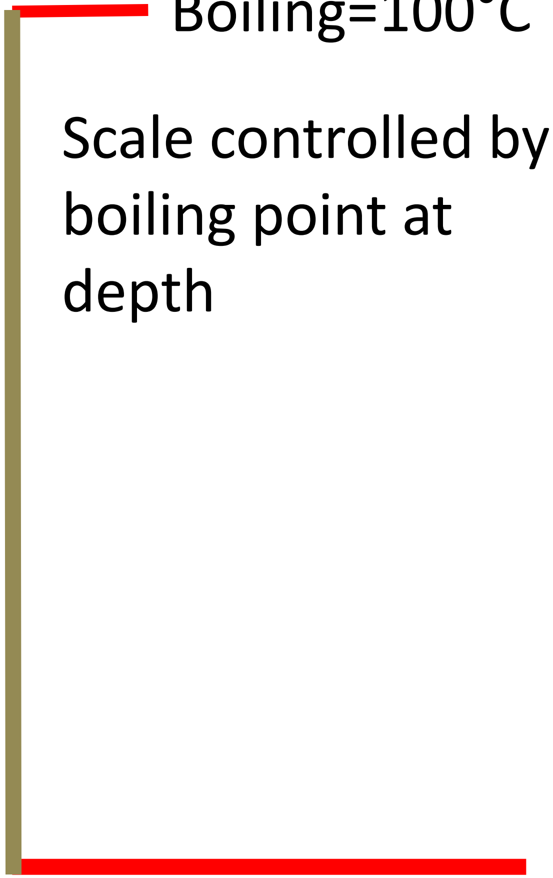
Thermal Fluids
Move through pipe

Loss of productivity due to blockage

Scaling = precipitation of calcite, silica, sulfides.

Scaling in production wells

Atmospheric pressure =1 Bar(100kPa)



Ground level

Boiling=100°C

Scale controlled by boiling point at depth

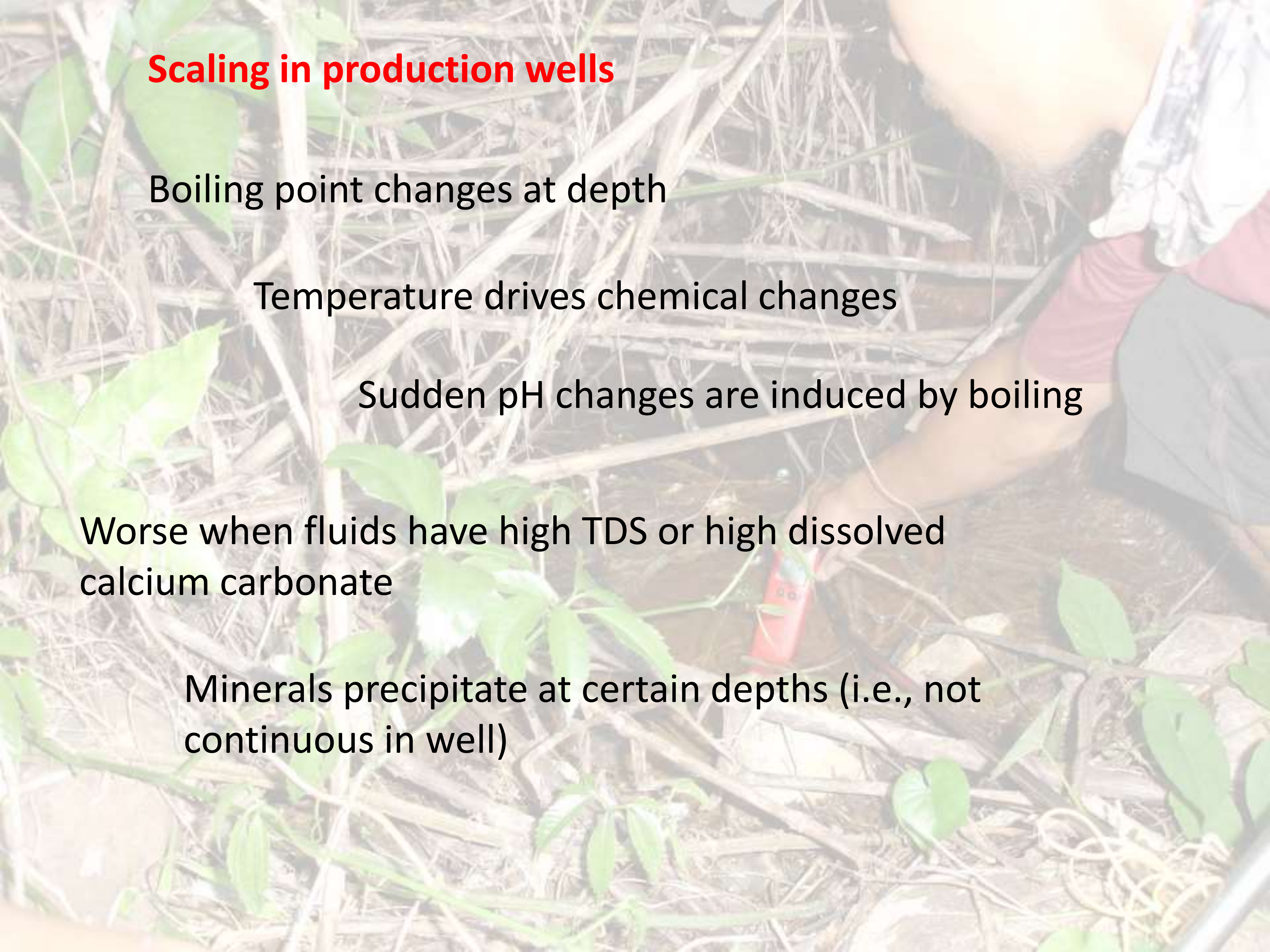
Types of scaling

1. Calcium carbonate (calcite)
2. Silica
3. Metal sulfides

1000m below ground level Pressure ~ 100 Bar

Boiling=310°C

Scaling in production wells



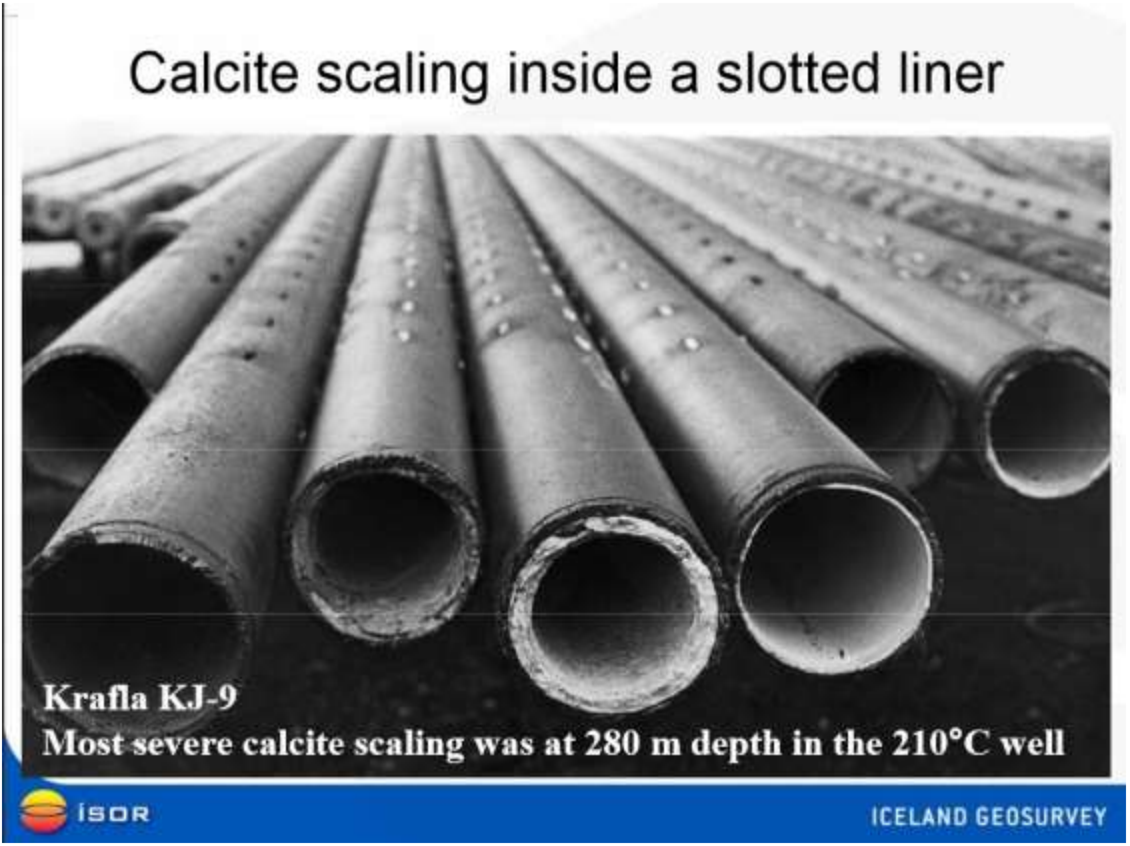
Boiling point changes at depth

Temperature drives chemical changes

Sudden pH changes are induced by boiling

Worse when fluids have high TDS or high dissolved calcium carbonate

Minerals precipitate at certain depths (i.e., not continuous in well)



Calcite scaling inside a slotted liner

Krafla KJ-9

Most severe calcite scaling was at 280 m depth in the 210°C well

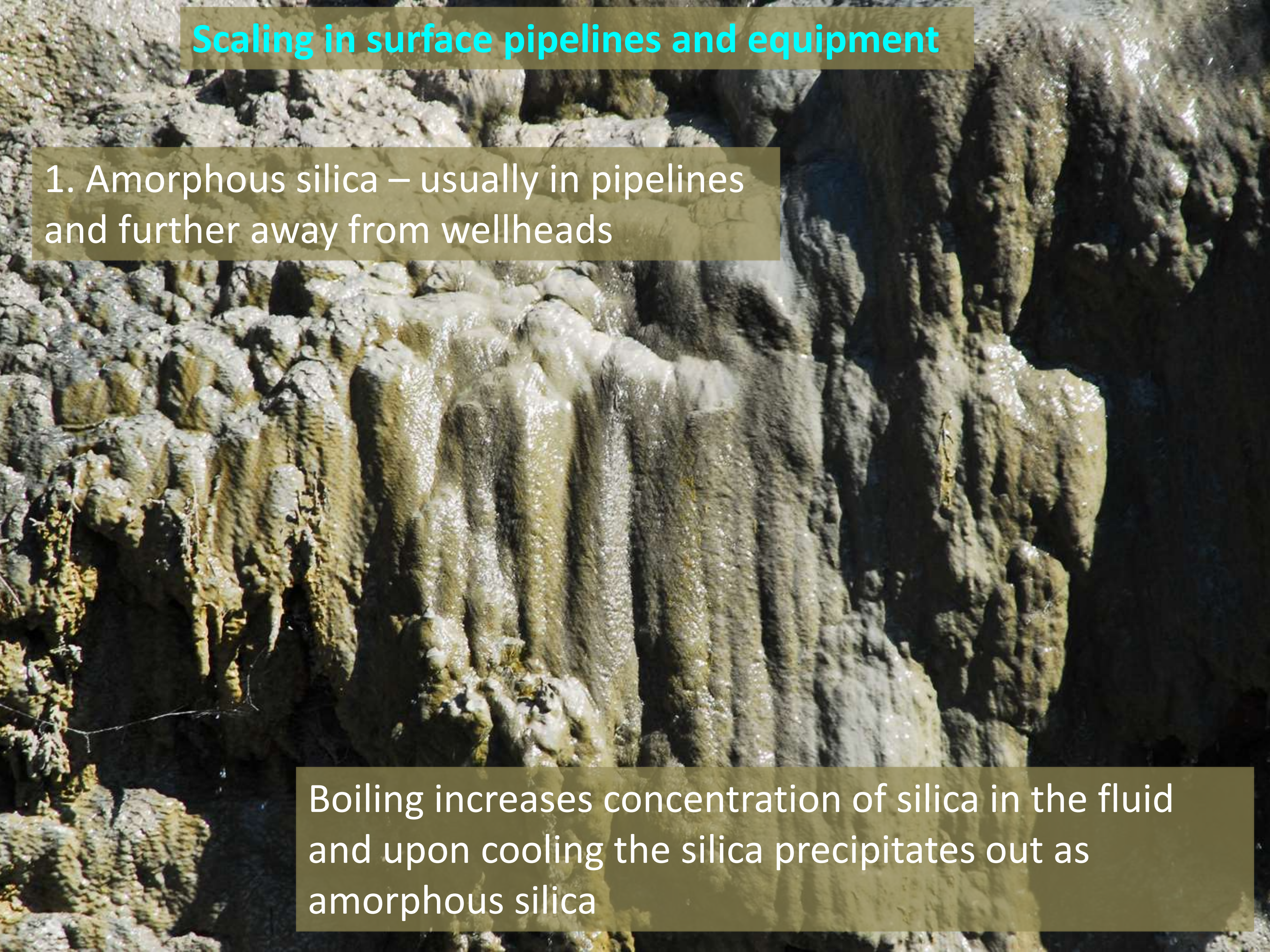
Solutions

Chemical dosing- scale inhibitor

Cleaning - removing

Gradually decrease wellhead pressure to lower the boiling point which lowers the scaling point

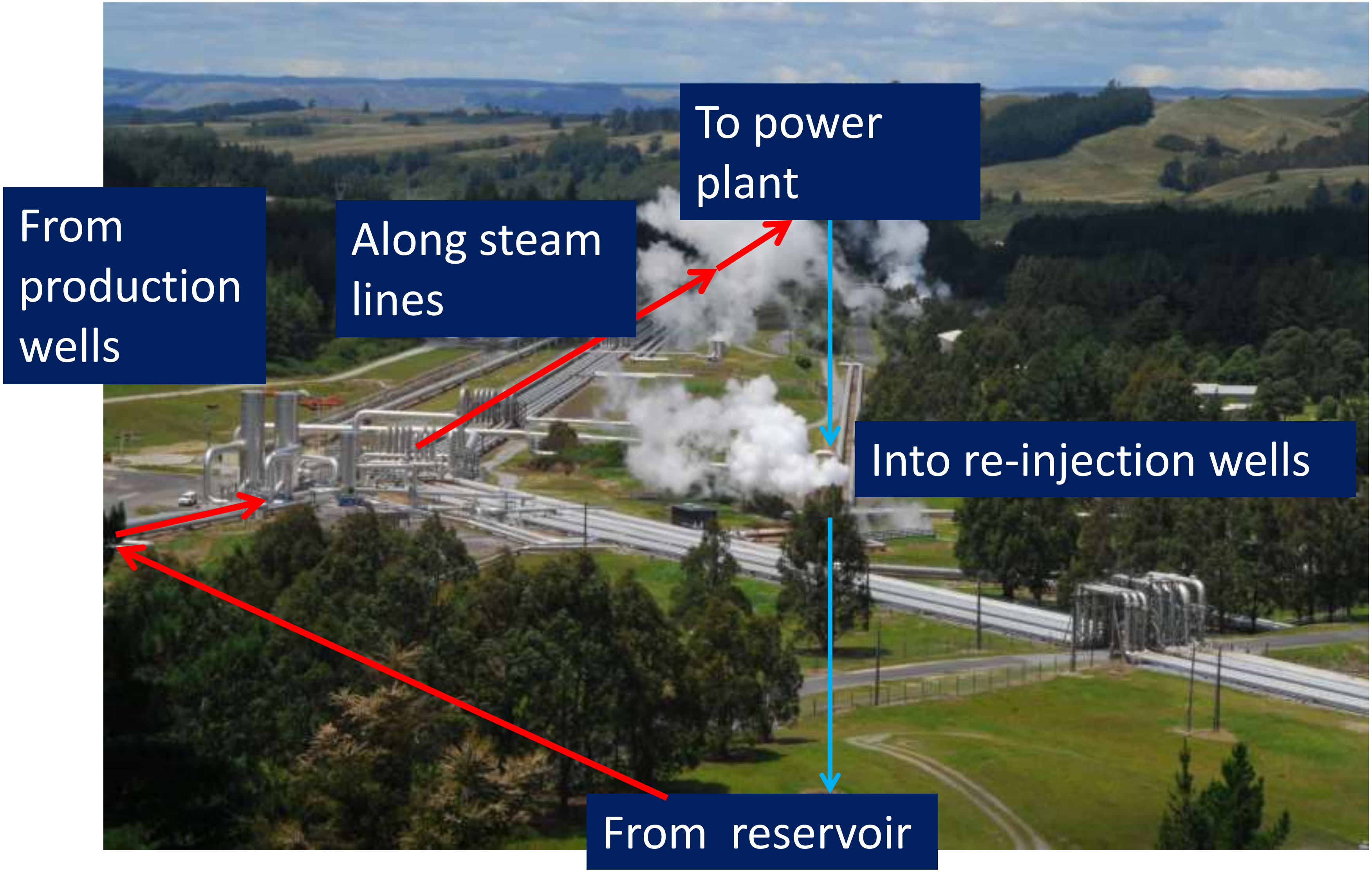
Scaling in surface pipelines and equipment



1. Amorphous silica – usually in pipelines and further away from wellheads

Boiling increases concentration of silica in the fluid and upon cooling the silica precipitates out as amorphous silica

Silica scale can form at many places



From production wells

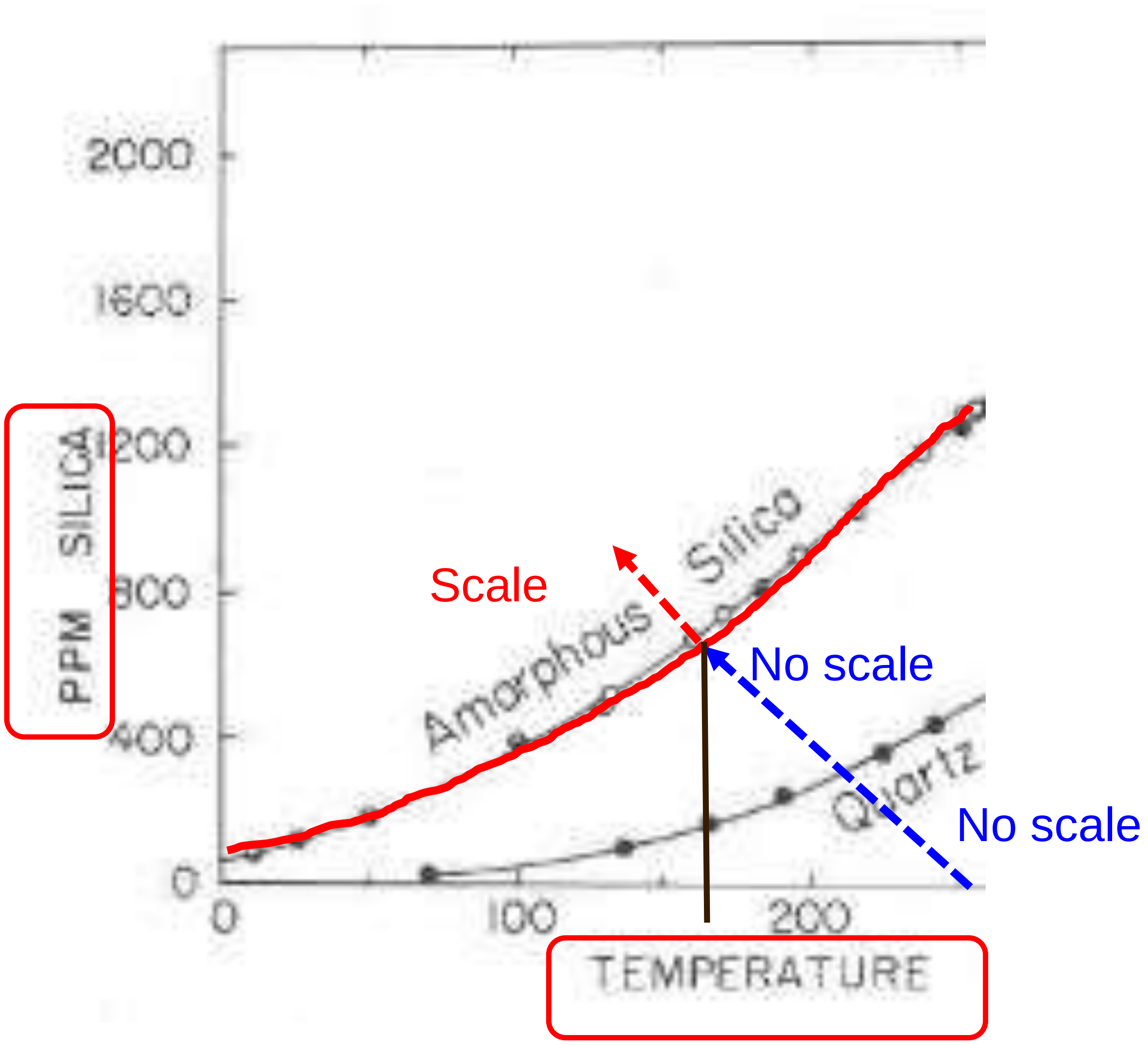
Along steam lines

To power plant

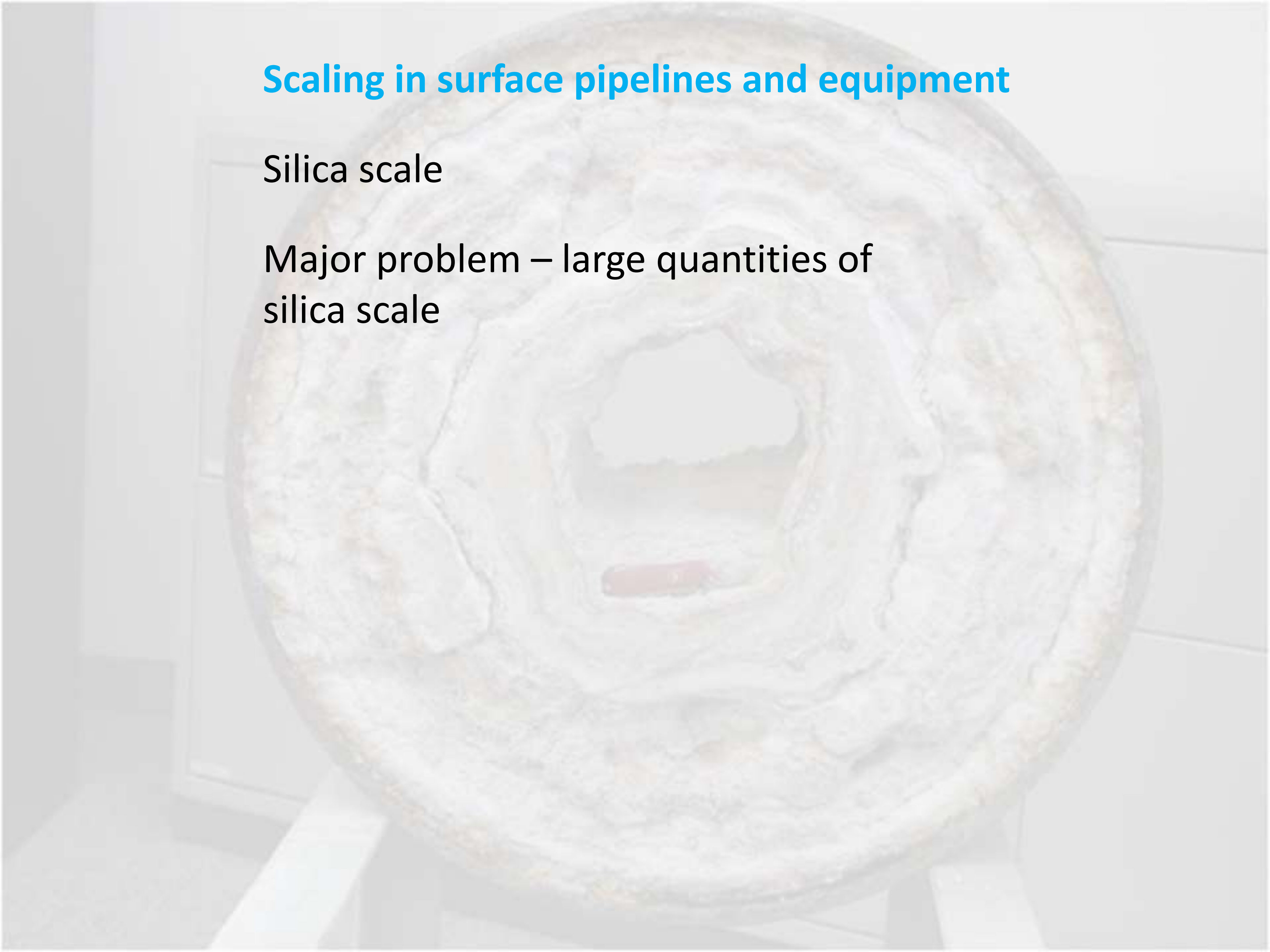
Into re-injection wells

From reservoir

Silica solubility and scaling



Scaling in surface pipelines and equipment



Silica scale

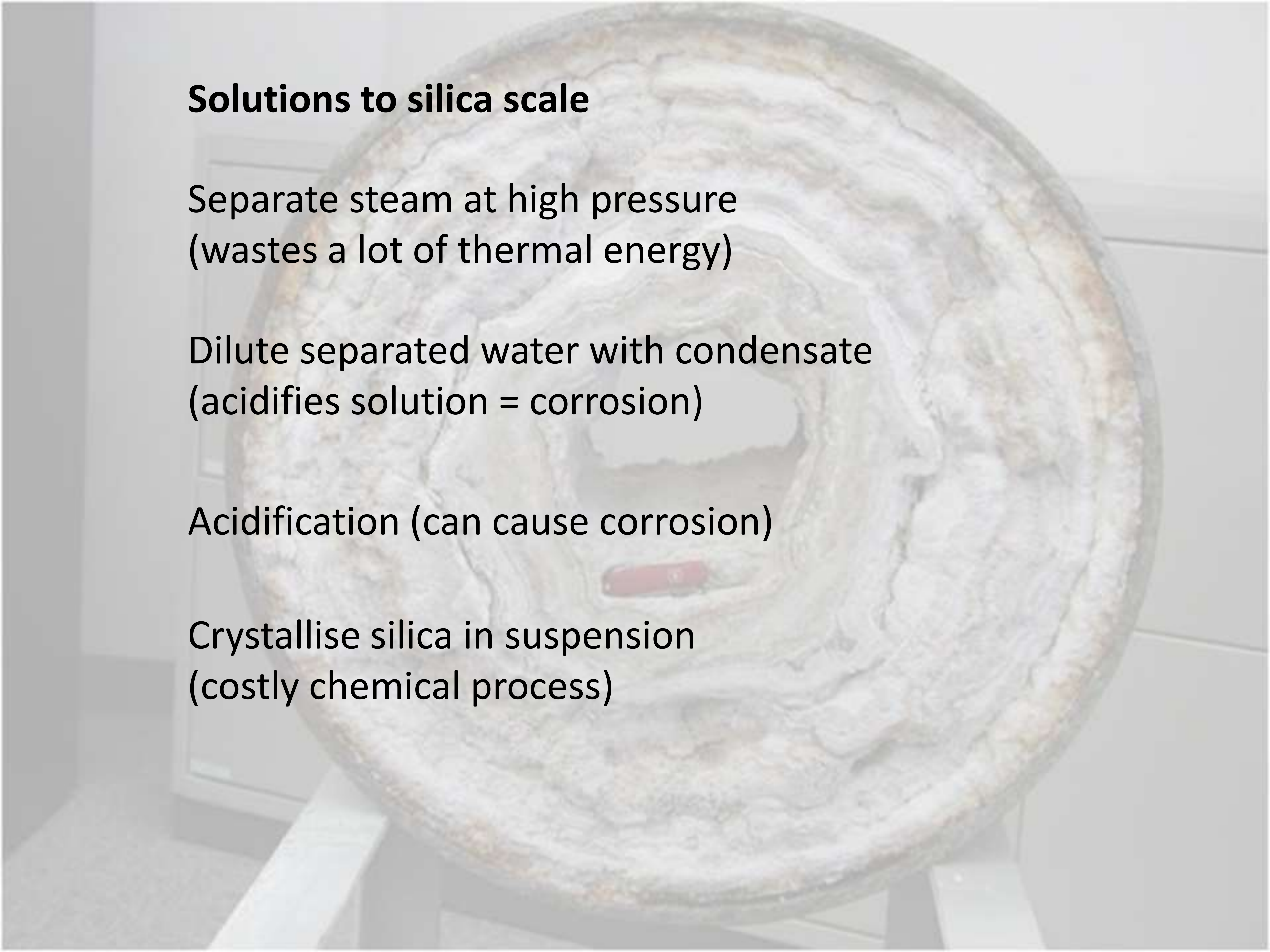
Major problem – large quantities of silica scale

Silica scale in waste 1 m x 1 m water discharge channel

~6 kms of Silica cleaned out every 6 months

Wairakei discharge drain

Silica scale rich in gold and silver



Solutions to silica scale

Separate steam at high pressure
(wastes a lot of thermal energy)

Dilute separated water with condensate
(acidifies solution = corrosion)

Acidification (can cause corrosion)

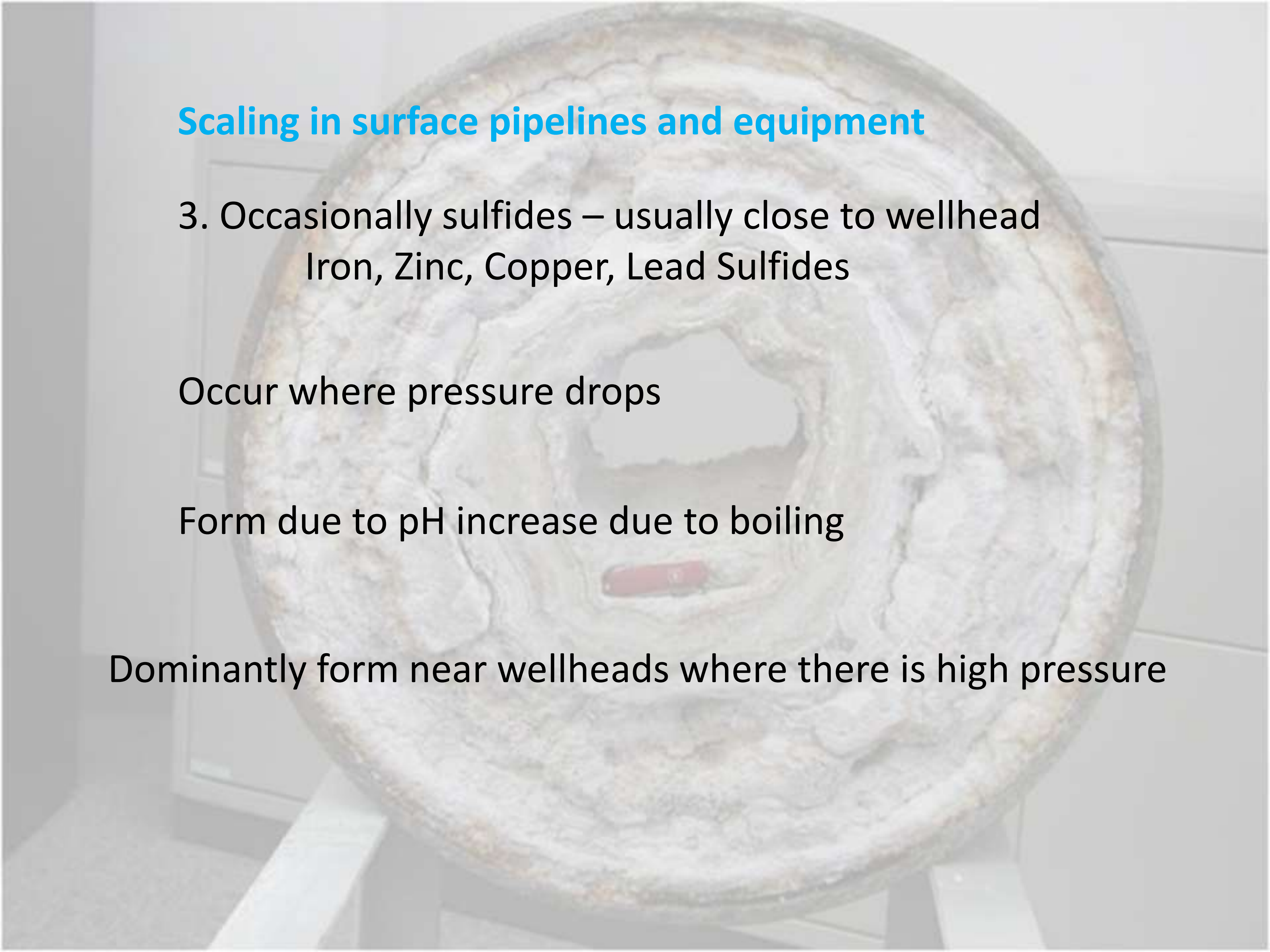
Crystallise silica in suspension
(costly chemical process)

Scaling in surface pipelines and equipment

2. Calcium carbonate (calcite)

In pipelines

Scaling in surface pipelines and equipment



3. Occasionally sulfides – usually close to wellhead

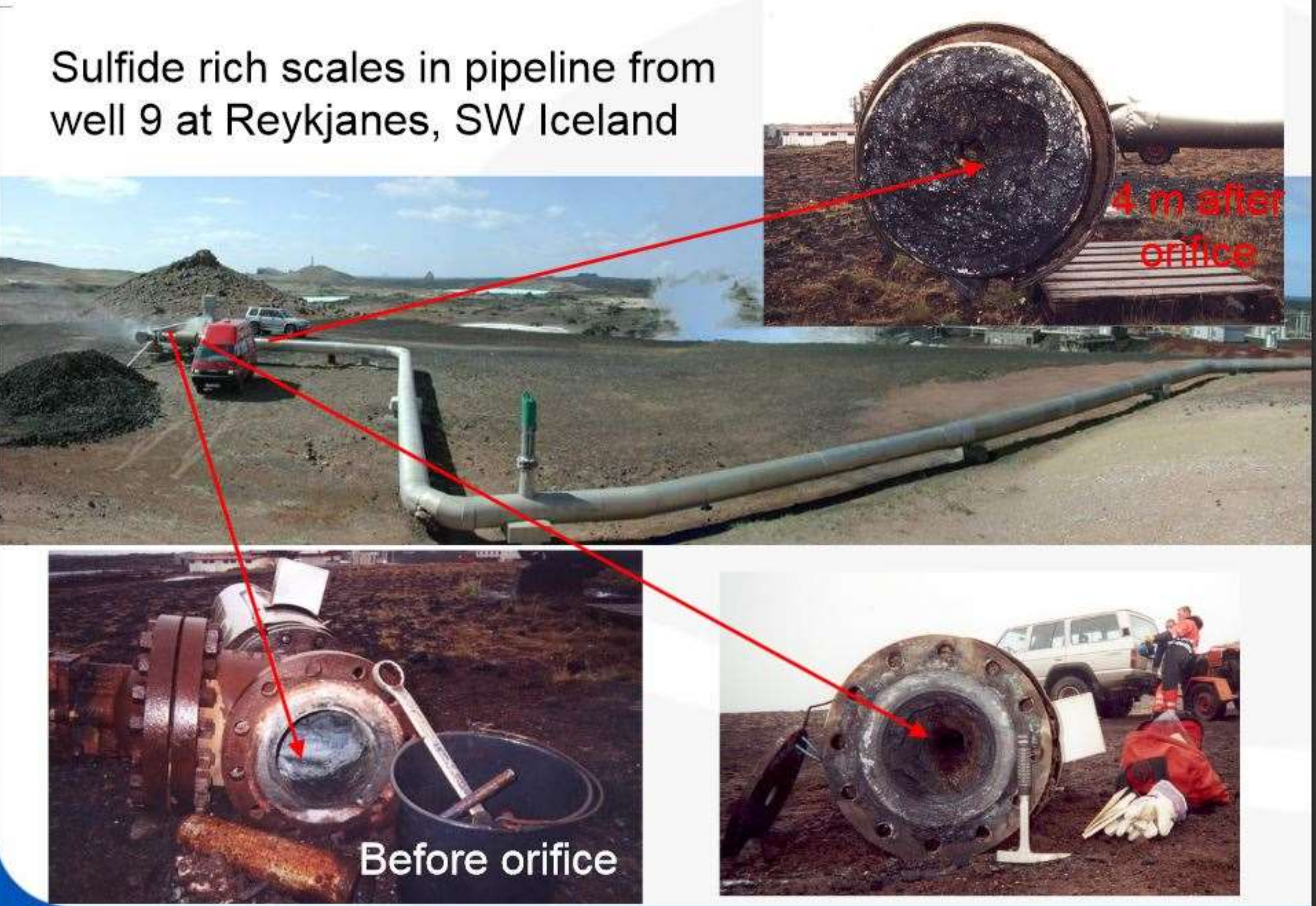
Iron, Zinc, Copper, Lead Sulfides

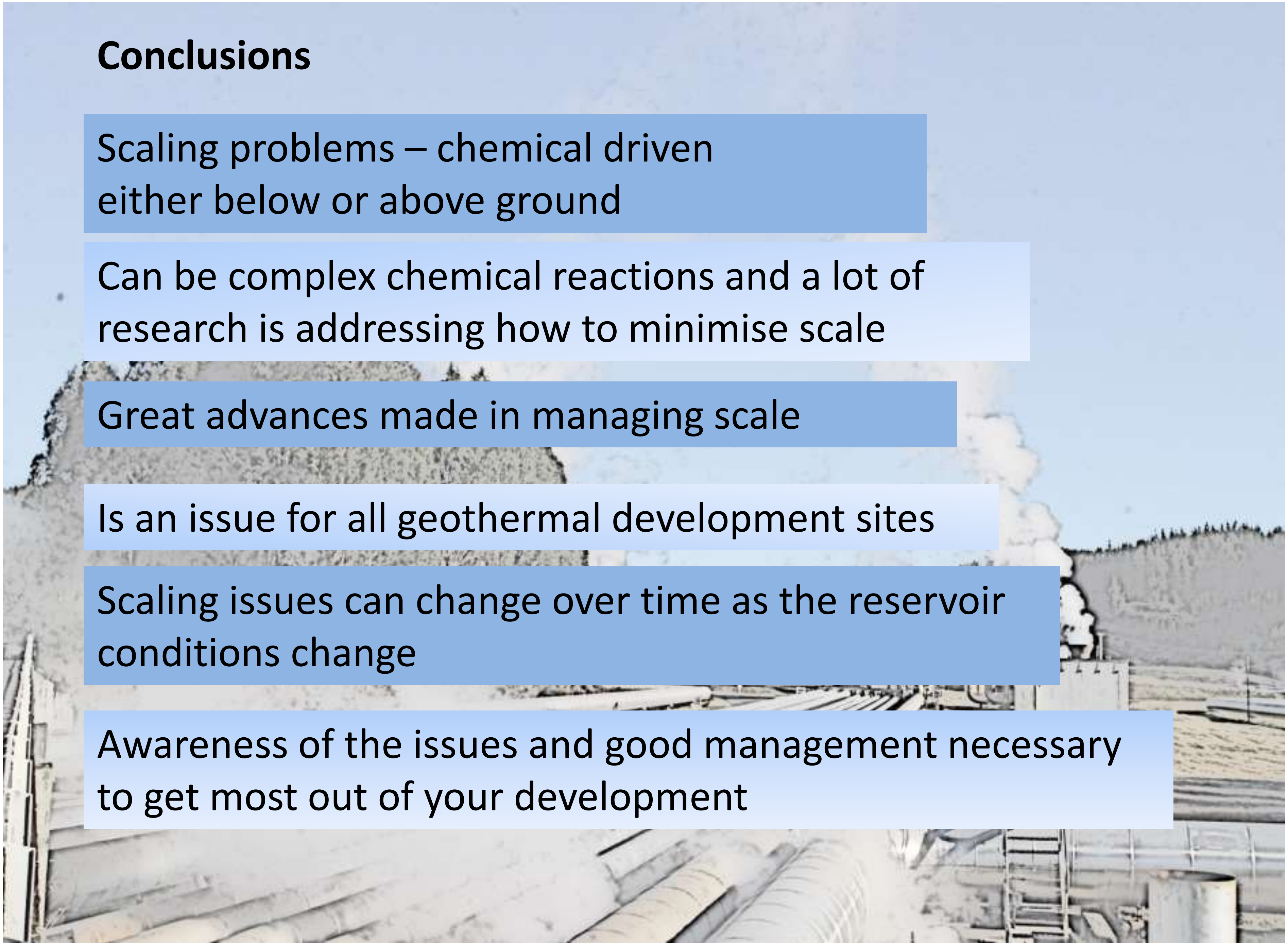
Occur where pressure drops

Form due to pH increase due to boiling

Dominantly form near wellheads where there is high pressure

Sulfide rich scales in pipeline from well 9 at Reykjanes, SW Iceland





Conclusions

Scaling problems – chemical driven
either below or above ground

Can be complex chemical reactions and a lot of research is addressing how to minimise scale

Great advances made in managing scale

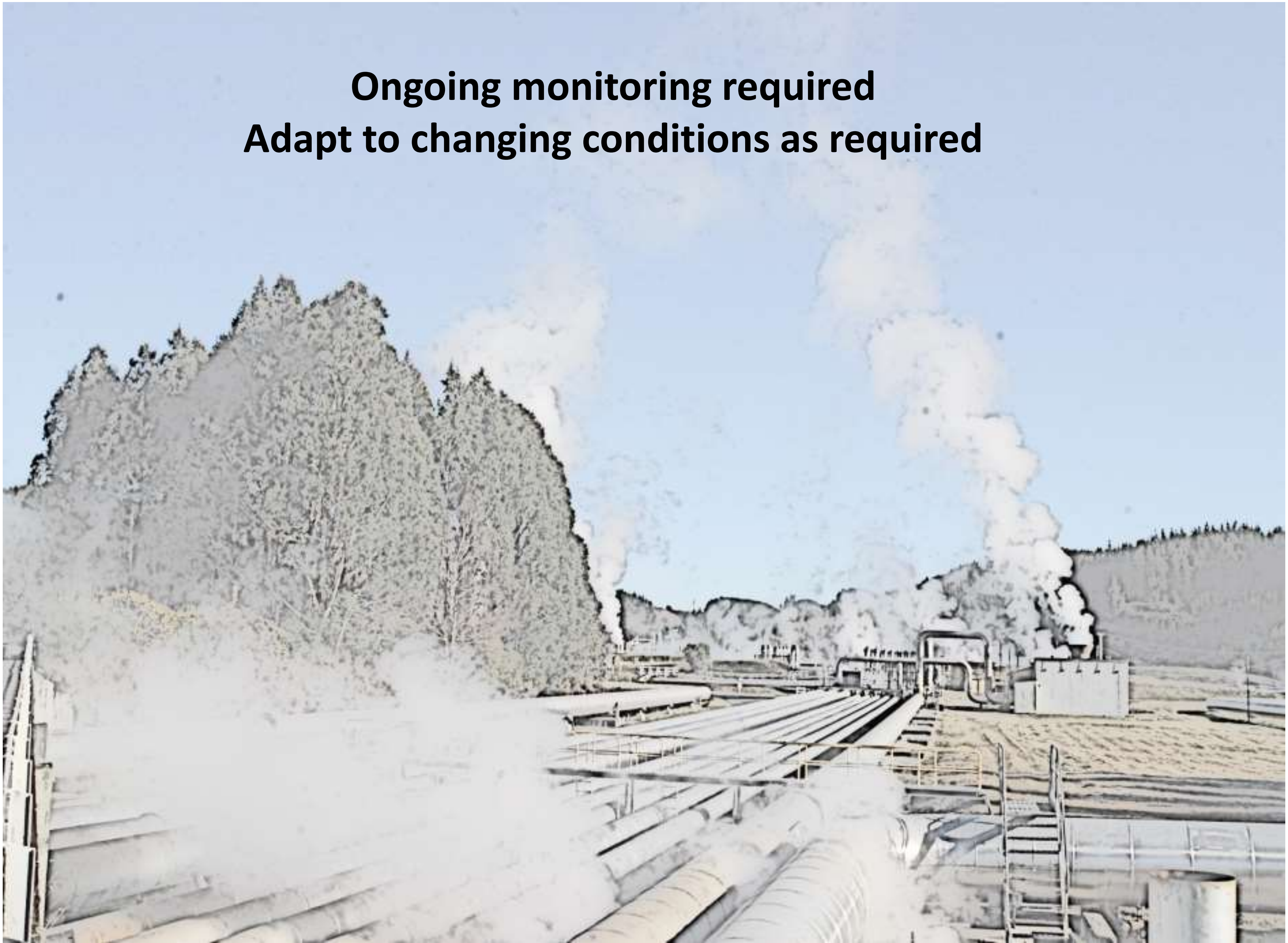
Is an issue for all geothermal development sites

Scaling issues can change over time as the reservoir conditions change

Awareness of the issues and good management necessary to get most out of your development

Ongoing monitoring required

Adapt to changing conditions as required



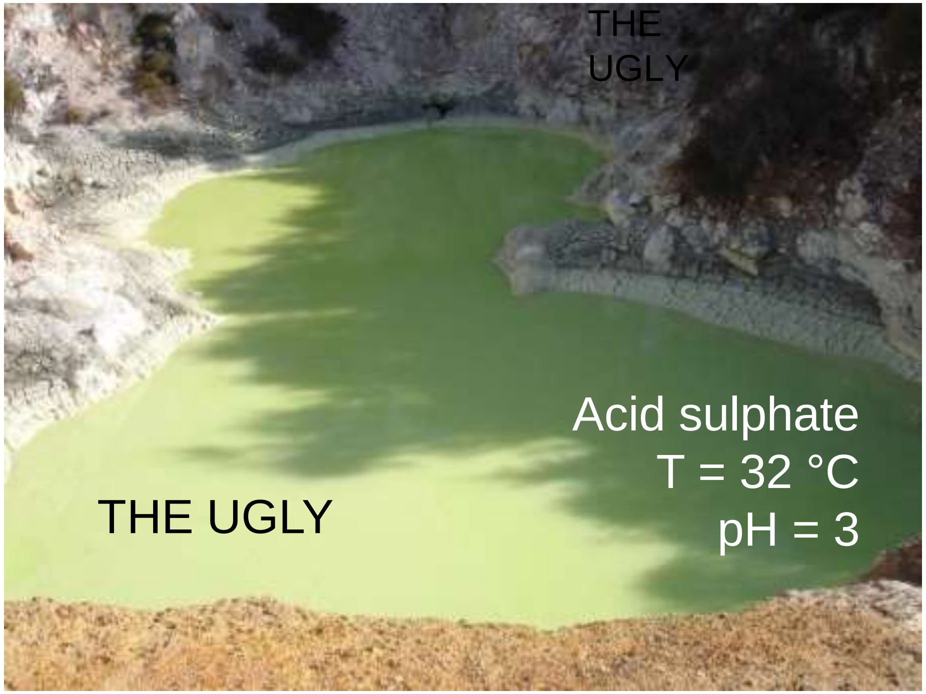
Don’t ignore scale

Plan for it

Manage it

Minimise it

THE UGLY



THE
UGLY

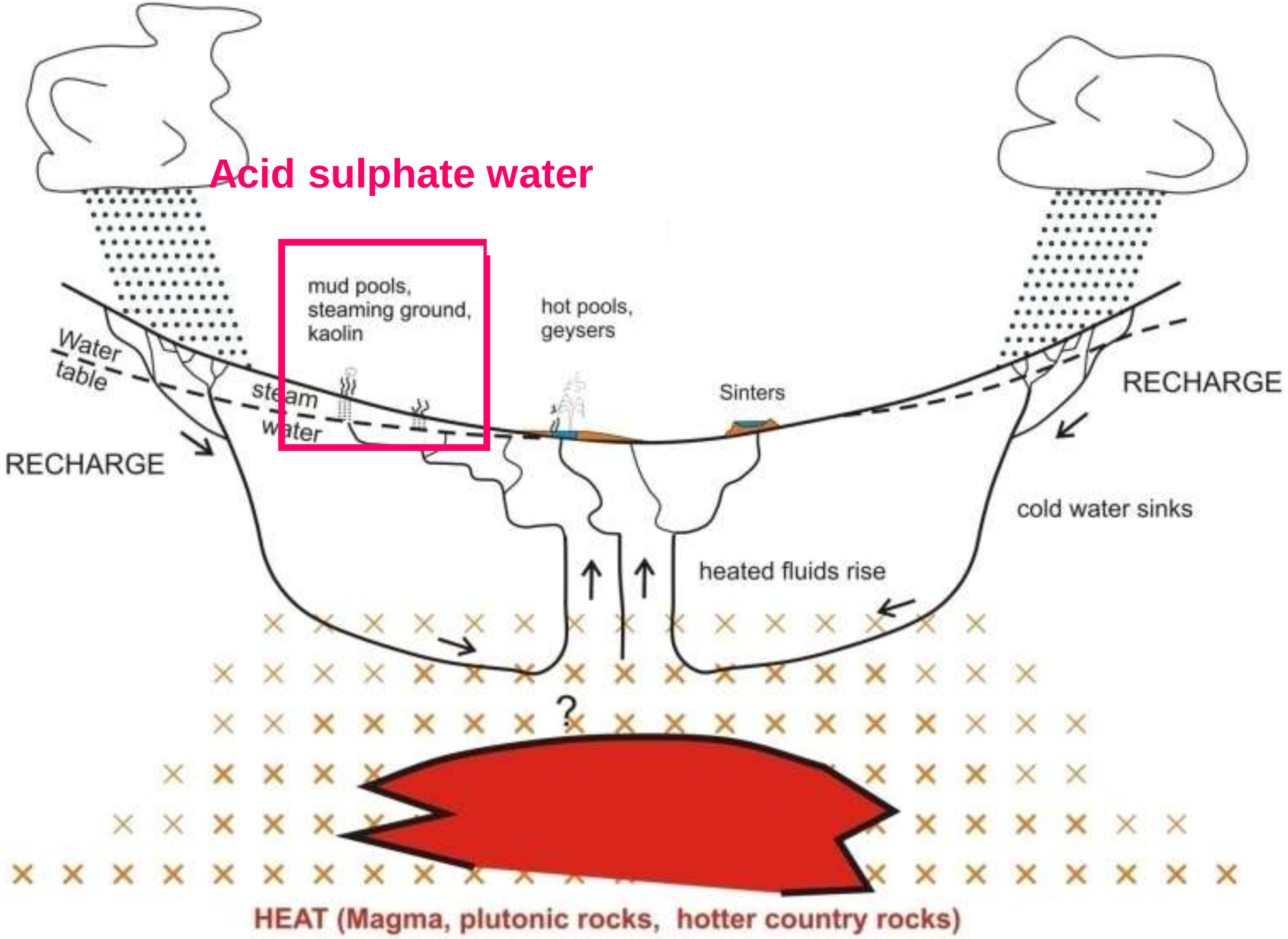
Acid sulphate
T = 32 °C
pH = 3

THE UGLY

Mixed water
T = 66 °C
pH = 4.5

THE UGLY

Acid sulphate water



Coloured

Murky

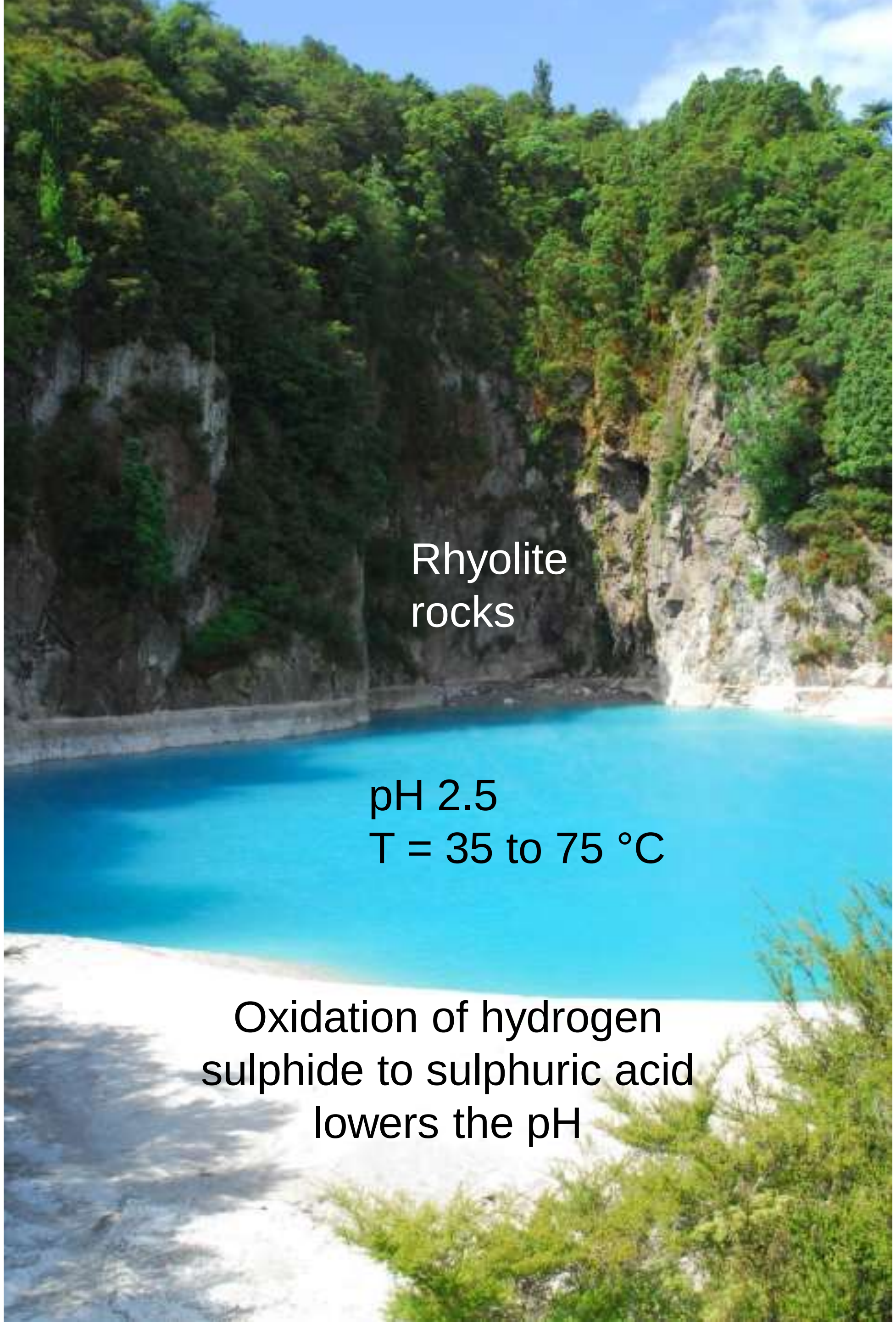
Pools

Steam heated

High SO_4

Low pH
Low Cl
Low SiO_2

Inferno Crater
Waimangu
NZ




Rainbow Mountain, Waiotapu

LANDSLIDES

Acidic steam condensate overprinting

-thermally stressed vegetation
-kaolinite clay


Te Kopia landslide

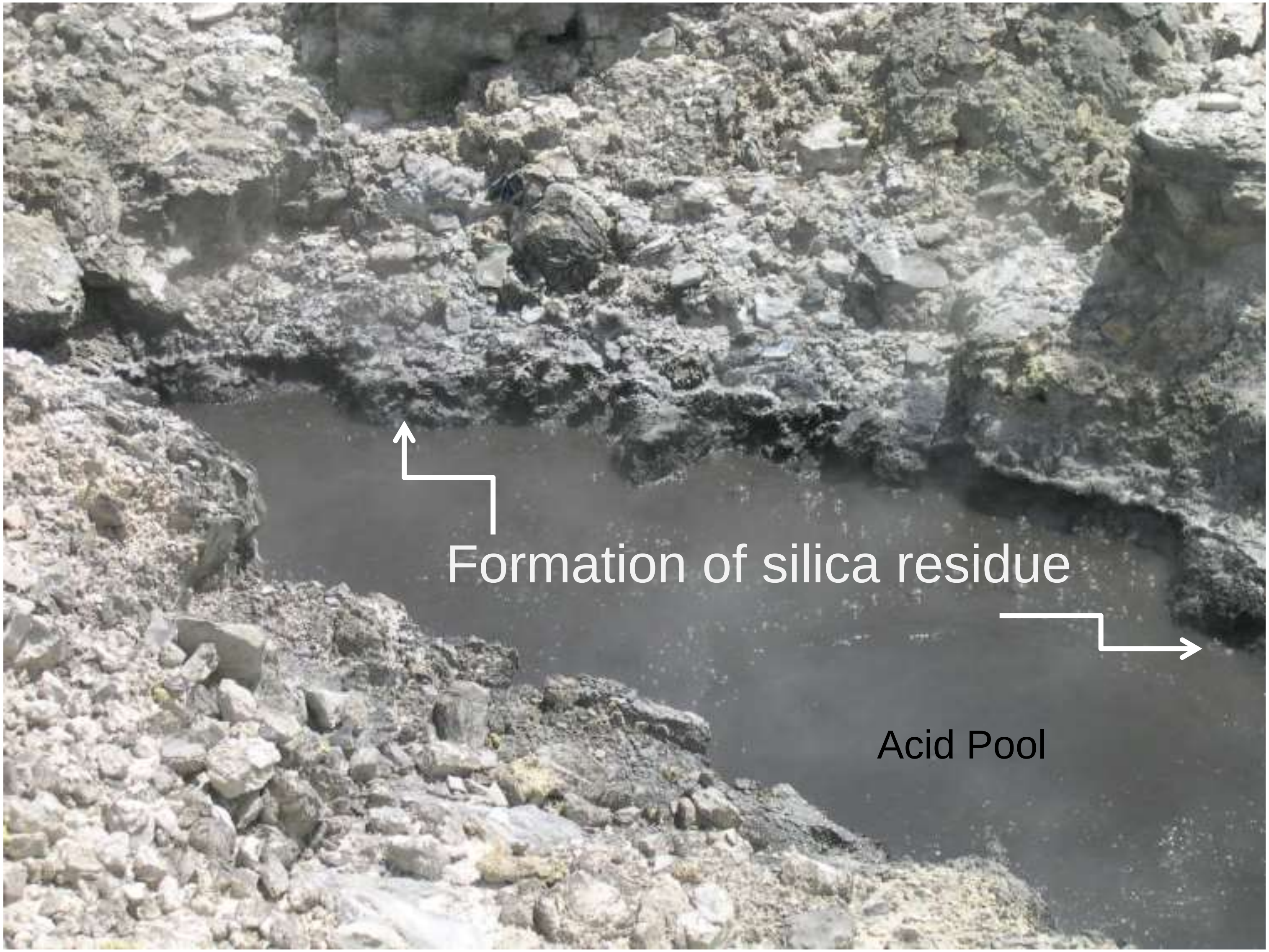
Full of sinter blocks
from old sinter terrace

Silica Residue

Typical environment

Ignimbrites etc + steam heated features

Dissolution of silica-rich rocks and reprecipitation of silica to form silica-residue

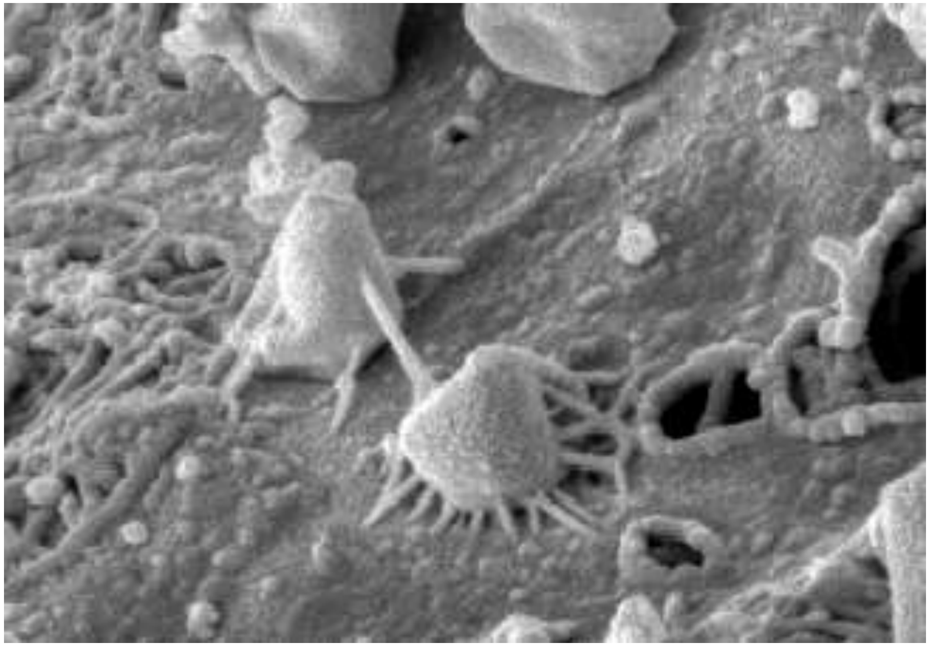

Formation of silica residue
Acid Pool

Silica Residue
Acid environment
Steaming ground
Mud vents
Hot, thin crust
Dangerous

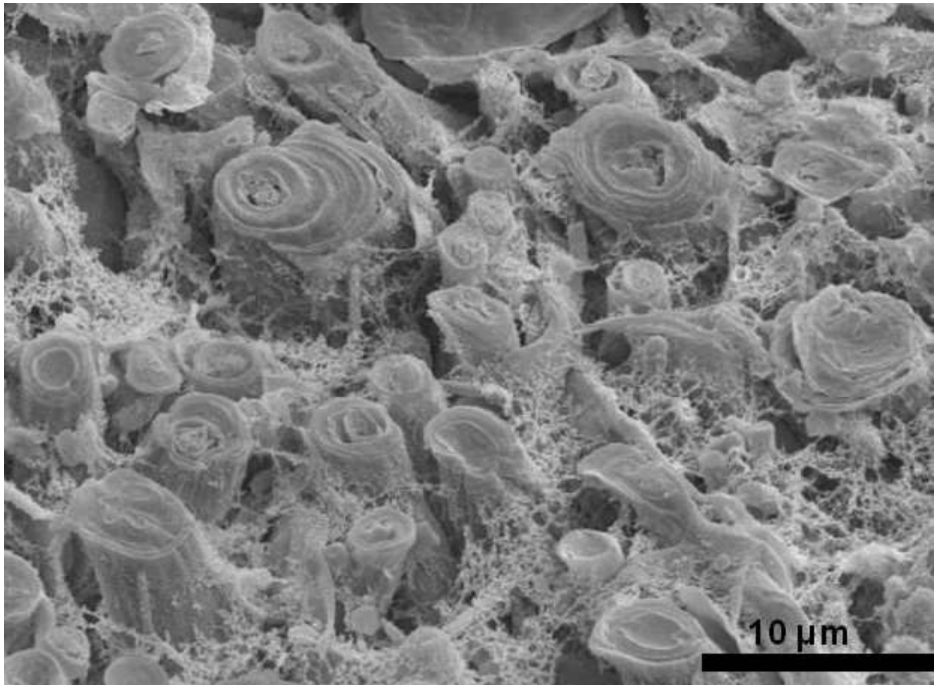
Silica Sinter

Silica Residue

Important to know your fluid type



Acidophiles
Silica residue
Acid conditions



Thermophiles
Siliceous sinter
Alkali chloride water

The Ugly and Drilling

Turbines essential part of the power plant

Inspection of turbine blade quality

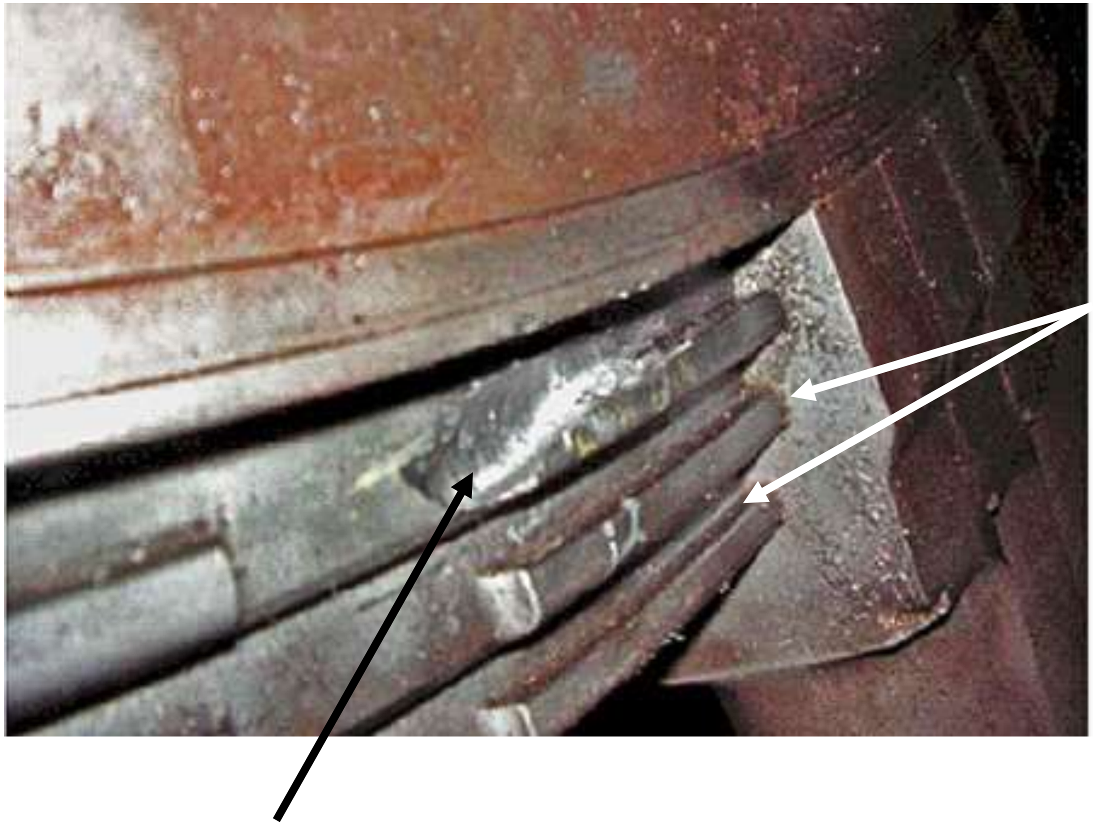
Steam to liquid transitions can occur when temperatures decrease

Leads to a thin film of liquid forming on the turbine blade

Result is turbine corrosion

Form pits which transition into stress corrosion cracking and ultimately result in failure of steel components

Localised corrosion of turbine blades



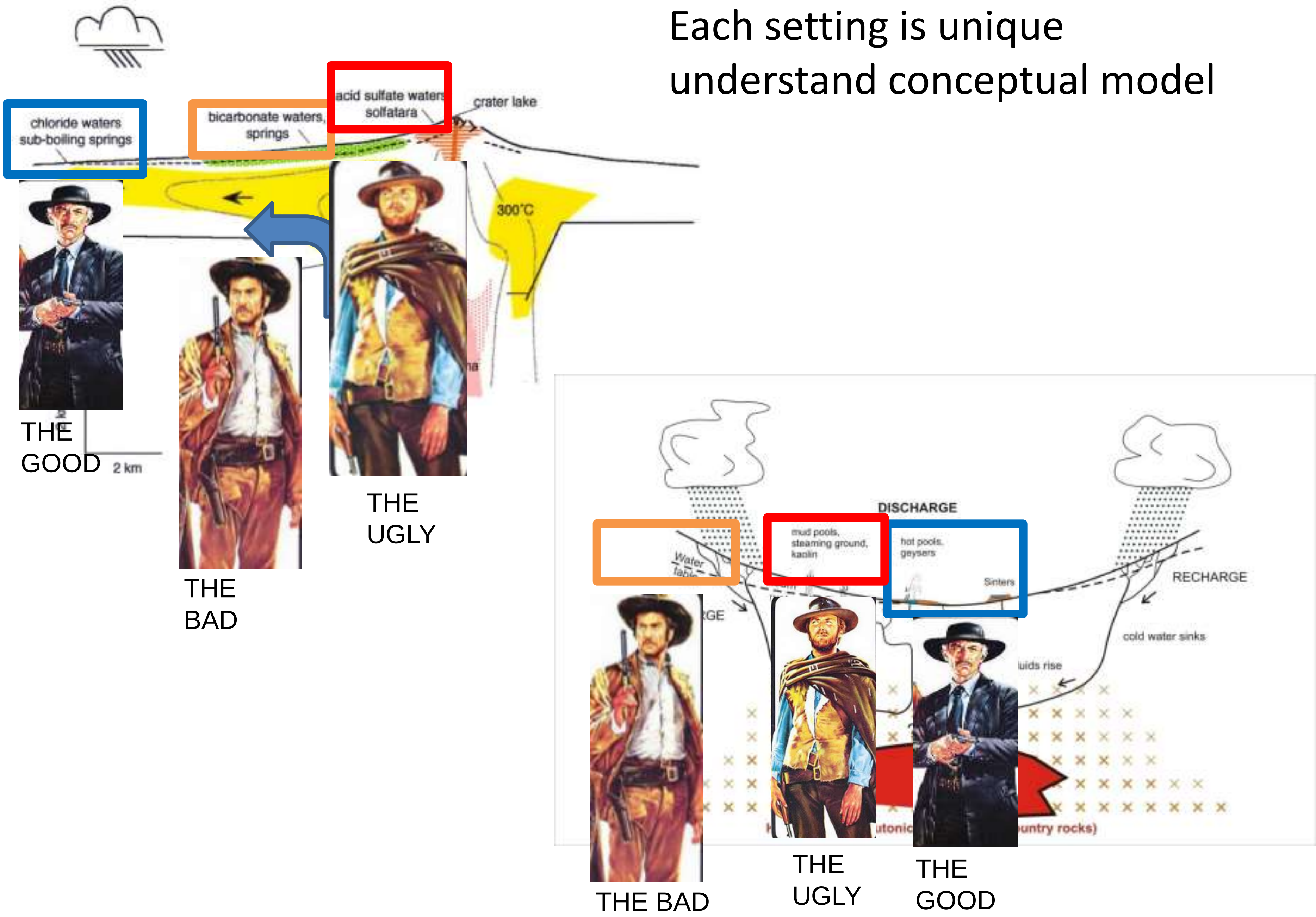
Corrosion

Corrosion ground out for repair

ROOF OF TURBINE HALL BLOWN OPEN: Feb 10 2011 – Duvha Power Station turbine destruction: pure incompetence, lack of quality-control: http://www.netnewspublisher.com/repairs-to-eskoms-duvha-power-station-to-take-time/

Holes in roof due to turbine blow out

Each setting is unique
understand conceptual model



Summary

- Know your geothermal system to know what fluids to expect
- Use a team of people to advise on fluid types, and how they will affect development
- Bad or Ugly fluids means careful management required (doesn’t necessarily prevent development)