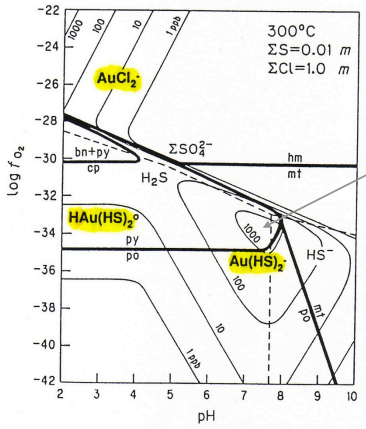
Gold

- Solubility controlled by H_2S, pH and redox
- Deposits in hot springs, wells and altered rocks via boiling & adsorption on colloids
- Concentration in solids 10^6 greater than concentration in solution
- Aqueous concentration varies 100x
- Solutions undersaturated
- Huge hydrothermal metal flux
- Magmatic origin

phase diagram: Hayashi & Ohmoto, 1991

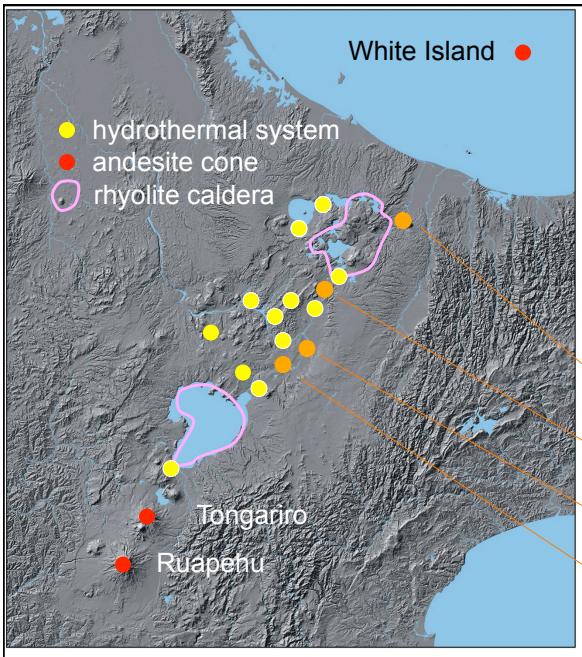


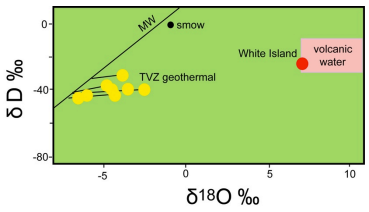
Maximum gold solubility

$Au + 2H_2S\ (aq) = Au(HS)_2^- + H^+ + 0.5\ H_2\ (gas)$

$Au + 2H_2S\ (aq) = HAu(HS)_2^\circ + H_2\ (gas)$

$Au + H^+ + 2Cl^- = AuCl_2^- + 0.5\ H_2\ (gas)$





Precious metal deposits

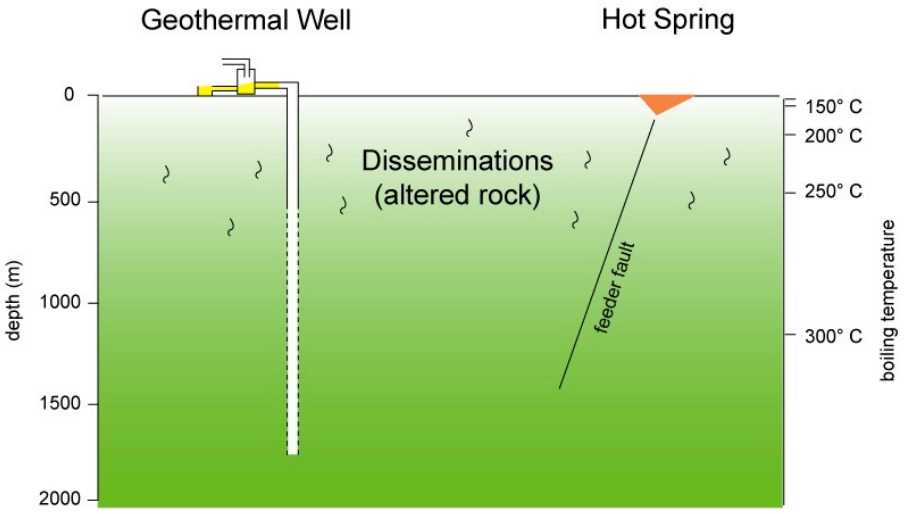
Kawerau

Waiotapu

Broadlands-Ohaaki

Rotokawa

Environments of Precious Metal Deposition



Simmons & Browne, 2000

Champagne Pool, Waiotapu

Hot Spring Environment

Chloride water: 74°C
pH ~5
2000 ppm Cl
3 ppm H_2S

0.10 ppb Au
0.02 ppb Ag

Au & Ag deposit on As-Sb-S rich colloids via adsorption

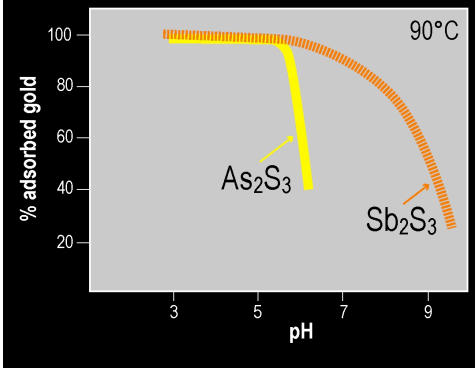
540 ppm Au
750 ppm Ag

Pope et al, 2005

Hot Spring Environment

High CO_2 concentration acidifies pH & stabilizes precipitation of As-Sb-S colloids.

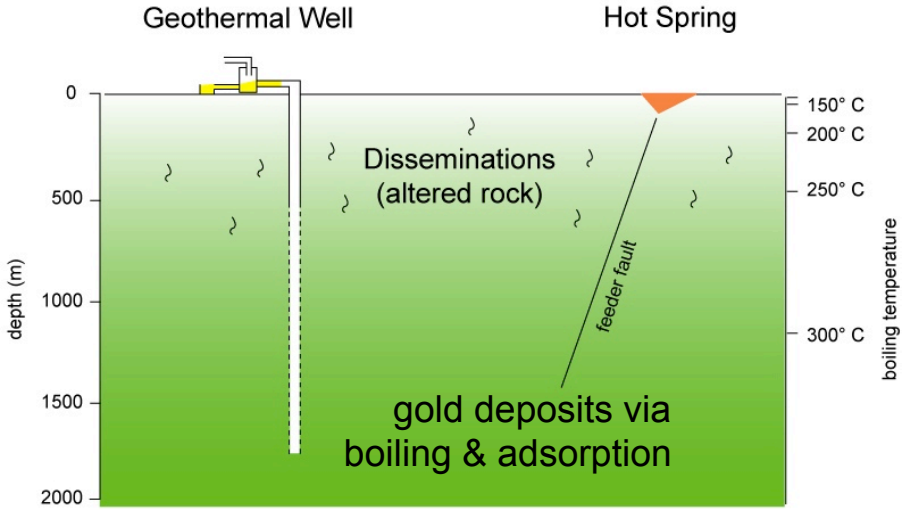
Hedenquist & Henley, 1985
Pope et al, 2005



Gold adsorption efficiency pH sensitive & favored at acid conditions

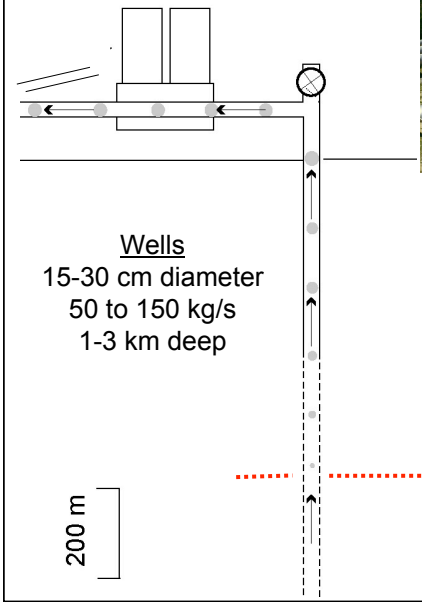
Renders & Seward, 1989

Environments of Precious Metal Deposition



Simmons & Browne, 2000, Economic Geology

2 phase (boiling) well



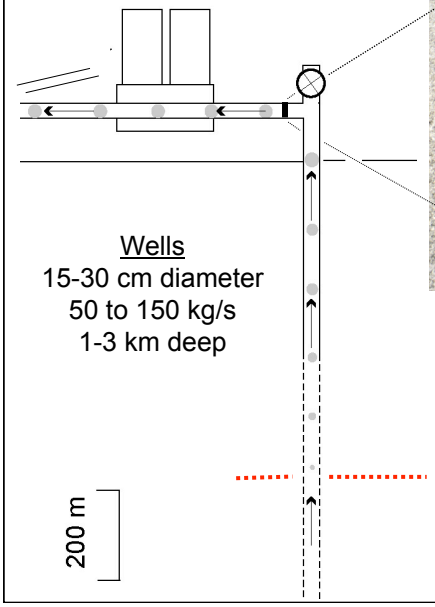
Wells
15-30 cm diameter
50 to 150 kg/s
1-3 km deep

two-phase boiling conditions confined to well

~25% of deep liquid evaporates to steam on ascent to the surface

level of boiling

2 phase (boiling) well



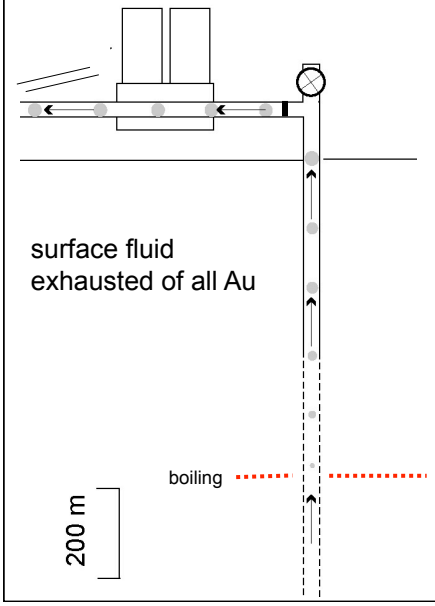
Wells
15-30 cm diameter
50 to 150 kg/s
1-3 km deep

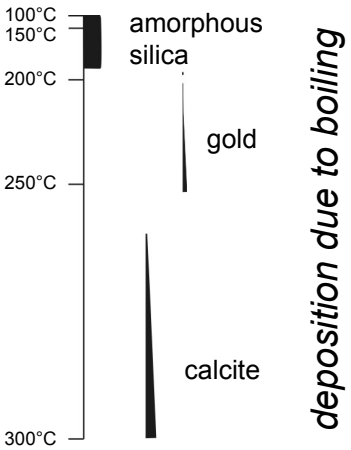
chalcopyrite scale	*solution*
60,000 ppm Au	1 ppb Au
>100,000 ppm Ag	8 ppb Ag

Brown, 1986

2 phase (boiling) well

$Au + H_2S + HS^- = Au(HS)_2^- + 0.5\ H_2$

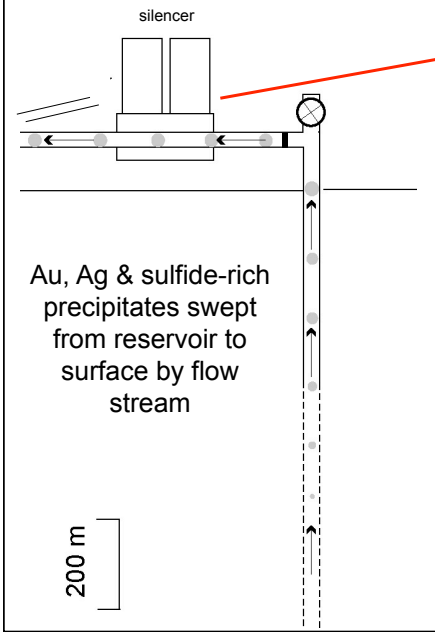




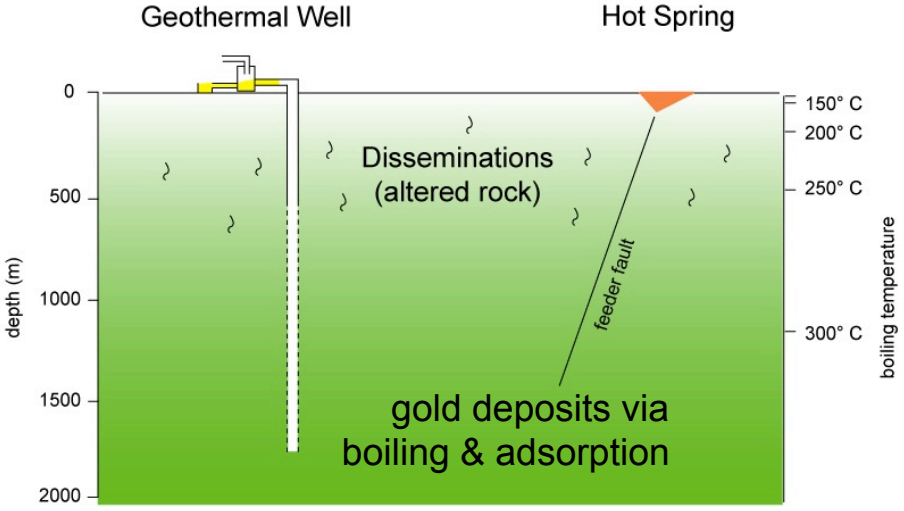
deep solutions 1-10% of Au saturation

Brown, 1986; Simmons & Browne, 2000

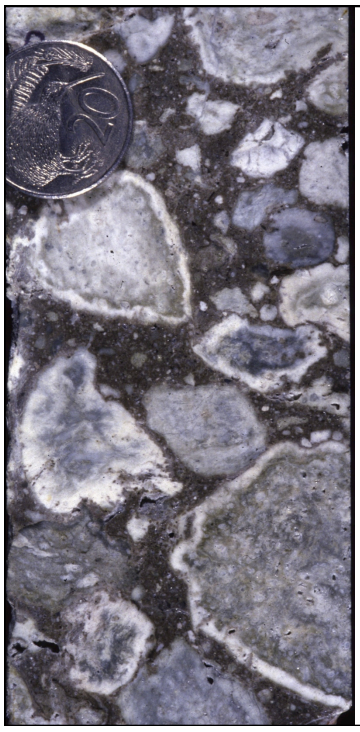
2 phase (boiling) well



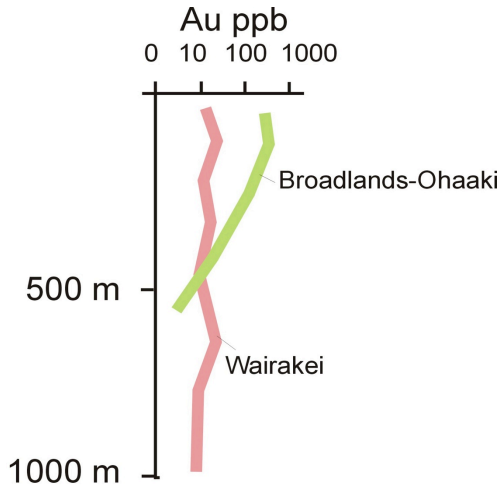
Environments of Precious Metal Deposition

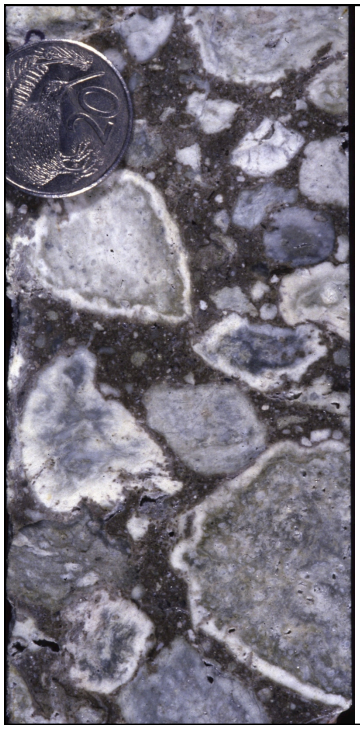


Simmons & Browne, 2000

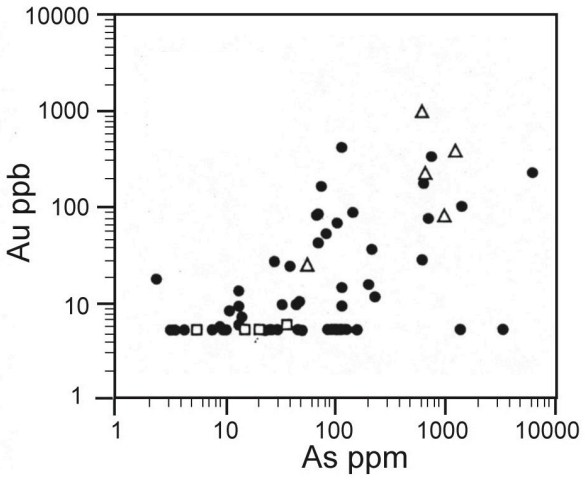


altered volcanic rocks





altered volcanic rocks



Simmons & Browne, 2000

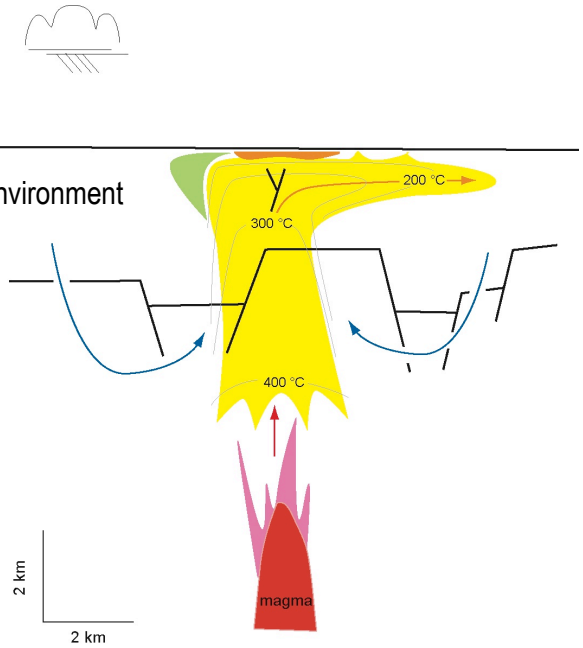
White Island-andesitic volcano
aerosols from 850°C discharge (1988)

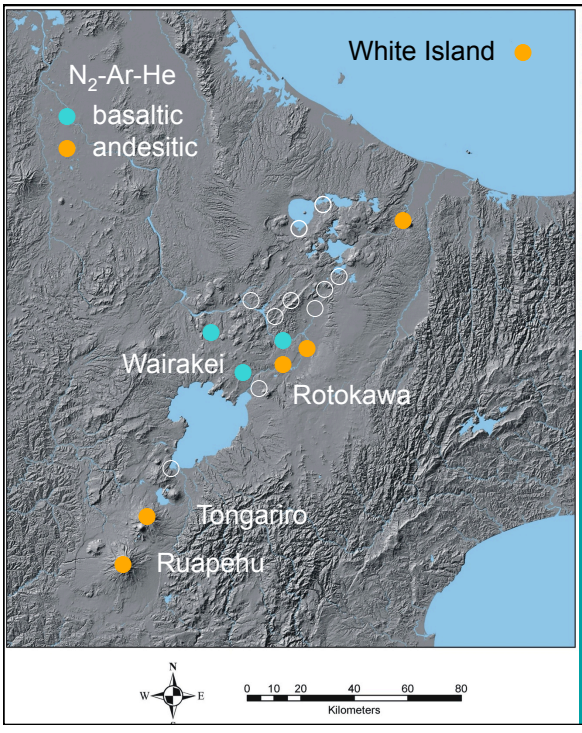
100 tonnes Cu/yr
.037 tonnes Au/yr

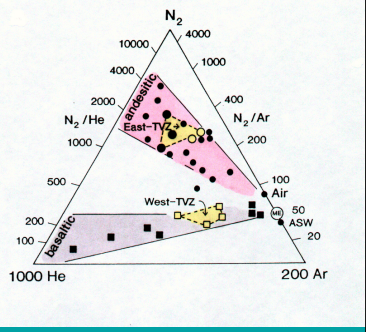
<1000 yrs to flux 1 million oz Au at White Island
>6000 yrs to flux 1 million oz Au at Broadlands-Ohaaki

(Hedenquist et al., 1993)

Ore forming environment





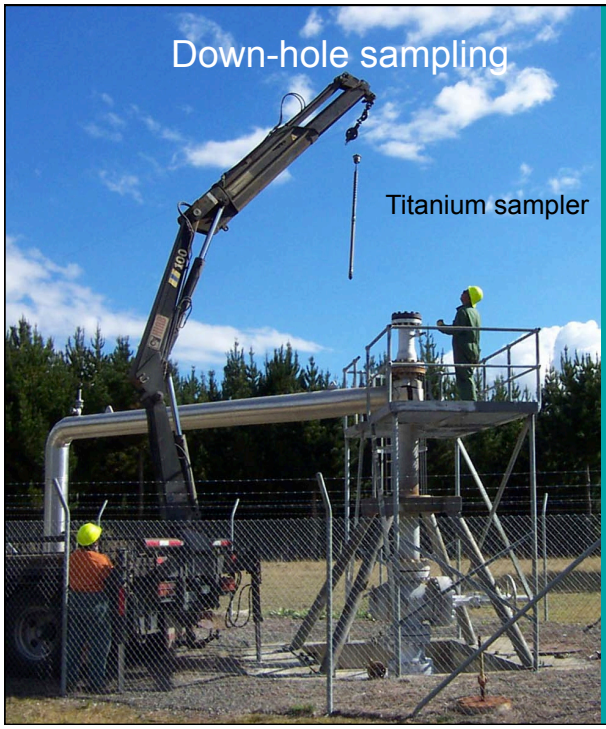


Hydrothermal gas compositions indicate:

east systems—andesitic intrusions

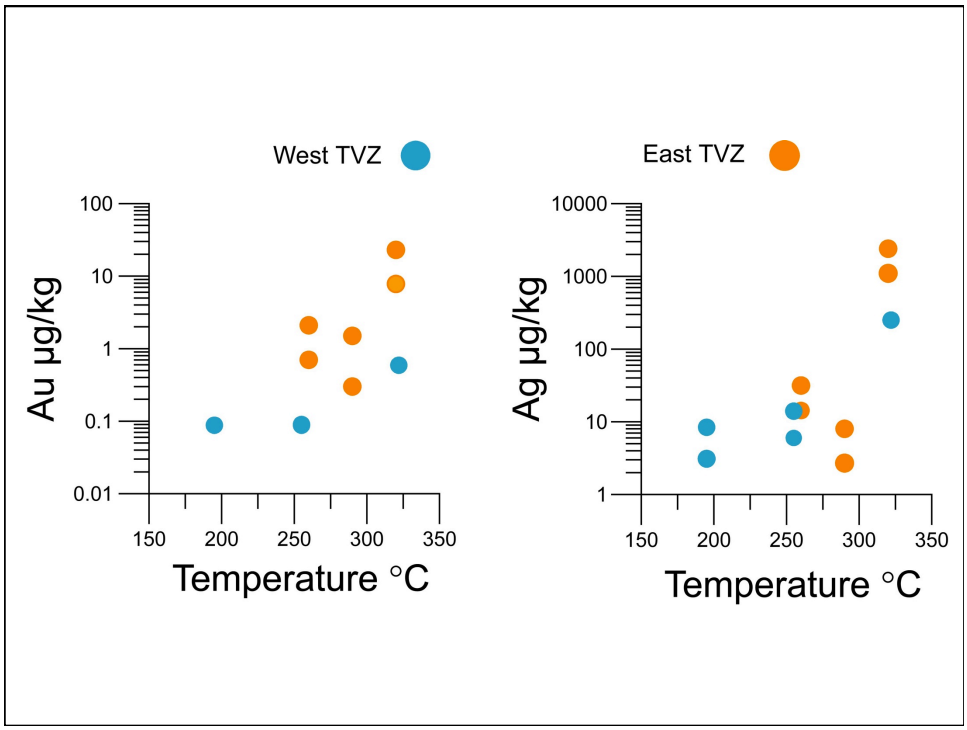
west systems—basaltic intrusions

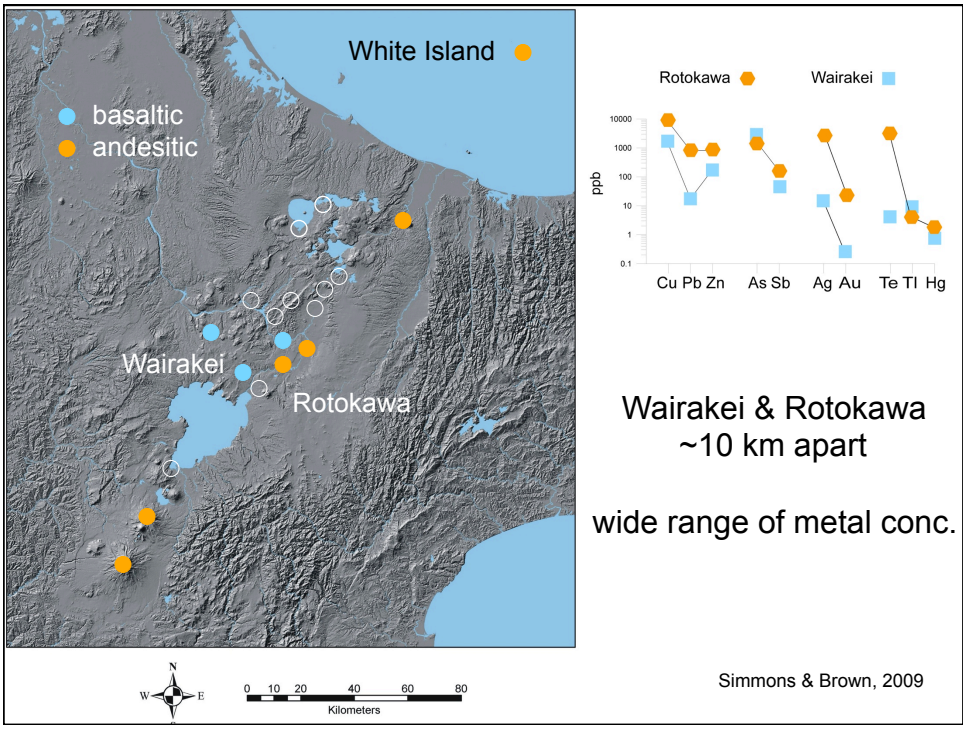
(Giggenbach, 1992)



Gold Transport

- measure deep metal concentrations
- sample = 500-700 mls
- analysis by ICP-MS CSIRO, Australia
- limited runs ($$$), 5 years to complete
- 8 geothermal systems sampled

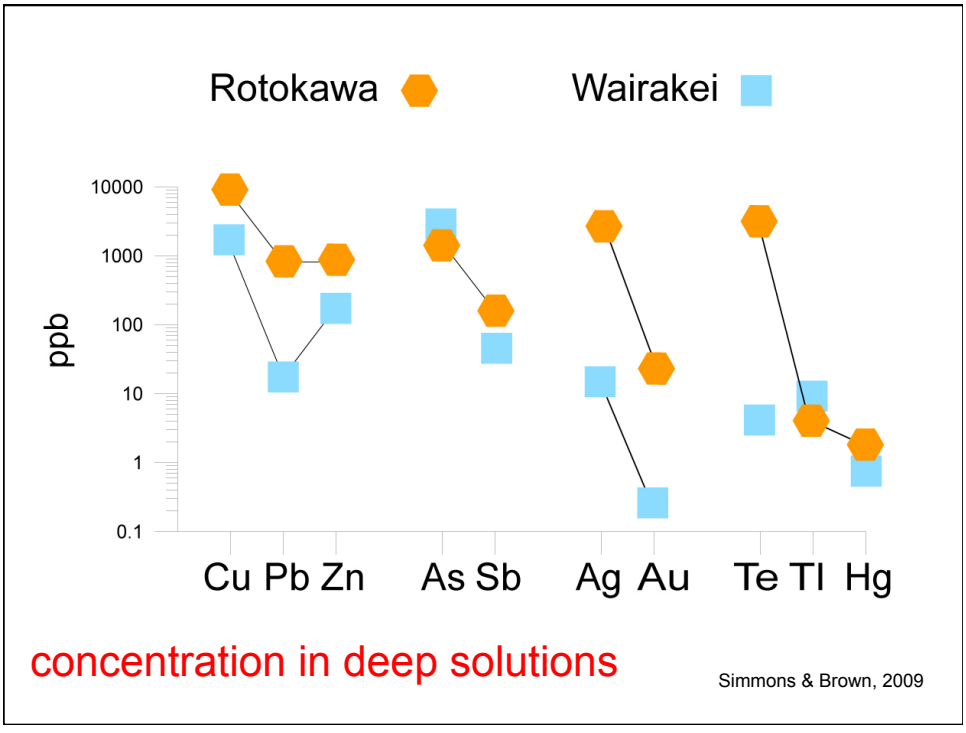




Wairakei & Rotokawa
~10 km apart

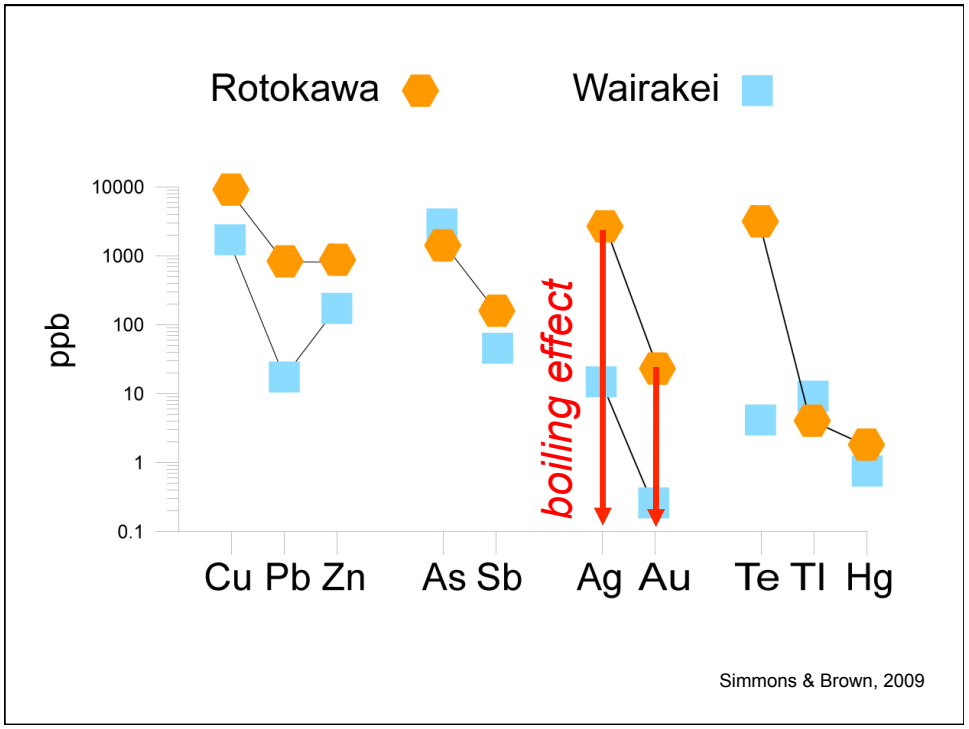
wide range of metal conc.

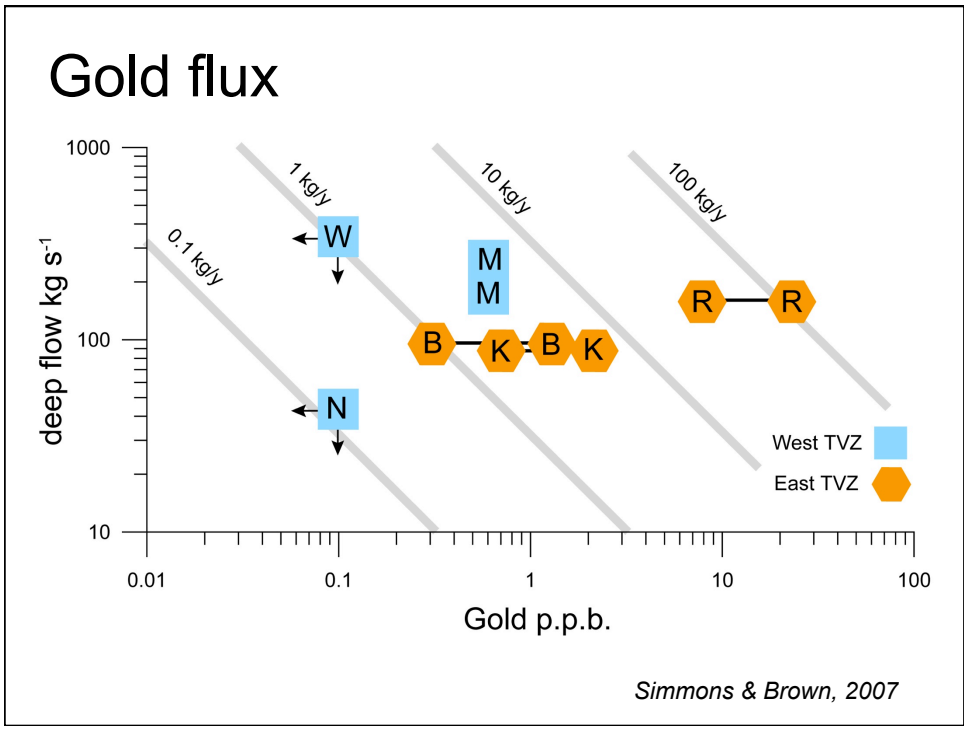
Simmons & Brown, 2009



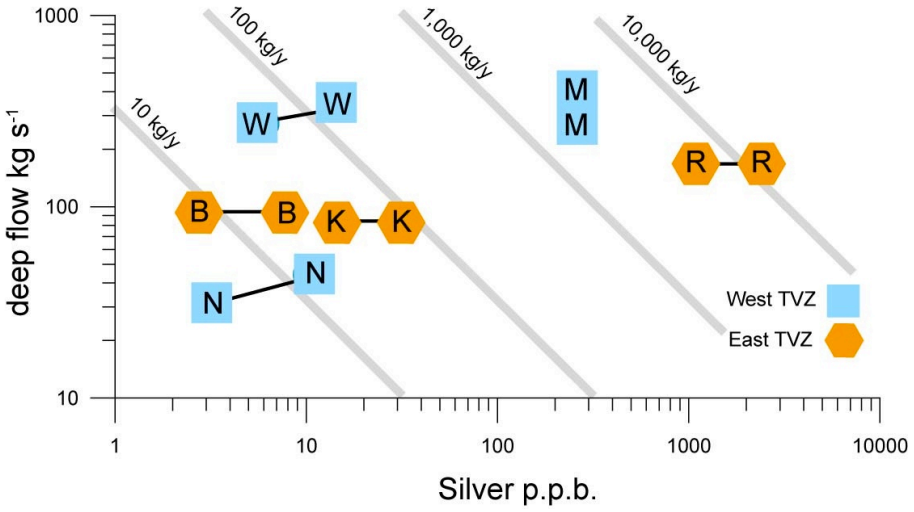
concentration in deep solutions

Simmons & Brown, 2009

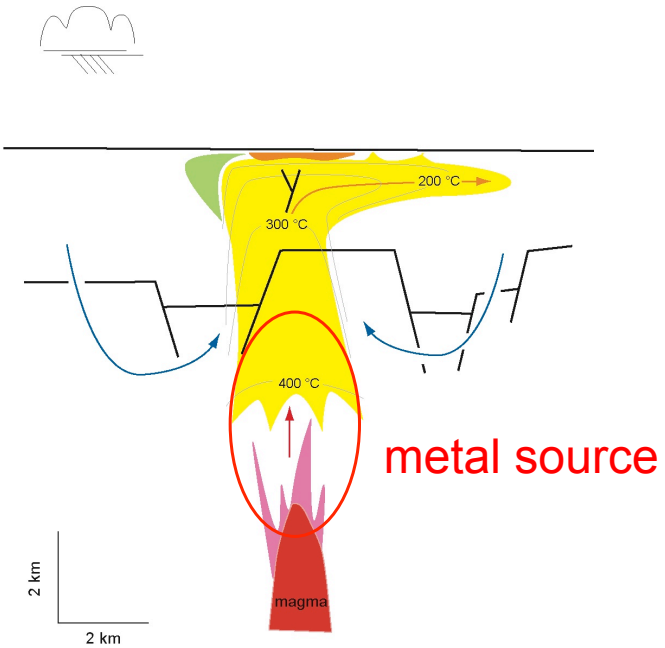

Rotokawa
Wairakei
ppb
10000
1000
100
10
1
0.1
boiling effect
Cu Pb Zn
As Sb
Ag Au
Te Tl Hg
Simmons & Brown, 2009


Gold flux
deep flow kg s-1
1000
100
10
0.1 kg/y
1 kg/y
10 kg/y
100 kg/y
W
N
M
M
B
K
B
K
R
R
West TVZ
East TVZ
0.01
0.1
1
10
100
Gold p.p.b.
Simmons & Brown, 2007

Silver flux



Simmons & Brown, 2007

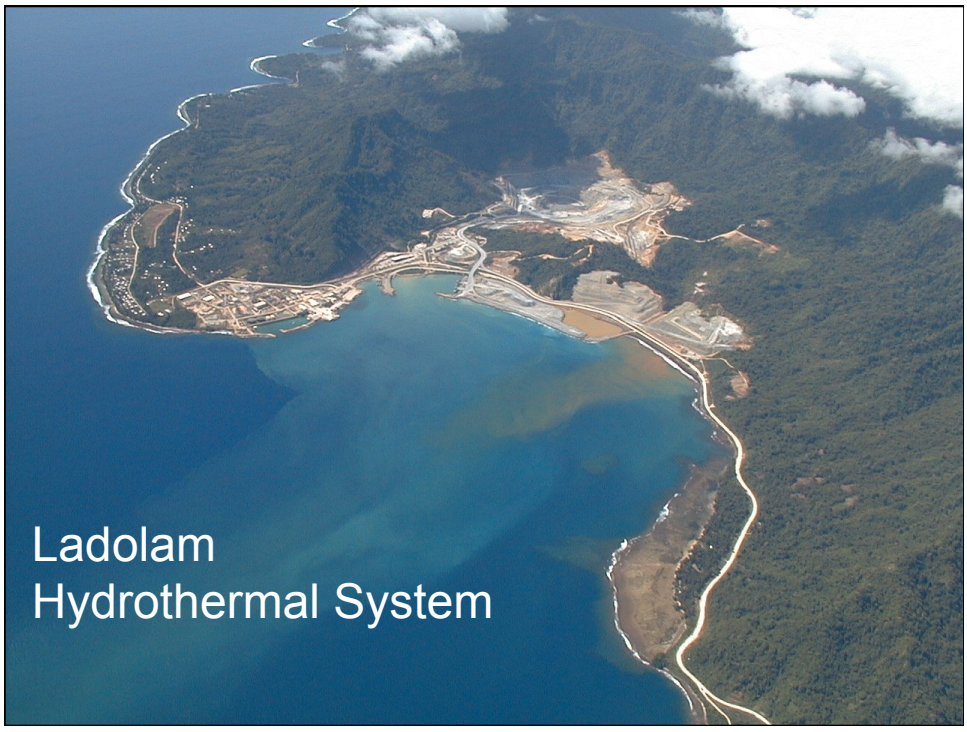


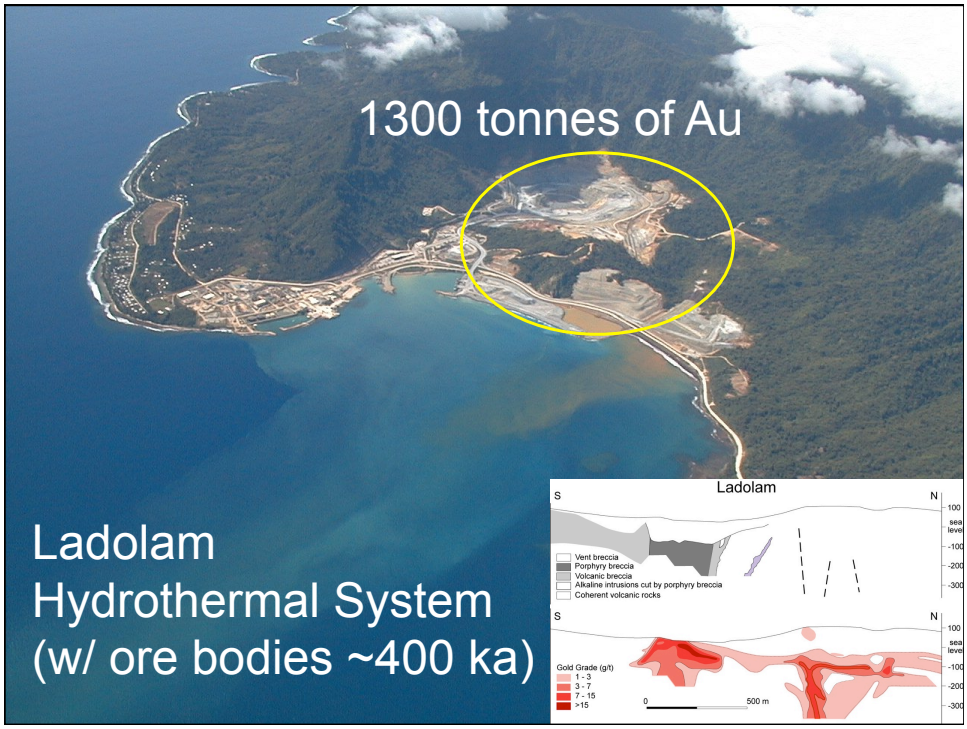
Rotokawa Metal Fluxes

~100 t Au/ky & ~11,000 t Ag/ky

20,000 yrs → 2,000 t Au!

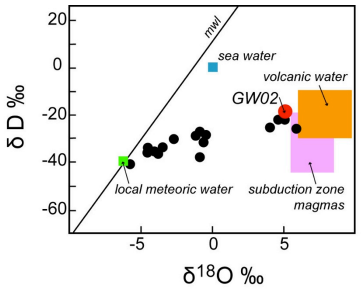
9,000 yrs → 100,000 t Ag!

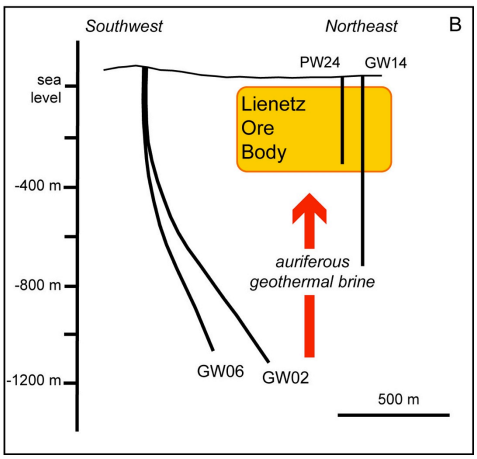




Ladolam Hydrothermal System

Ladolam Hydrothermal Solutions



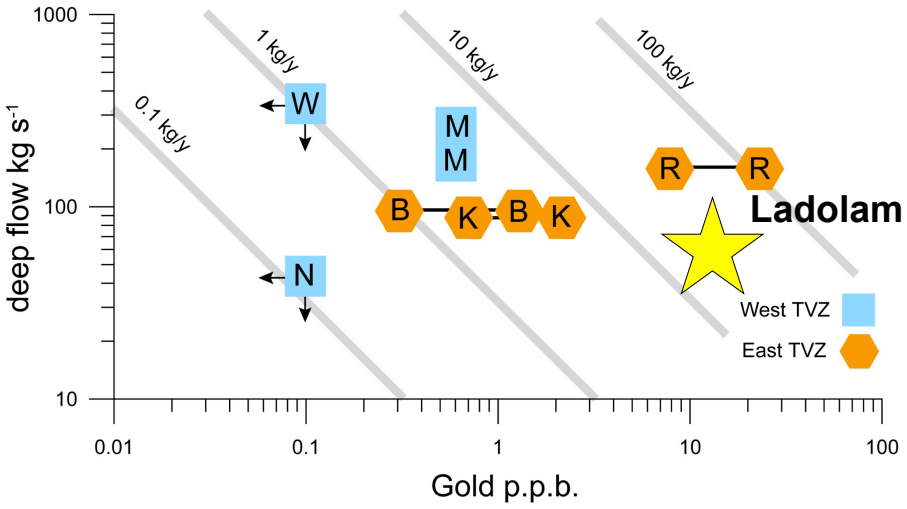


270 deg C

SO_4	30,000 ppm
Cl	20,000 ppm
pH	neutral

Simmons & Brown, 2006

Gold flux



Ladolam gold origin & flux

Magmatic origin of metals

55,000 years to flux all gold in "mineable" resource

Relatively efficient metal deposition

Gold

- Solubility controlled by H_2S, pH and redox
- Deposits in hot springs, wells and altered rocks via boiling & adsorption on colloids
- Concentration in solids 10^6 greater than concentration in solution
- Aqueous concentration varies 100x
- Solutions undersaturated
- Huge hydrothermal metal flux
- Magmatic origin