Heat loss: Surface Manifestations

The more thermal input at the base of the convection cell, the more fluid upflow, the more heat discharged at the surface, and the more surface manifestations. Assessments accurate to only ± 25%.

Diffusive	warm ground steaming ground hot pools (evaporation) mud pools (evaporation)
Direct & Continuous	warm-hot springs (liquid discharge) fumaroles (audible steam discharge)
Intermittent	geysers
Catastrophic	hydrothermal eruptions
Concealed	seepage

Surface Manifestations & Heat Loss

Heat Transfer Units (Heat Flow)

Convective heat transfer: energy/time (kW or MW)

Conductive heat transfer: energy/time/area (mW/m^2, kW/km^2)

Continental heat flow is typically 40 to 80 mW/m^2

1-dimensional conductive heat flow = k (t_1-t_2)
k= thermal conductivity (2.5 ± 1.5 W/m°C)

Heat flow of 80 to 100 mW/m^2 is anomalous and hence heat flow mapping (temperature gradients) have some value in exploration

Diffusive Heat Discharge

Warm ground

Thermal energy is discharged by conduction, which is related to the thermal conductivity (k) of the upper most layer and its temperature gradient.

Soil temperature surveys are used to determine the occurrence and extent.

It is the dominant mode of heat transfer in low & intermediate temperature systems.

In high temperature systems, warm ground accounts for a very small portion of the total heat flow

Diffusive Heat Discharge

Steaming ground

Steam rises to shallow depth where it condenses due to cooling, tranferring thermal energy to shallow, but intensely altered (clay) rocks.

Temperature gradients above 100 °C/m occur in the upper 15 cm easily detected by shallow temperature surveys.

Conductive heating of moist air produces a thin diffuse layer of steam, but its appearance is dependent on atmospheric humidity (ie. only visible when the air is humid).

Detectable by thermal infrared measurements.

Vegetation stunted by shallow root development.

Ephemeral and sensitive to changes in shallow hydrology that might impede steam movement to the near surface environment such as mineral deposition & alteration.

Diffusive Heat Discharge-Safety Warning

All thermal areas can be dangerous but steaming ground is especially hazardous.

The ground can be soft and collapse under foot due to acid leaching.

Boots that extend up to near knee height and long trousers are essential.

Ensure you are accompanied by a colleague & never enter the same thermal area together.

Measurement of thermal ground should be undertaken by experienced personnel.

Diffuse & Continuous Heat Discharge

Hot pools & discharging springs

calm pools (sub-boiling)
boiling pools (vapor saturated)
effervescing pools exist (CO_2 bubbling)—sub-boiling

Reflects discharge of chloride waters, steam-heated waters or just steam.

Discharging chloride waters deposit silica sinter & are near neutral pH. Steam-heated waters are acidic reaching pH ~ 2, associated with mud pools.

Heat transfer is by evaporation (diffuse) & liquid overflow (continuous).

Heat loss/transfer is proportional to area, surface temperature, & other processes that enhance heat transfer (ie. wind velocity).

Heat transfer < 20 MWt

Diffuse Heat Discharge

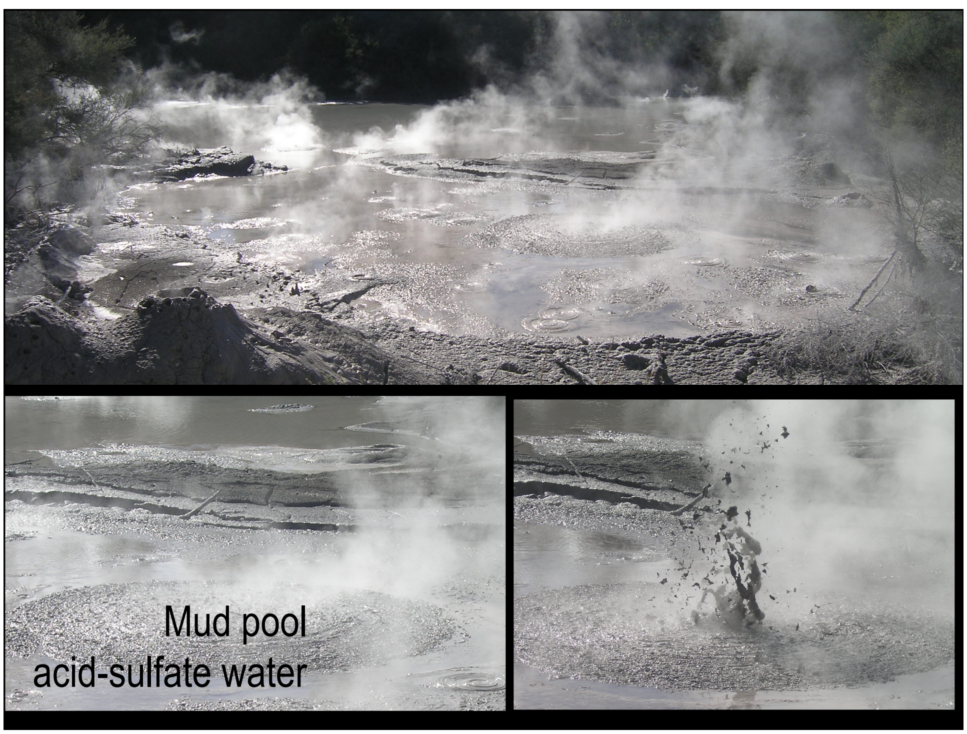
Mud pools

Transfer heat by minor steam discharge through numerous small vents.

Mud forms by steam-heated acid-sulfate water interacting with rock, & it is held in suspension to form a thick slurry.

Mud is made of kaolinite, alunite, amorphous silica, & pyrite.

Mud pools are usually associated with steaming ground & collapse craters that involve acid dissolution of country rock. So be careful in working around mud pools.



Continuous Heat Discharge

Fumaroles, Steam Vents, and Gas Discharge

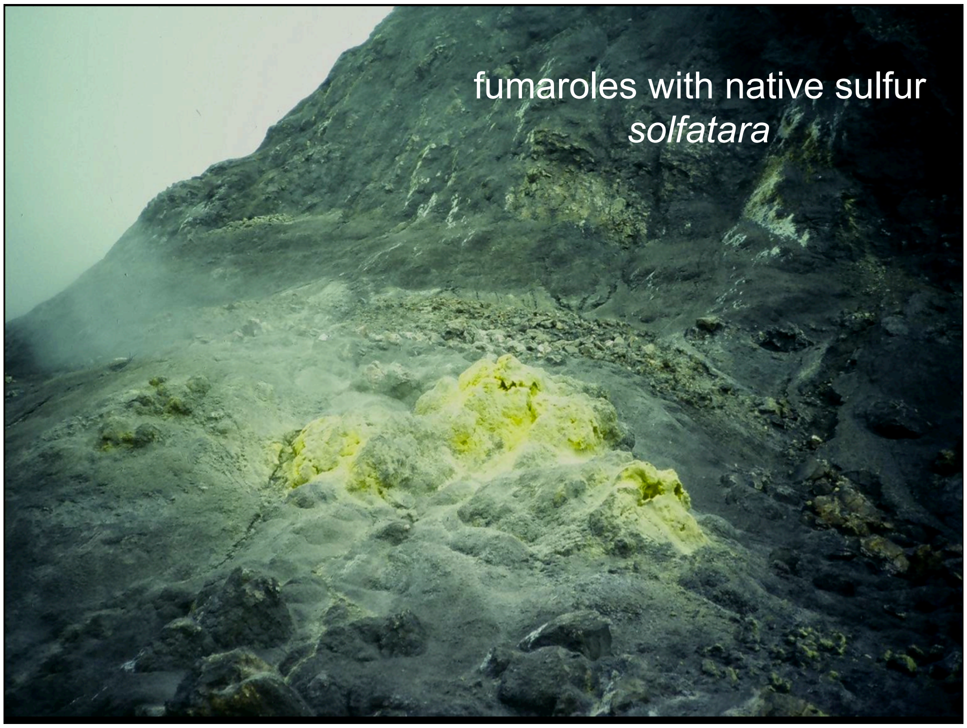
Wet steam (steam at saturation containing droplets of condensed water) is discharged by fumaroles over all sub-types of high temperature systems. Dry steam (steam hotter than saturation temperature) can also discharge but these occurrences are less common (e.g. Darajat 145°C).

Fumaroles are audible at discharge velocity >20 m/s; steam vents are quiet at discharge <20 m/s.

Heat transfer is typically low (~5 MW max).

Steam vents with sulfur deposts are called *solfatara* and those with boric acid are called *soffioni*.

Cool CO_2 gas discharge vents are called *moffete* but in the Philippines they are called *kaipohan* which typically have sulfur deposits.


fumaroles with native sulfur
solfatara


fumaroles ~800°C

Intermittent Heat Discharge

Geysers (& Spouters)

Spectacular features that intermittently discharge a fountain of steam & boiling water are called geysers; spouters are tend to discharge continuously. Geysers & spouters are the only features with two-phase fluid discharge.

They occur over high temperature systems in flat terrain, usually over the upflow zone, and rarely over outflow tongues.

The heat output of the largest geysers is 5 MW max.

Geysering is the product of episodic boiling in a pipe-like vertical fracture network. They almost always discharge silica saturated chloride water so that sinter deposits are common, as are small cones that build up around the vents.

El Tatio, Northern Chile

Hydrothermal Eruptions and Geysers

Rotorua (population 67,000) located on top of a high temperature geothermal field

Intermittent Heat Discharge

Hydrothermal Eruptions

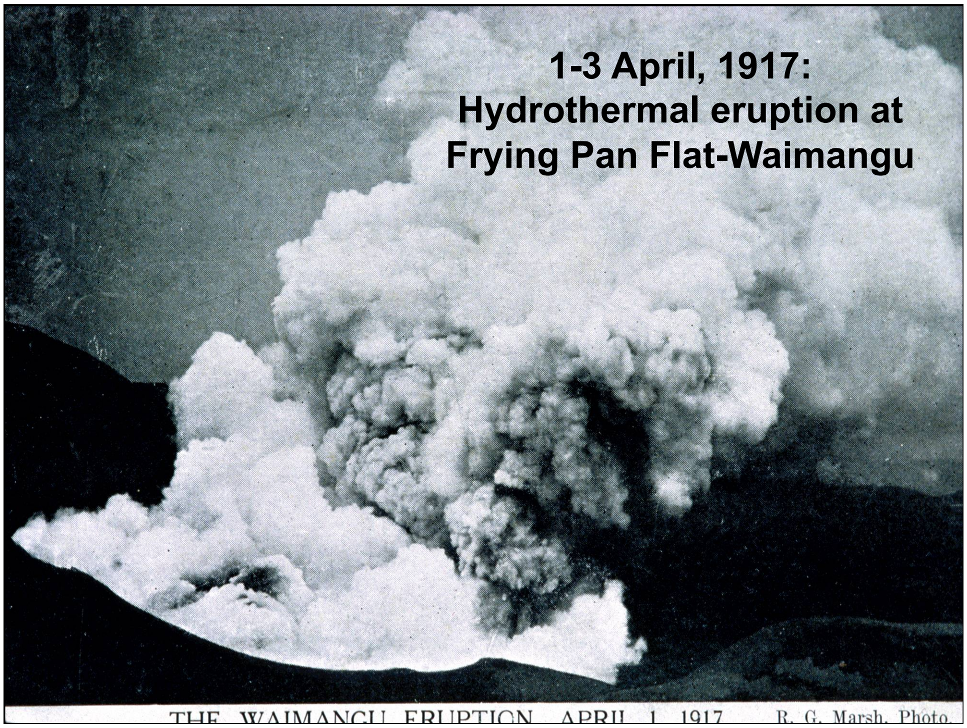
These occur infrequently in areas associated with boiling chloride springs, geysers and also steaming ground.

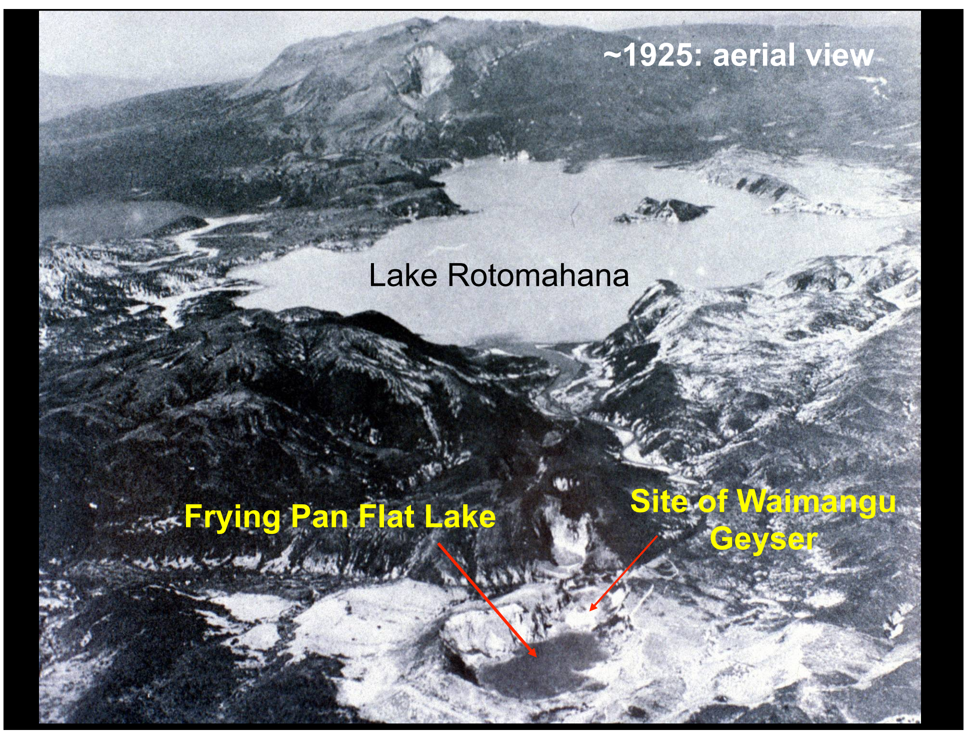
Eruptions are triggered by instability in the hydrostatic P-T gradient close to boiling. Pressure drops and pressure increases can both lead to eruptions, although the precise triggering mechanisms are poorly understood.

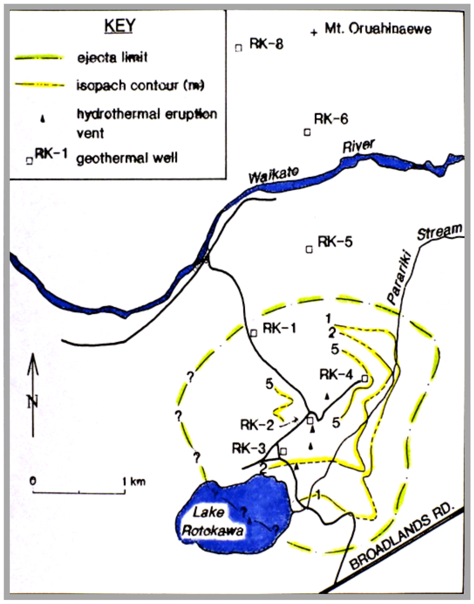
Excavation of a crater due to explosive discharge of steam and hot water is typical. Rock fragments can be derived from depths >200 m and lifted to the surface where it deposits as a matrix supported breccia surrounding the vent.

Study of eruption deposits provides useful clues of subsurface conditions.

Hydrothermal eruption vents are commonly filled with cold water.


1-3 April, 1917:
Hydrothermal eruption at
Frying Pan Flat-Waimangu
THE WAIMANGU ERUPTION APRIL 1 1917
R. G. Marsh, Photo.


~1925: aerial view
Lake Rotomahana
Frying Pan Flat Lake
Site of Waimangu
Geyser



<u>Geysers</u>

Regular periodic discharge of hot boiling water (typically chloride water) jetting upward 10s-100s of meters. Geysering can be sustained for 10s to 100s of years-tourist attraction

<u>Hydrothermal eruptions</u>

Catastrophic discharge of hot boiling water, typically without warning, jetting 10s to 100s of meters in height-geological hazard

Both sensitive to changes in water pressure.

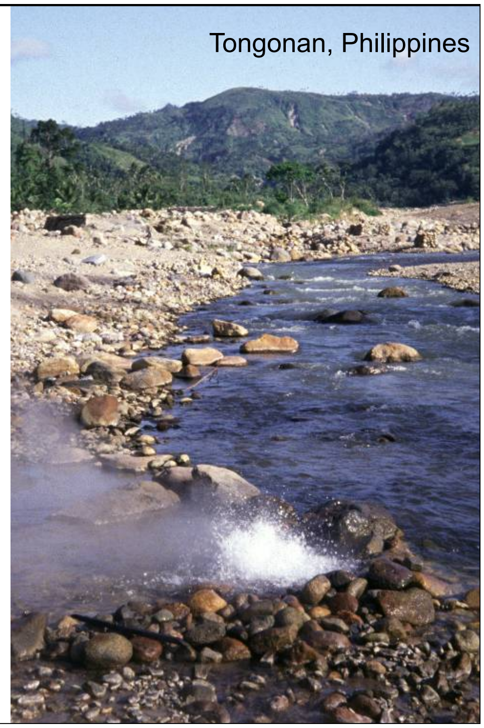
Concealed Heat Discharge

Seepage

Seeps include subsurface-surface discharge in water ways and lakes.

They are best recognized by chemical anomalies in water ways.

Elevated concentrations of chloride, boron and other dissovled constituents are typically indicative of seeps.



Gas seeps-sub-aqueous vents (Kaipohan)

Cold discharge, mainly CO_2 and minor H_2S

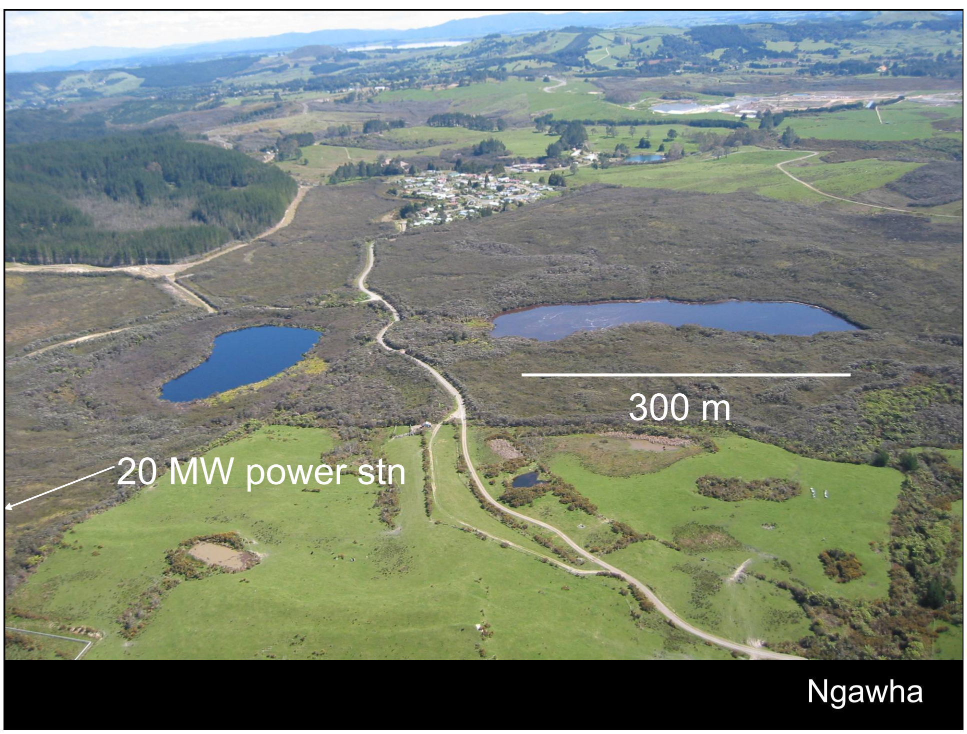
CO_2 is toxic to root systems of plants-kills vegetation

They occur over high temperature systems in steep terrain (e.g., Philippines); they also occur in flat terrain in unique circumstances (e.g. Ngawha geothermal field, New Zealand).

No heat output

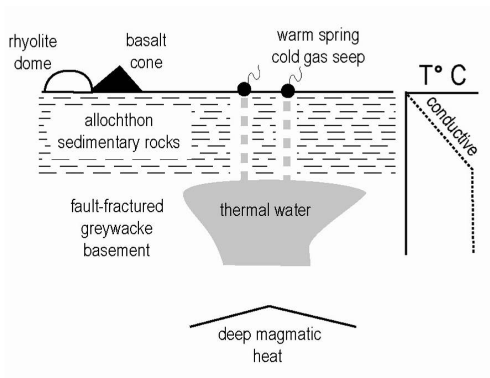
Subtle "geothermal" features


Cold lake with bubbling CO_2 gas.
Ngawha


300 m
20 MW power stn
Ngawha


Tiger bath 40°C.
Ngawha


Kaipohan: no vegetation; cold ground; sulfur deposits
Ngawha



Ngawha Reservoir

500-1500 m depth ~220°C

fractured Mesozoic greywacke

sub-boiling temperature gradient <500 m depth

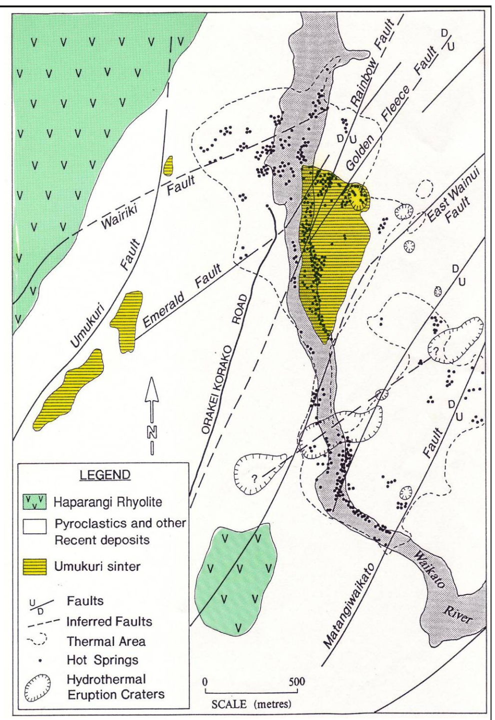
overlying Cretaceous-Tertiary sedimentary rocks-impermeable

bouyant water column feeding springs associated with CO_2 exsolution

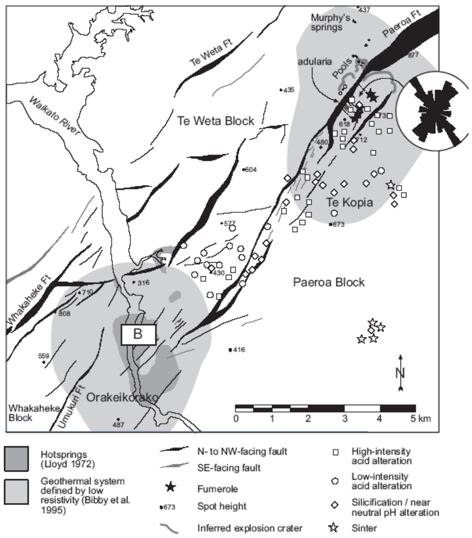
Orakeikorako

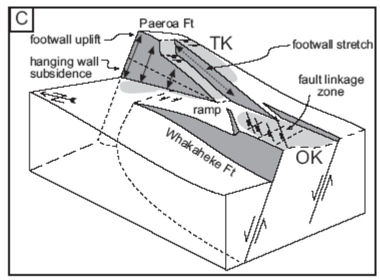
Many hot springs discharged along the Waikato River

Springs occur mainly where topography intersects the water table; just like streams, rivers and lakes

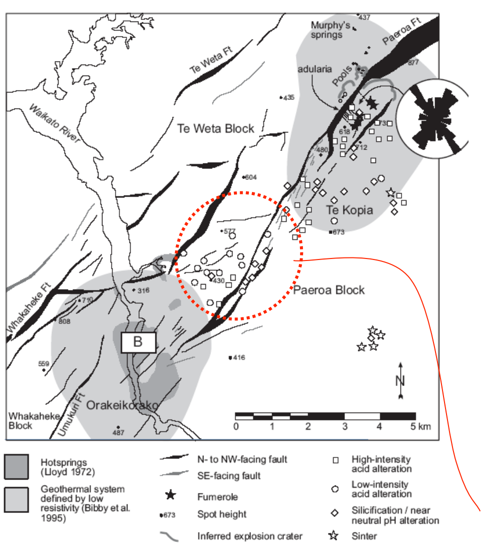


Surface Features

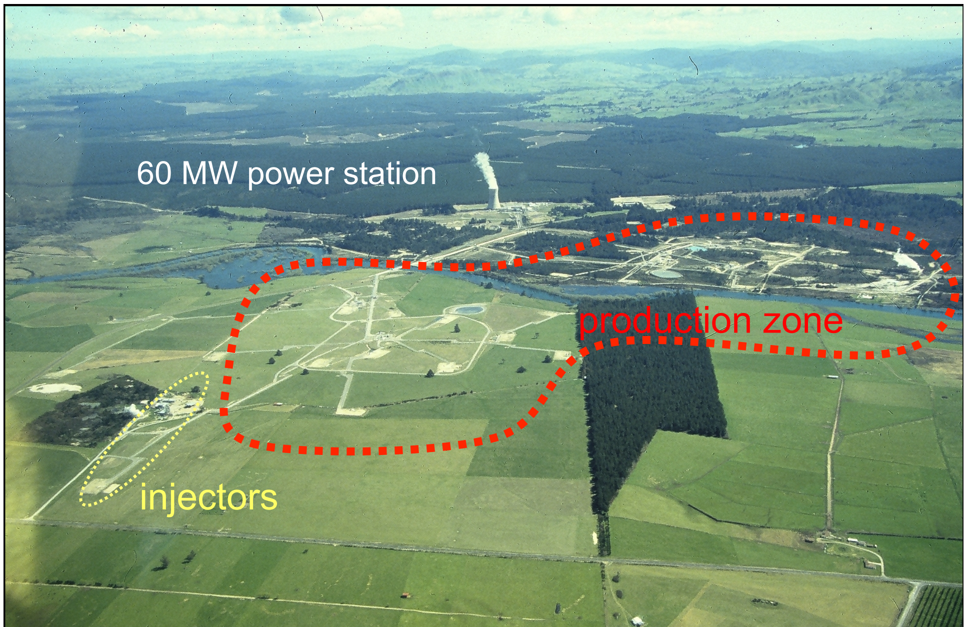




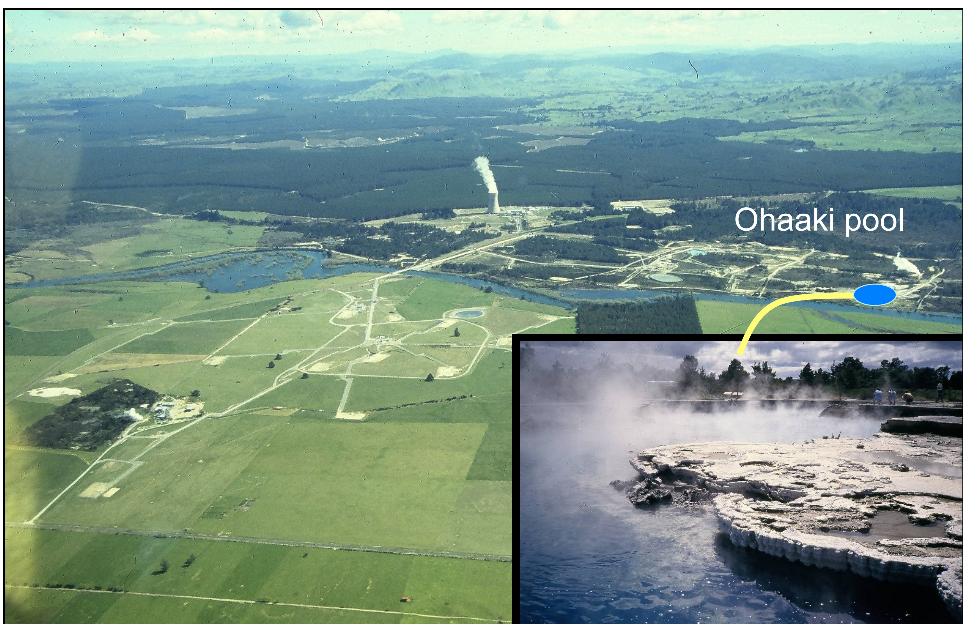
Surface Features



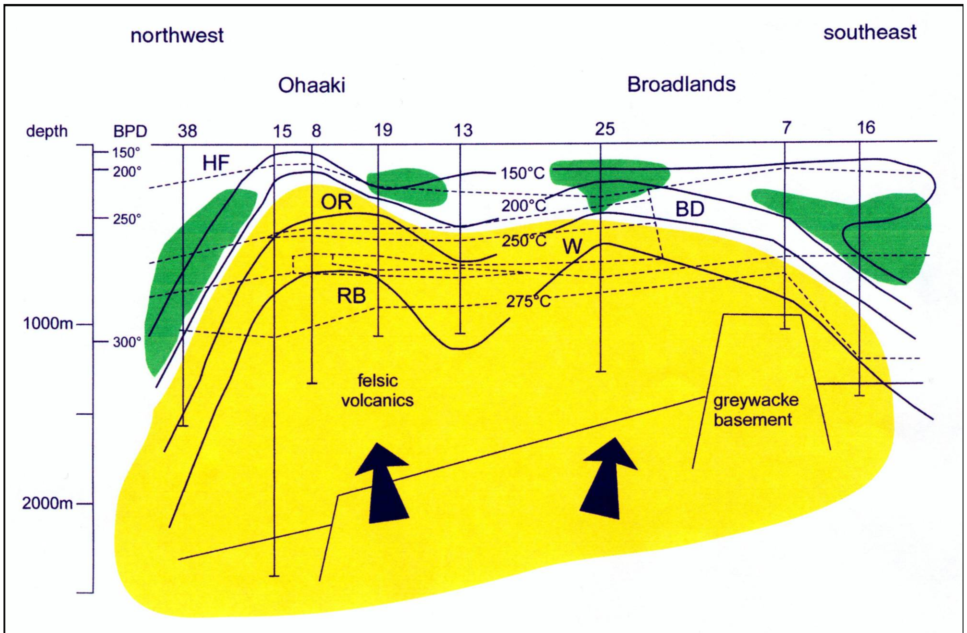
extinct features provide clues about past activity & evolution of the fluid flow paths



Case study:Broadlands-Ohaaki

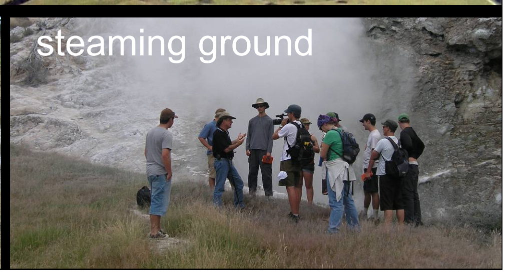


Case study:Broadlands-Ohaaki

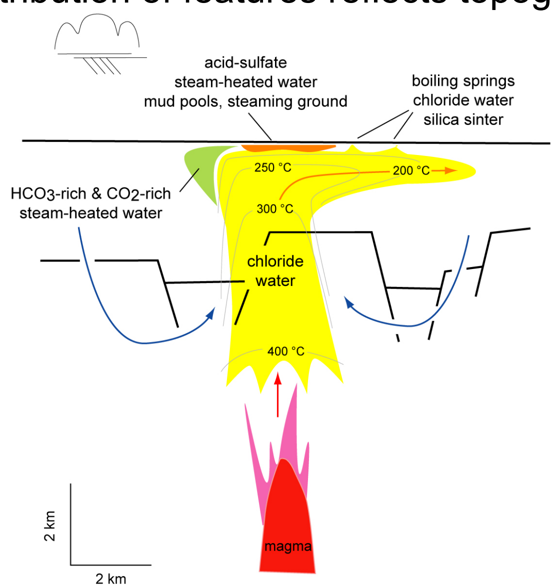


stratigraphy, temperature, fluid compositions

Mokai: “blind” resource with big production potential



Flat terrain-high temperature system distribution of features reflects topography



Steep terrain-high temperature system distribution of features reflects topography