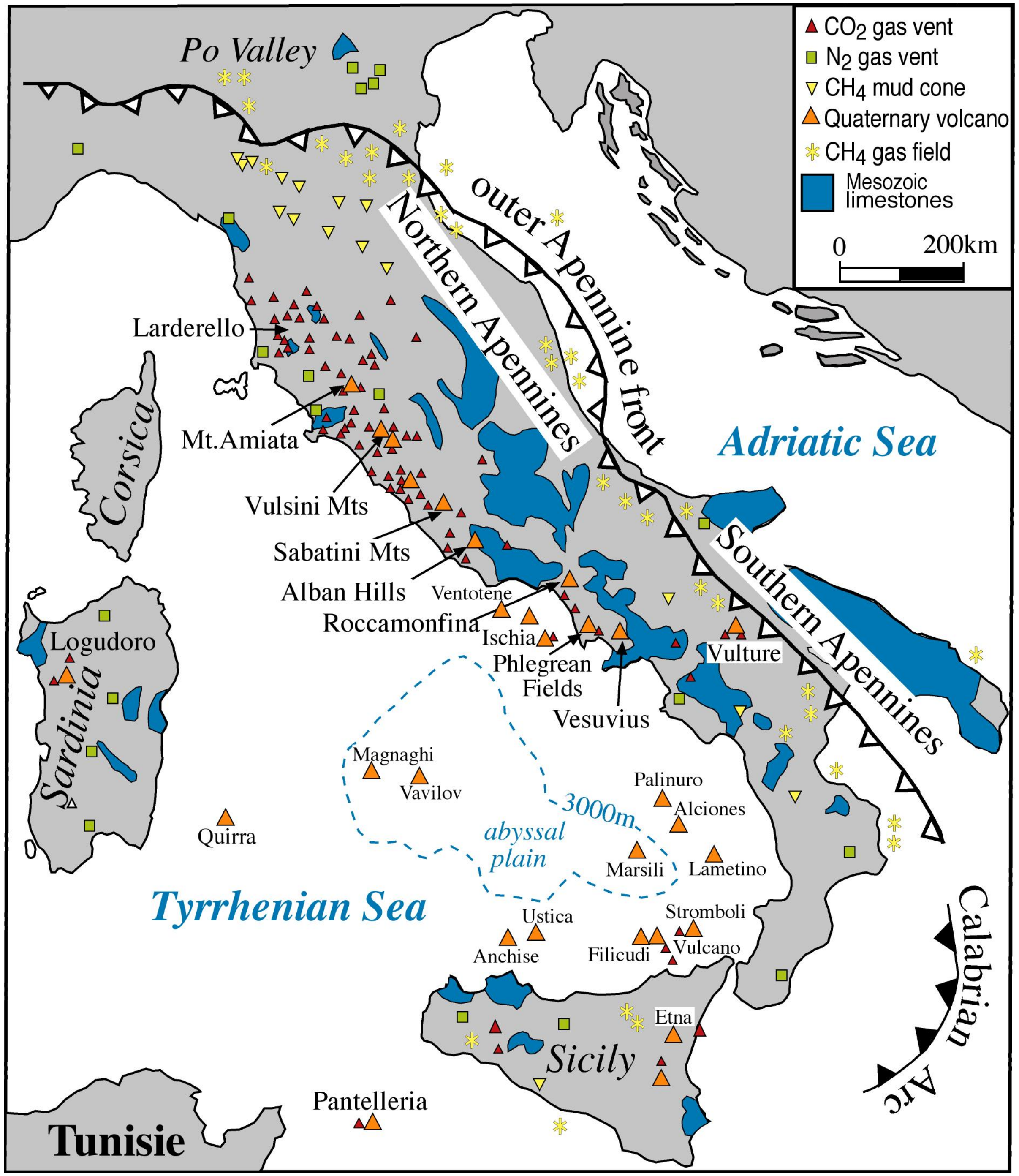
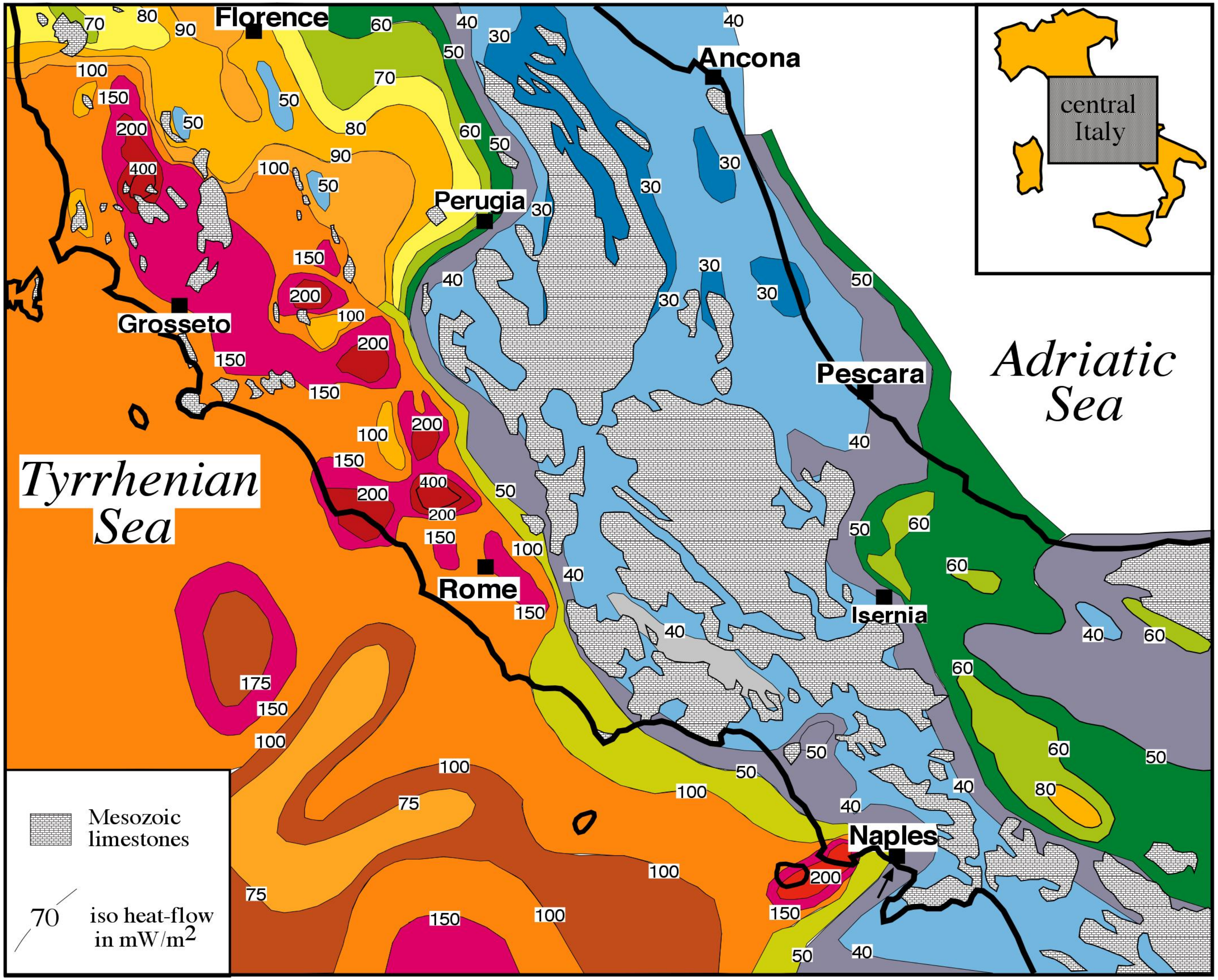
The Italian geothermal fields

Angelo Minissale

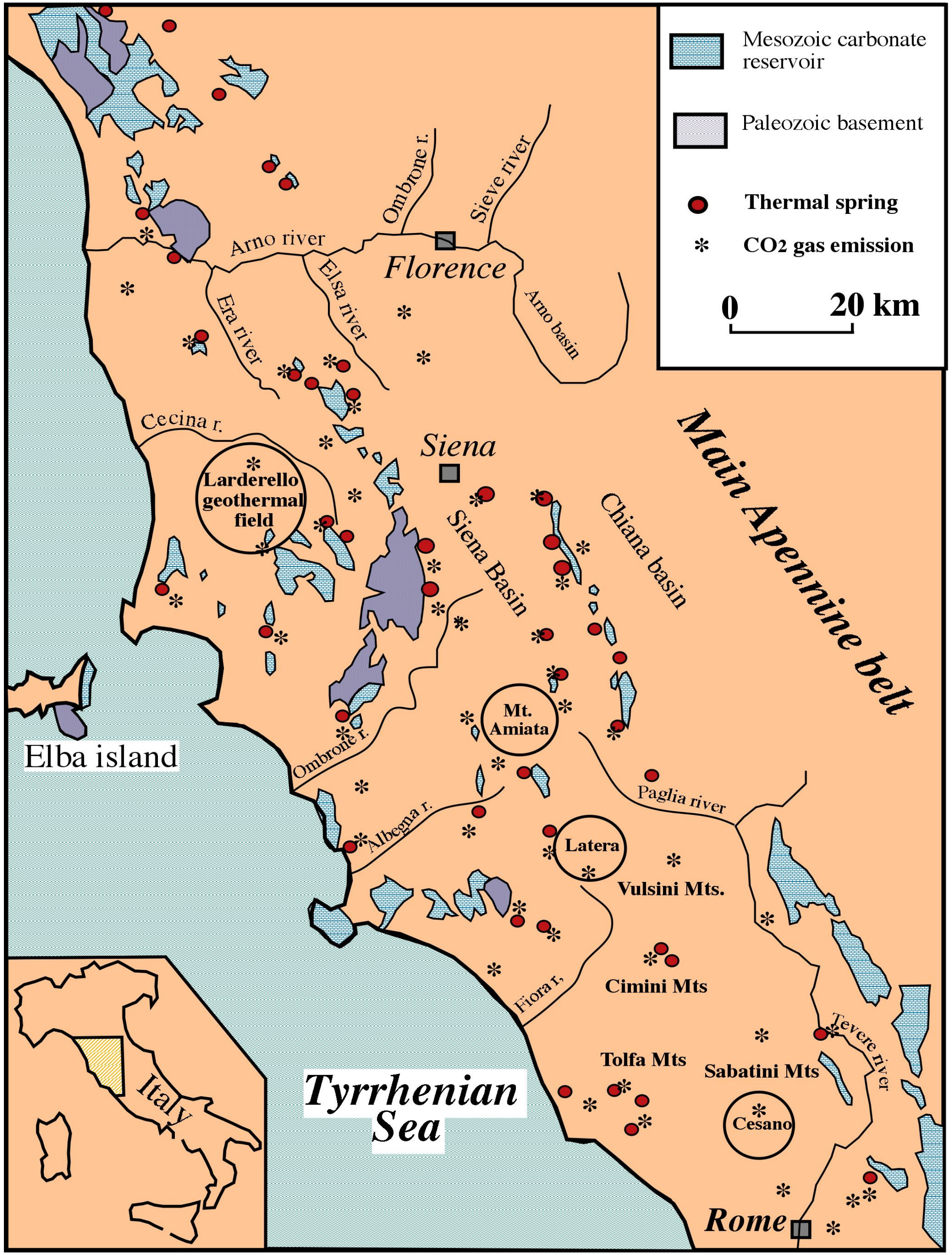
CNR-Ist. Geoscienze e Georisorse, Firenze



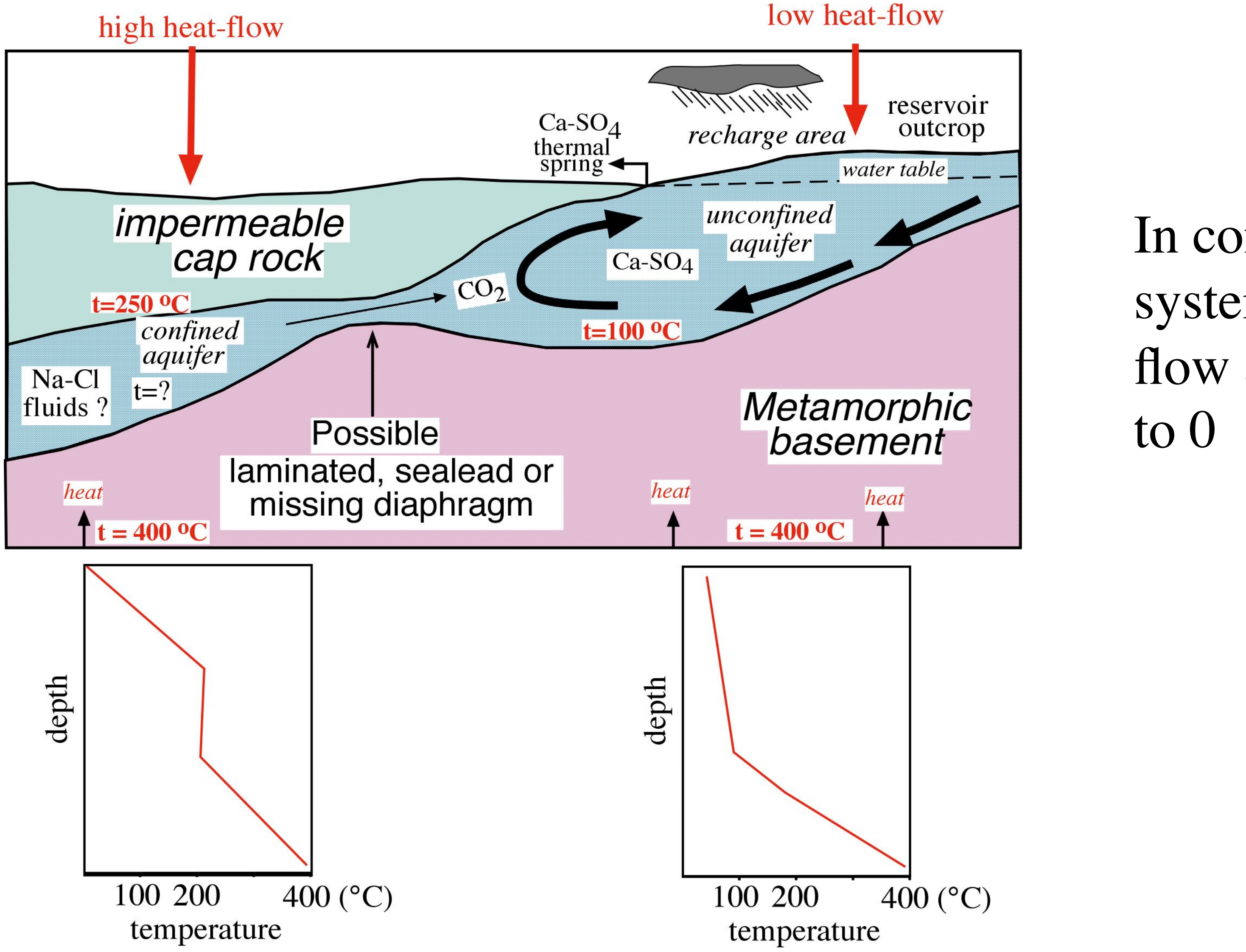
CO_2 gas vent
N_2 gas vent
CH_4 mud cone
Quaternary volcano
CH_4 gas field
Mesozoic limestones
0
200km
Po Valley
outer Apennine front
Northern Apennines
Southern Apennines
Adriatic Sea
Tyrrhenian Sea
Calabrian Arc
Corsica
Sardinia
Sicily
Tunisie
Larderello
Mt.Amiata
Vulsini Mts
Sabatini Mts
Alban Hills
Roccamonfina
Ventotene
Ischia
Phlegrean Fields
Vesuvius
Vulture
Logudoro
Magnaghi
Vavilov
3000m
abyssal plain
Palinuro
Alciones
Marsili
Lametino
Quirra
Ustica
Anchise
Filicudi
Stromboli
Vulcano
Etna
Pantelleria



Florence
Ancona
Perugia
Grosseto
Pescara
Rome
Isernia
Naples
Tyrrhenian Sea
Adriatic Sea
central Italy
Mesozoic limestones
70 iso heat-flow in mW/m2

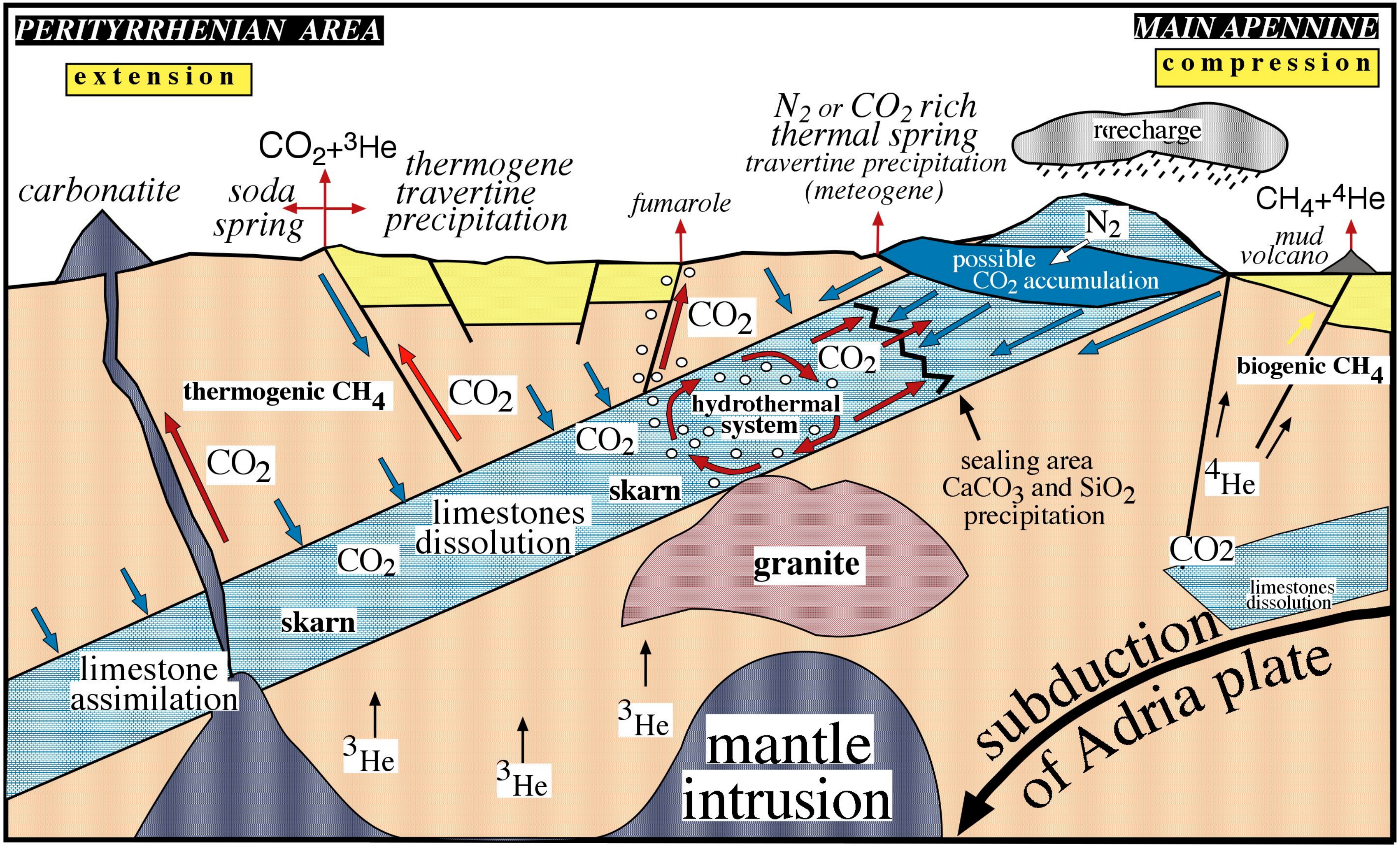


A quote basse le falde termali nei calcari tagliano la topografia e fuoriescono come a Saturnia, Bagno Vignoni, Chianciano …etc.



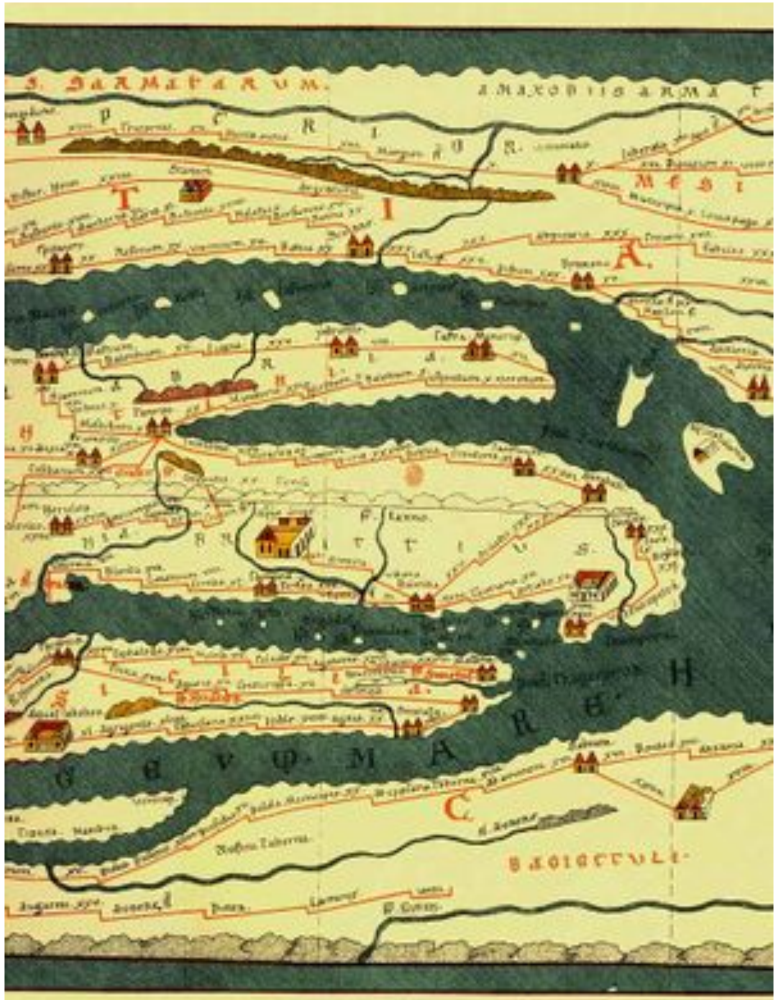
In convective system the heat flow approaches to 0

idealized W-E cross section of Italy



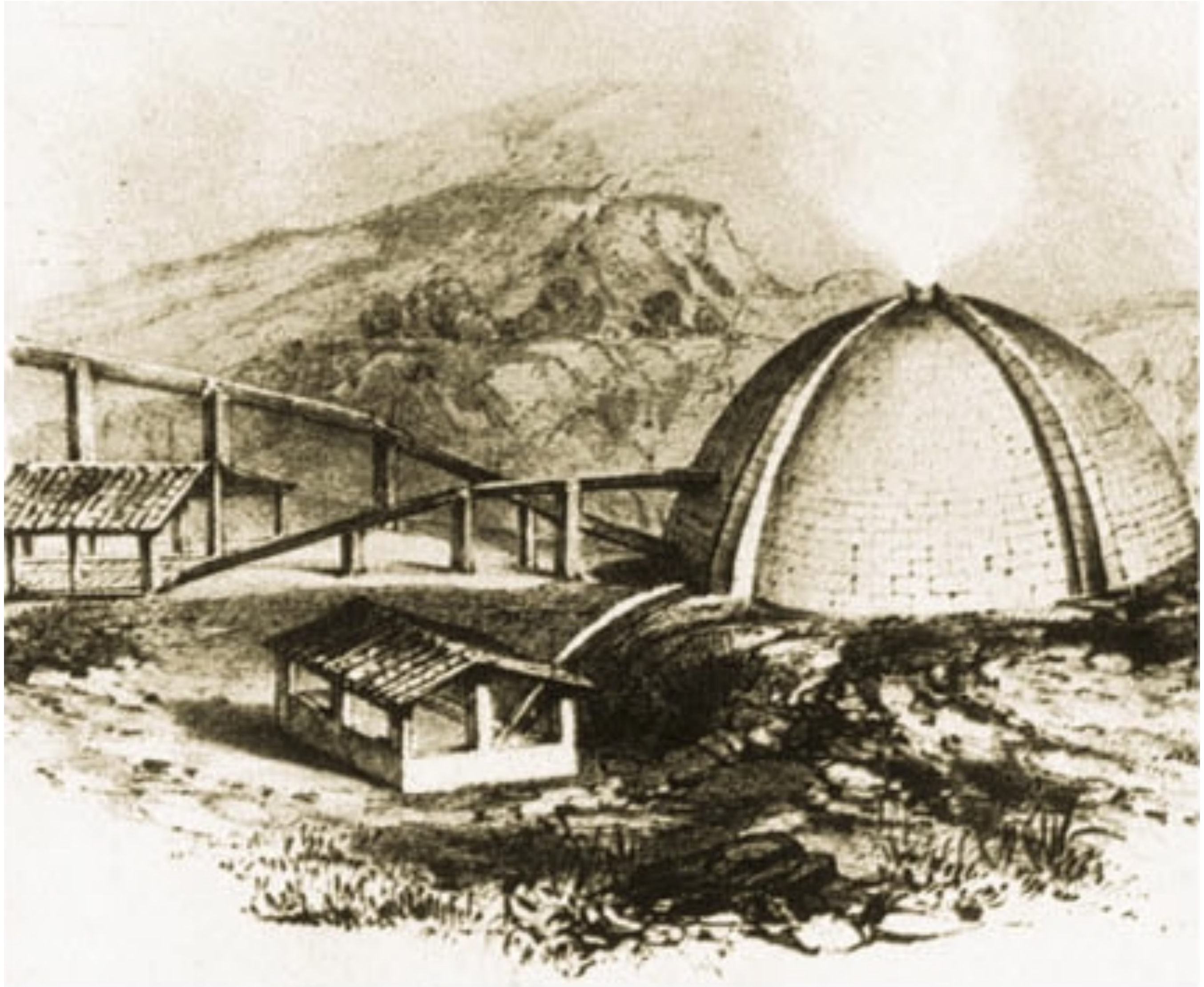
Roman map of ofthe empire (0.33 x 6.88 m)

Aque Volterrane

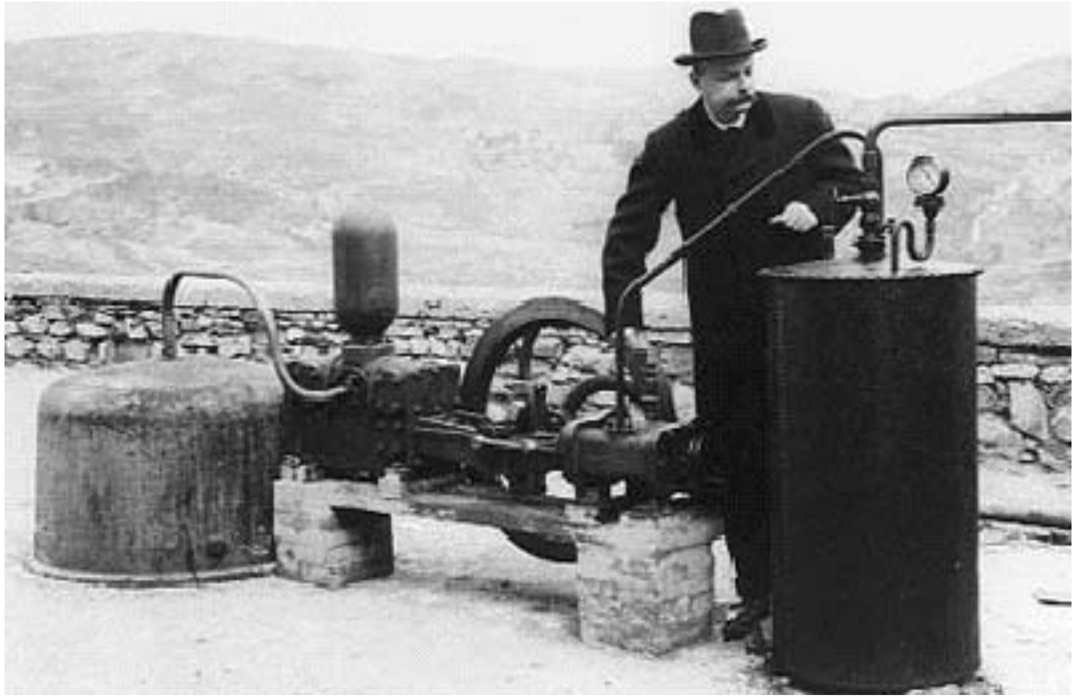


Before the descovering of boric acid in 1770 a.D. the natural products of the “lagoons” (coloured salts and alteration minerals) were used as colours for clothes colori (clothes in Middel Age were mostly pale brown)

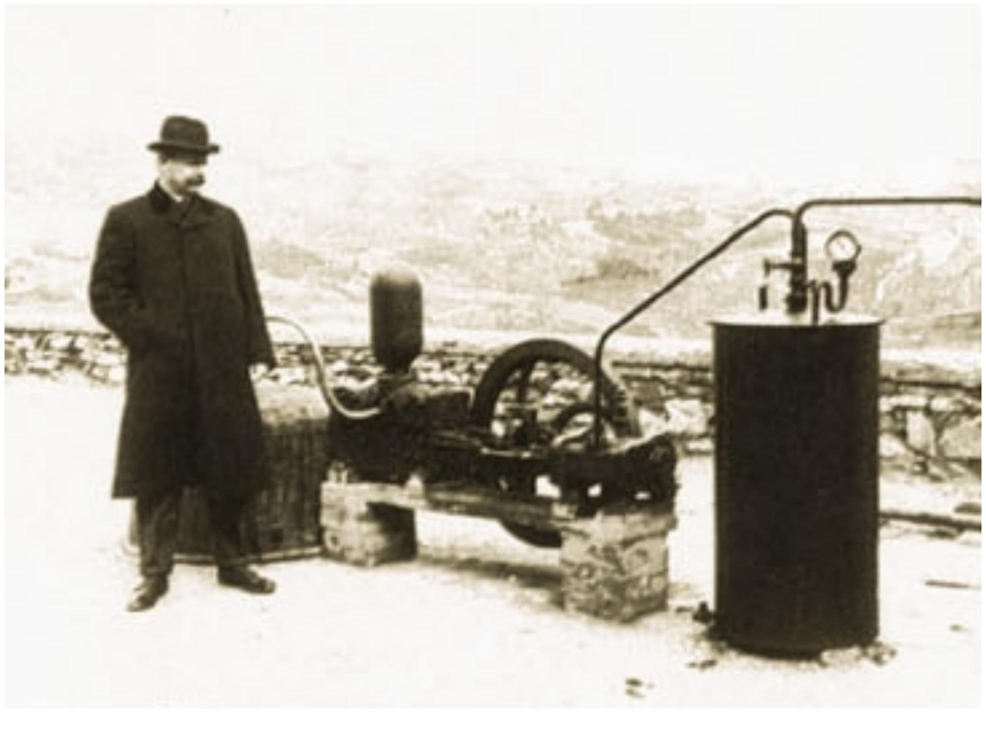
Covered lagoon



Steam was used
to increase the
evaporation
of condensates



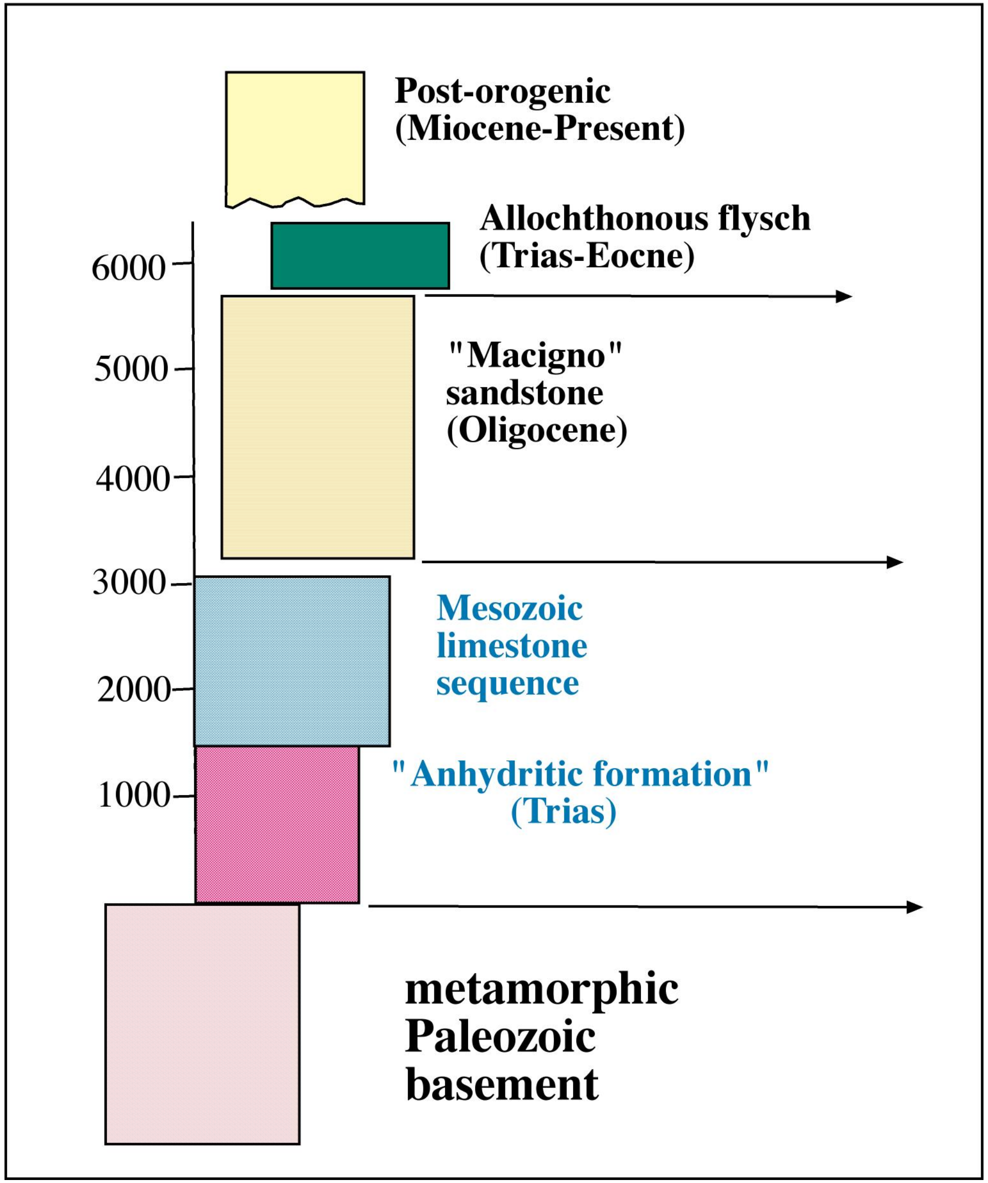
In 1904 the first power generation using steam

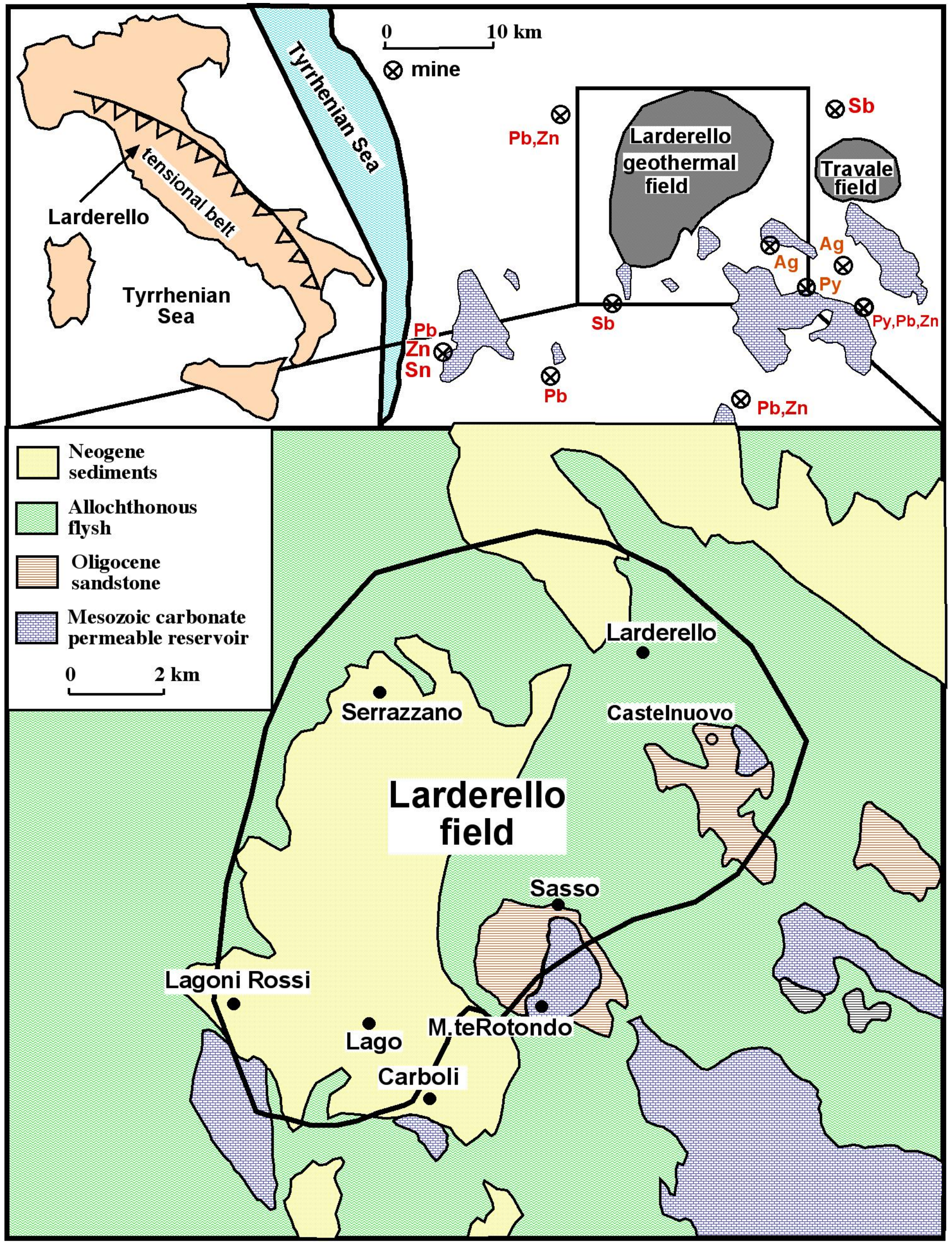


Electical power (2004)

Larderello	550 MW
Travale	160 MW
Mt Amiata	88 MW
	798 MW

Stratigraphy of the Apennines

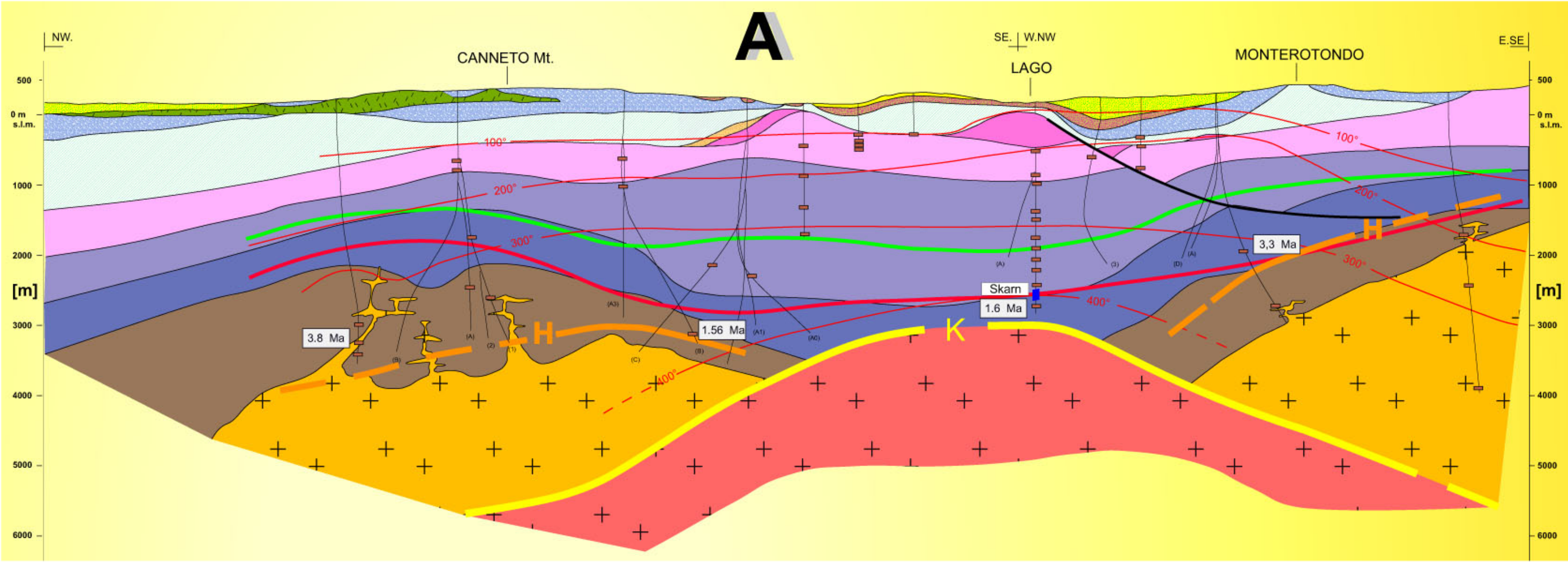




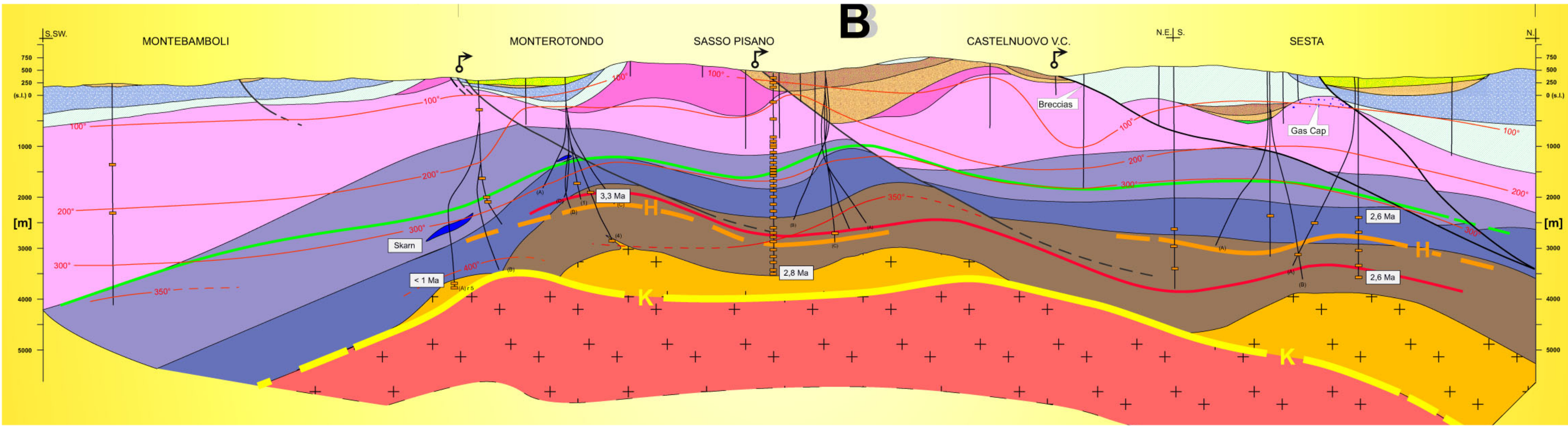
Larderello is surrounded by ore deposits

Geology of Larderello

1) Moho at 20 km (35 in the Apennines)
2) anomalous $^{3}He/^{4}He$ ratio
3) negative gravimetric anomaly
4) cooling granite (3 Ma old)
5) reflecting horizon (K) at 3/4 km depth



A
NW.
CANNETO Mt.
SE.
W.NW
LAGO
MONTEROTONDO
E.SE
500
0 m s.l.m.
1000
2000
[m]
3000
4000
5000
6000
100°
200°
300°
400°
3.8 Ma
H
1.56 Ma
Skarn
1.6 Ma
K
3,3 Ma

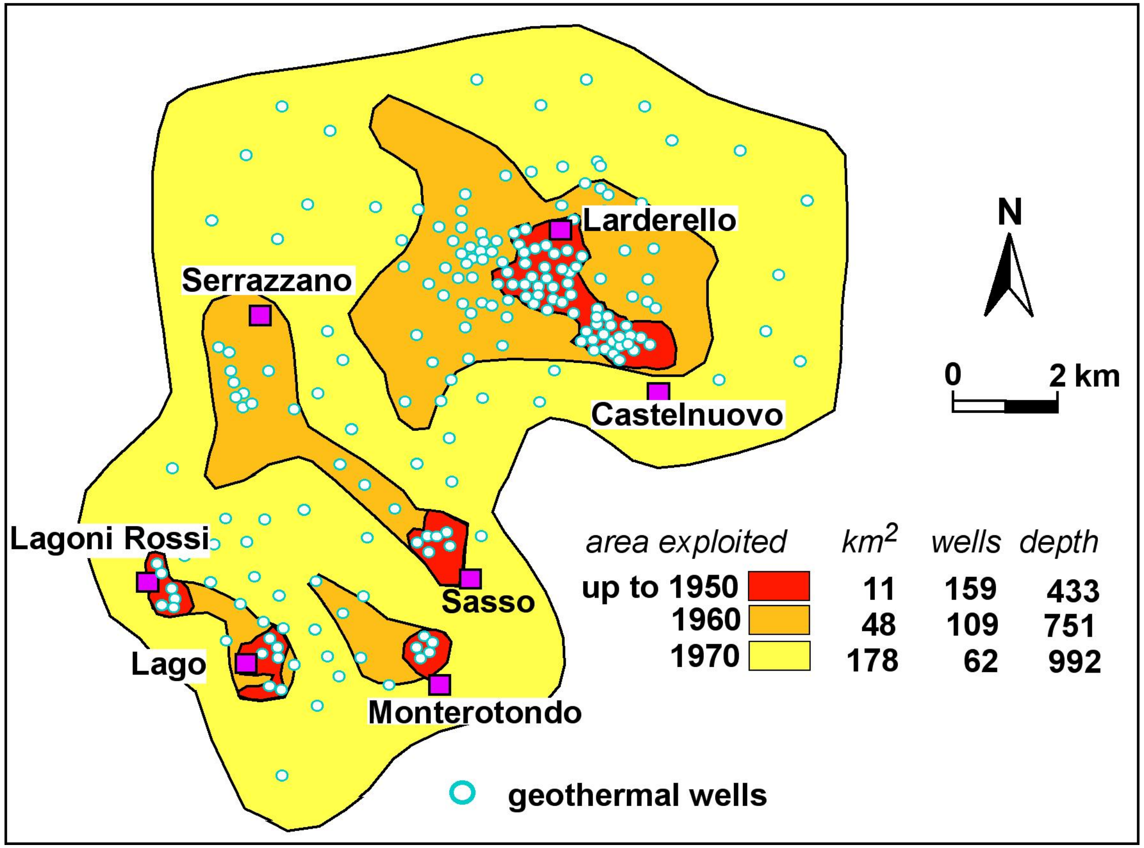


B
S.SW.
MONTEBAMBOLI
MONTEROTONDO
SASSO PISANO
CASTELNUOVO V.C.
N.E.
S.
SESTA
N.
750
500
250
(s.l.) 0
1000
2000
[m]
3000
4000
5000
100°
200°
300°
350°
400°
Breccias
Gas Cap
3,3 Ma
H
Skarn
< 1 Ma
2,8 Ma
2,6 Ma
2,6 Ma
K

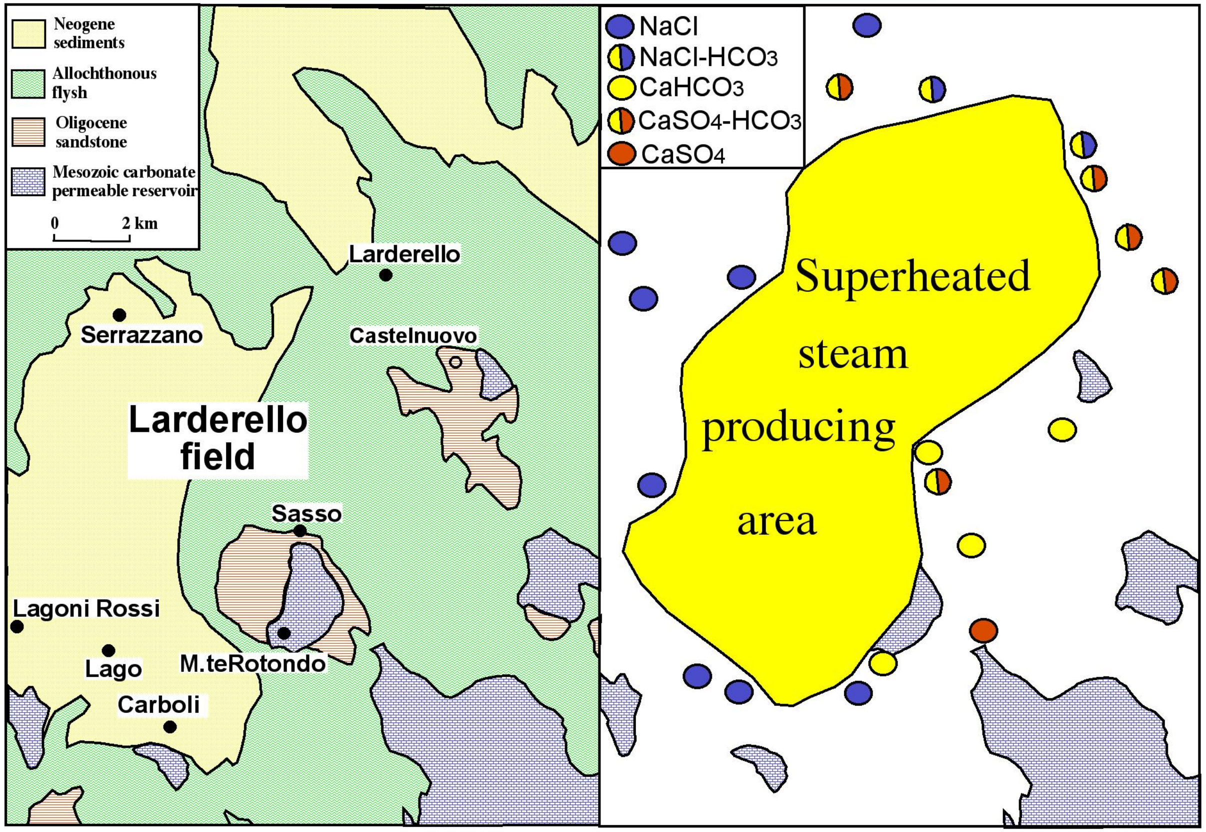
Larderello(-Travale) geothermal field

1) Steam-dominated (superheated) system.
2) Temperature 180-300°C; Pressure 10-50 bar.
3) Steam production ~ 3000 T/h.
4) Gas is about 10% of total fluid discharge (about 300 T/h, stable since 1964).
5) CO_2 is about 90% of the total gas phase.
6) Producing electricity since 1904 (250 KW).
7) Actuall production about 500 MW (stable since 1964).
8) More than 500 wells drilled.
9) The deepest well is more than 4000 m.
10) The highest measured temperature is >450°C
11) Reinjection active since 1974 (100 % of reinjection at present).
12) No volcanics in the area, a granite (regional negative Bouger gravimentric anomaly) is the source of the thermal anomaly (3.5 My).
13) No earthquakes below 8 km depth (ductile rheology) .

Development of Larderello field (1926-1979)



Chemistry of liquid-dominated wells



Questions about Larderello

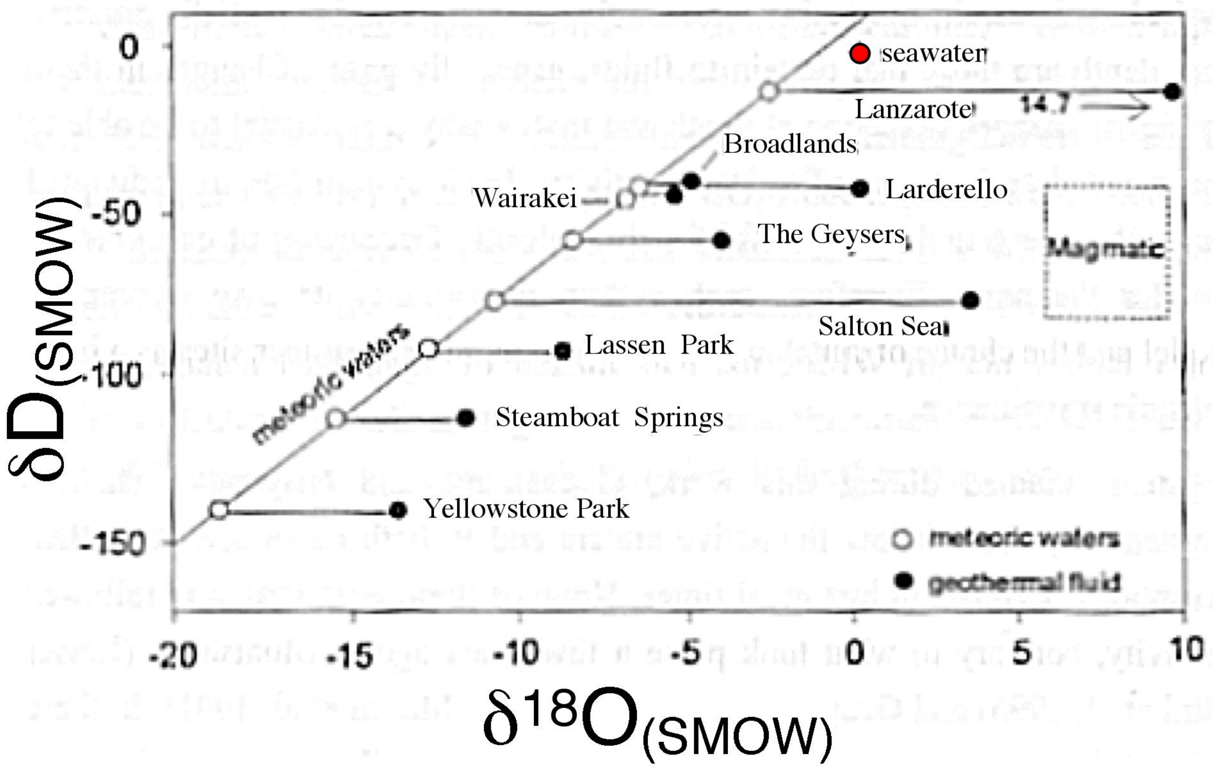
What is the origin of the fluid (magmatic versus meteoric) ?

What kind of fluid was present in the reservoir in the natural state ?

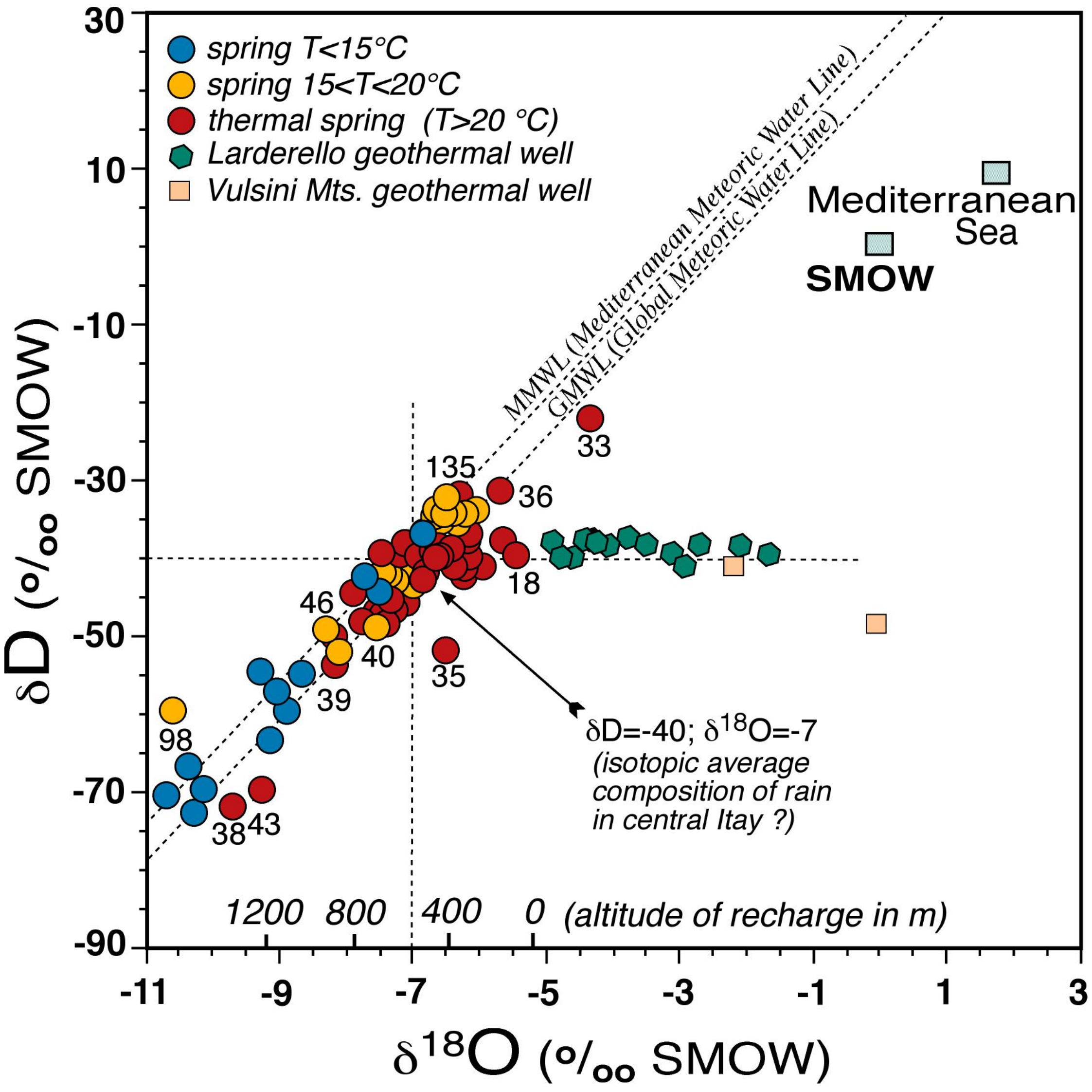
Is geothermal energy renewable ?

What about the natural water recharge ?

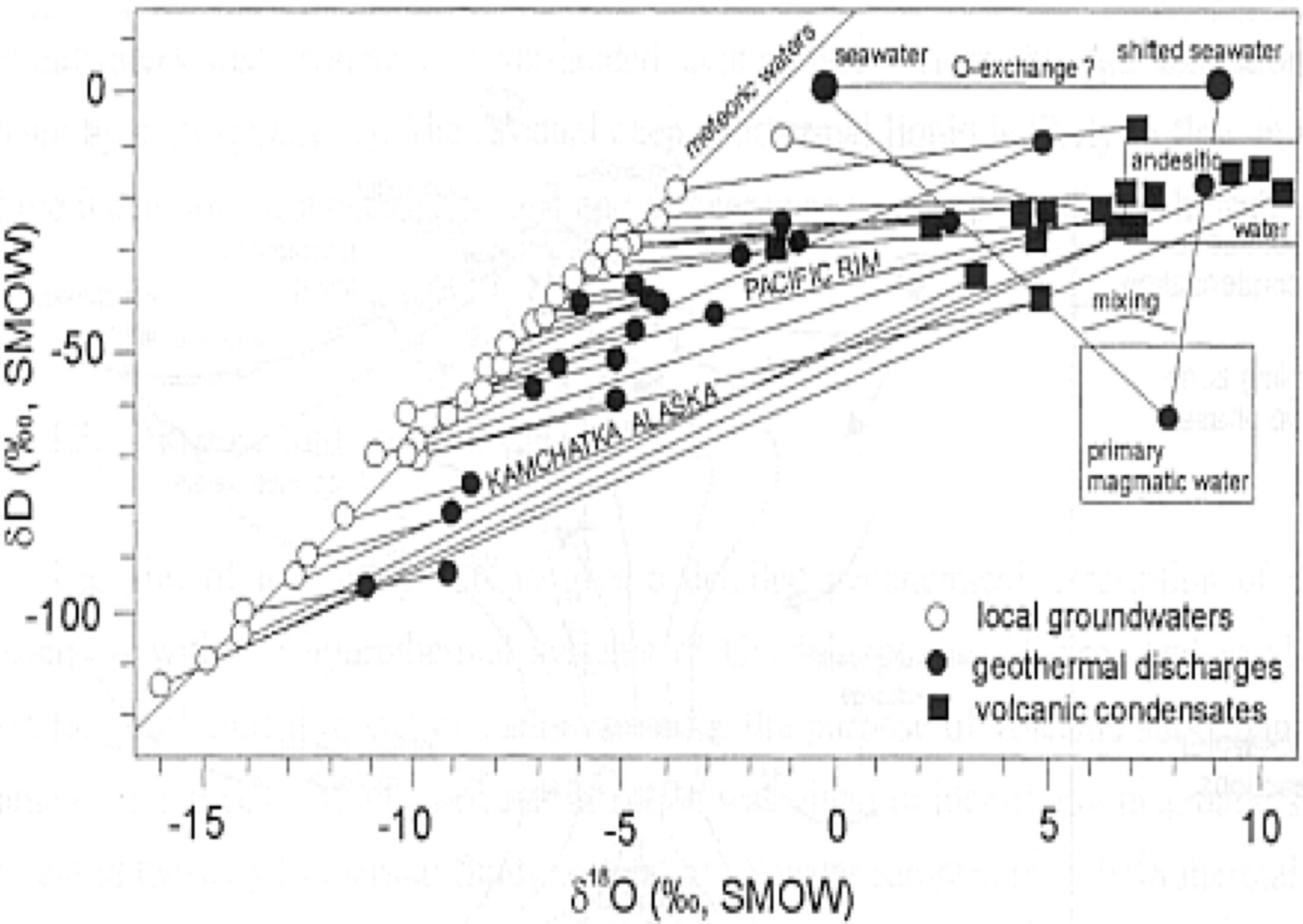
Craig (1963)
congresso di Spoleto



Origine dei fluidi



Giggenbach (1992)



Is geothermal energy renewable ?

yes, at least partly

evidences of recharge at Larderello:

1) δD and $\delta^{18}O$ are meteoric in origin

2) Larderello fluid has tritium (<50 years)

3) Steady production since 1964 that suggests equilibrium between fluid entering the system and fluid produced by wells

4) Clear evidence of recharge in the southern part of the field.

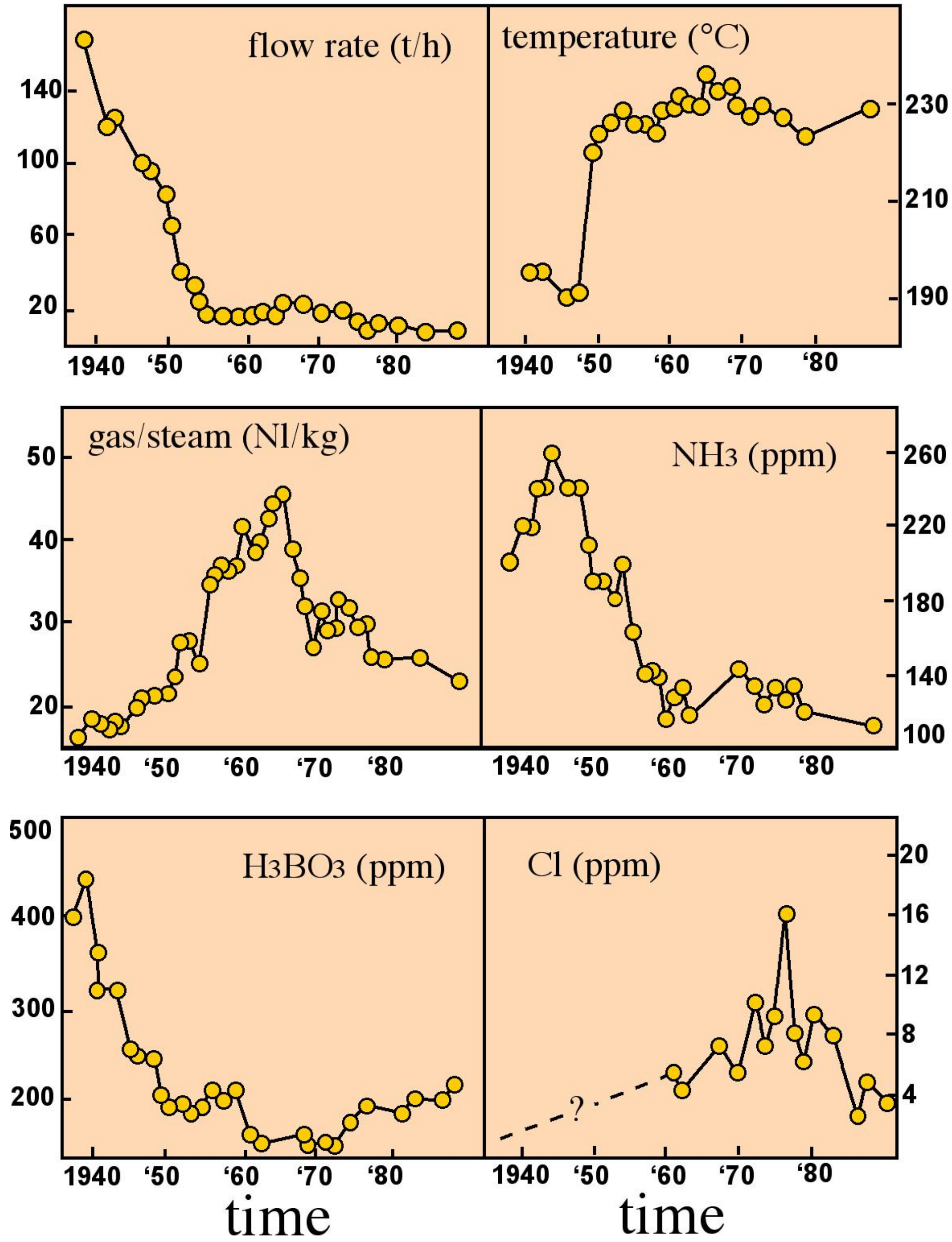
Natural state of the field:

1) was liquid dominated or vapor dominated ?

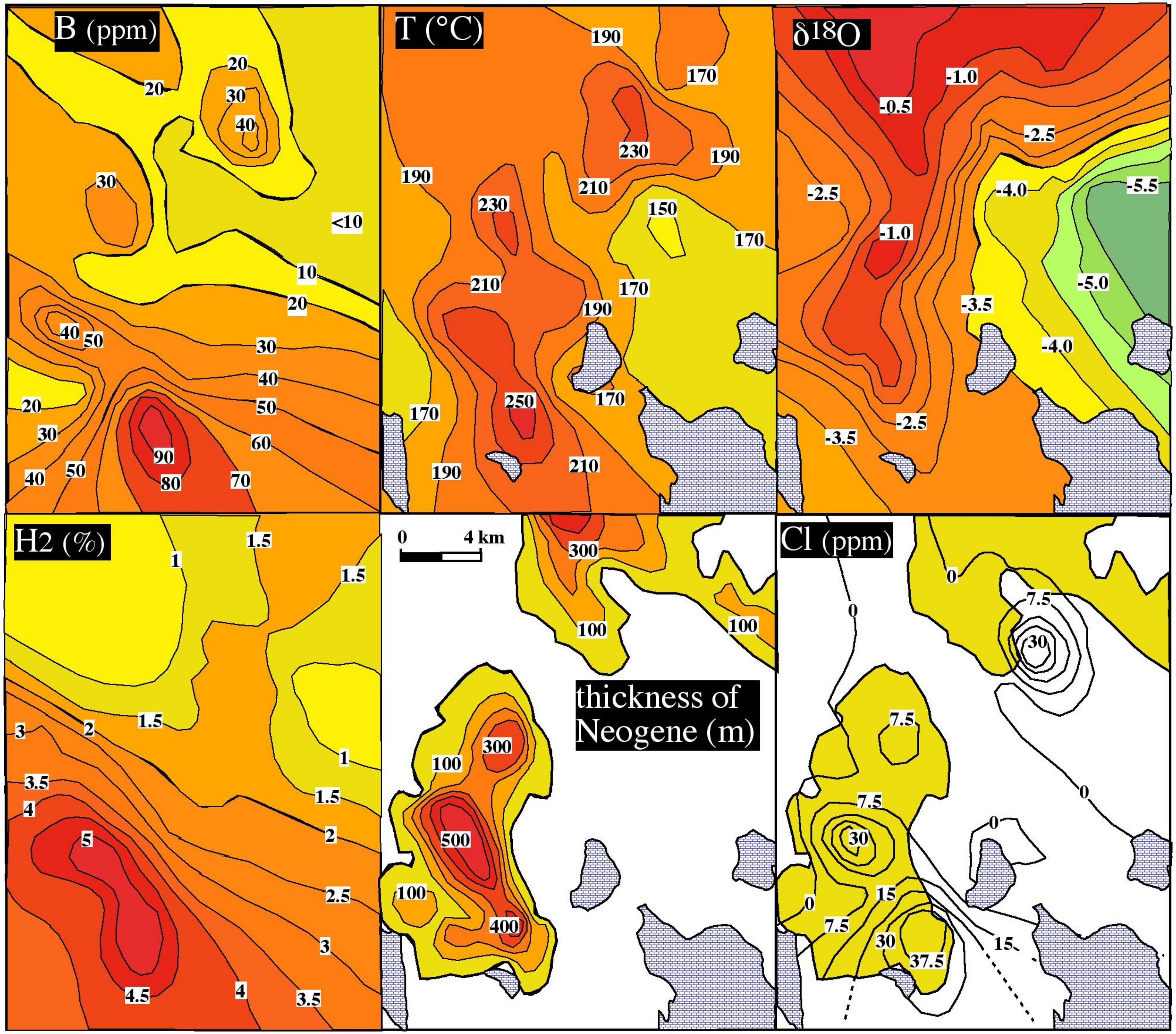
2) how was the evolution after 1904 ?

3) what about the deep "root" of the system ?
(boiling brine ?)

Alloro well (600 m deep)



isodistributions in the Larderello field

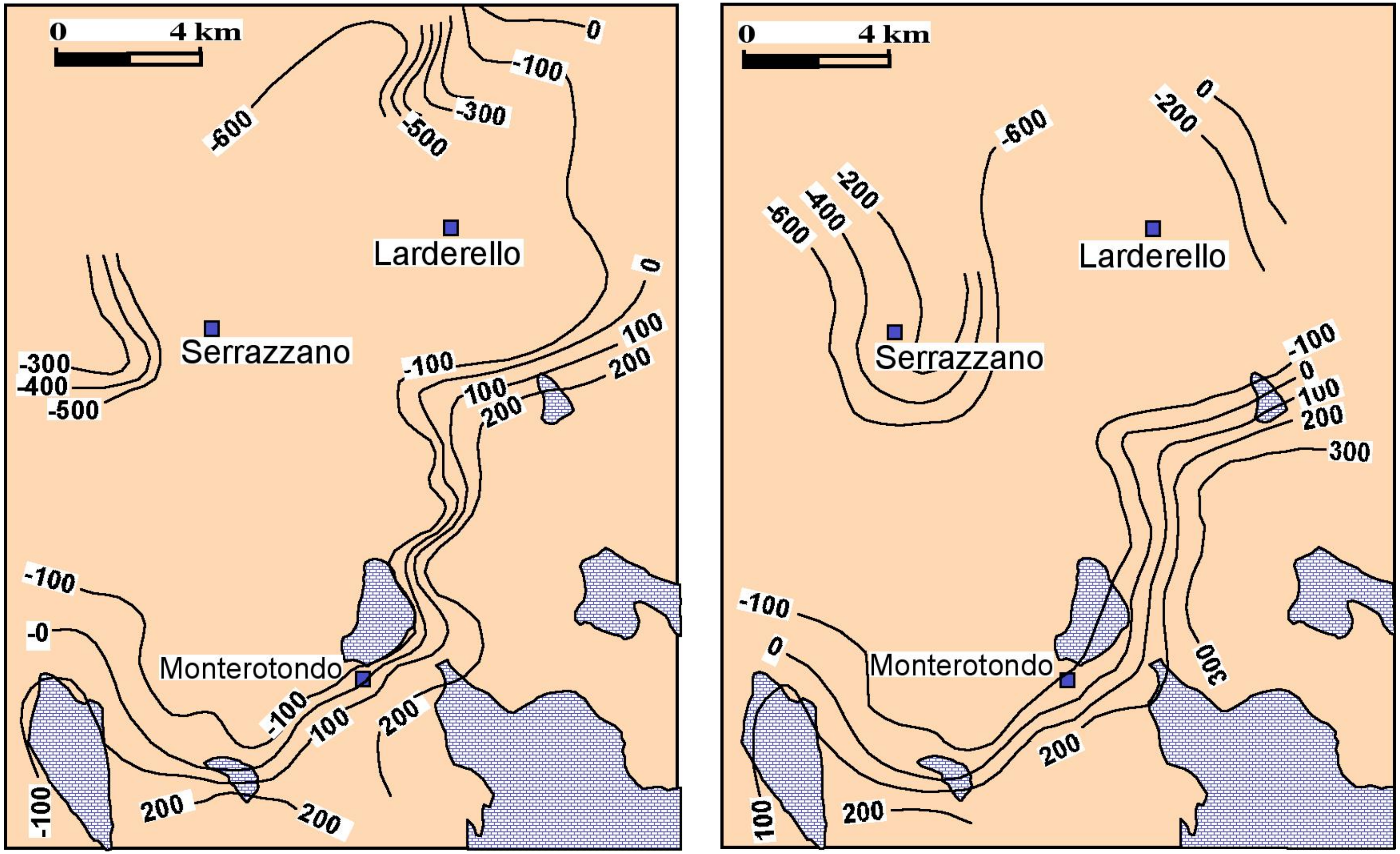


What about the boundary of the field ?

1) Deep bottom boundary (brine ?)

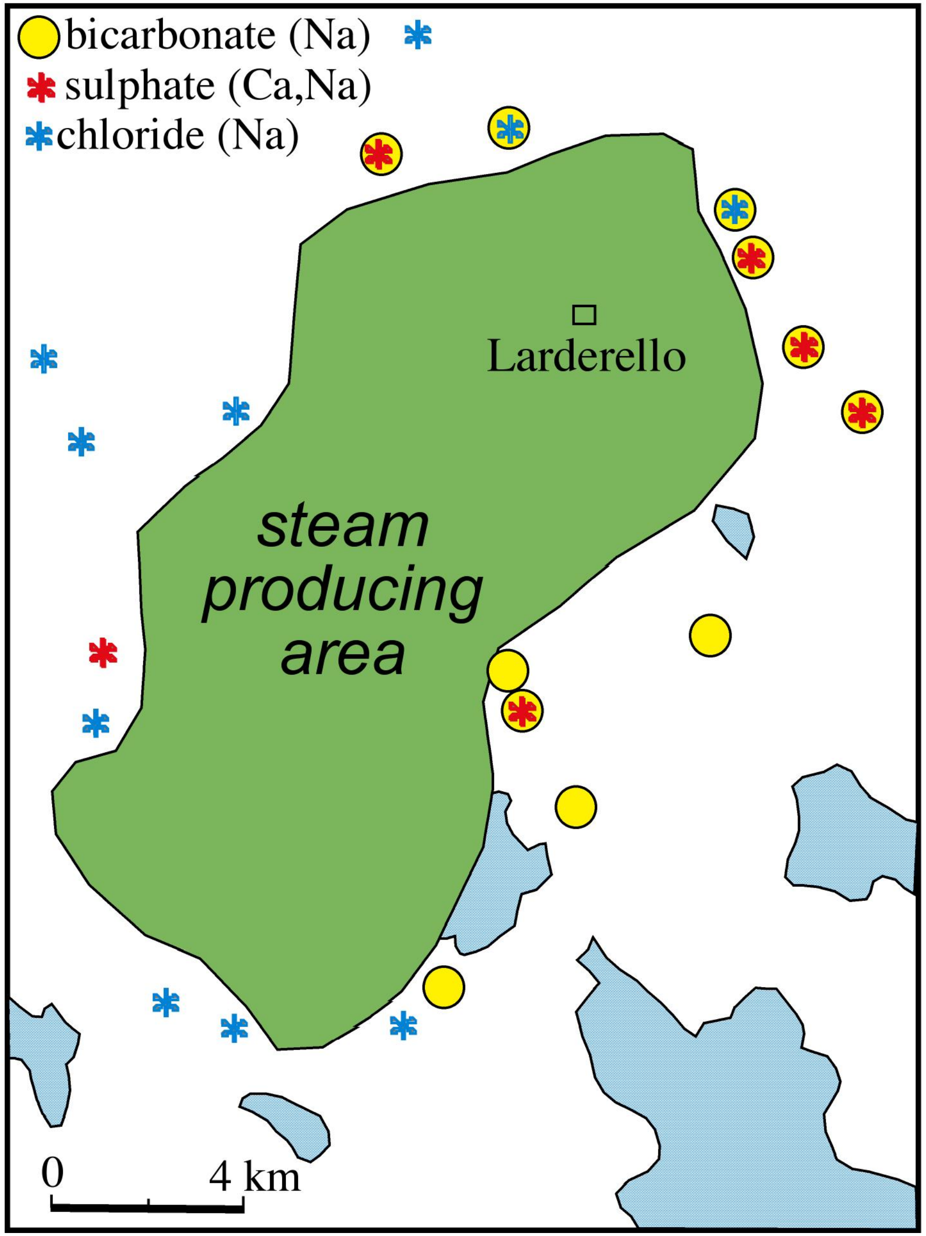
2) Lateral boundaries (shallow aquifers ?)

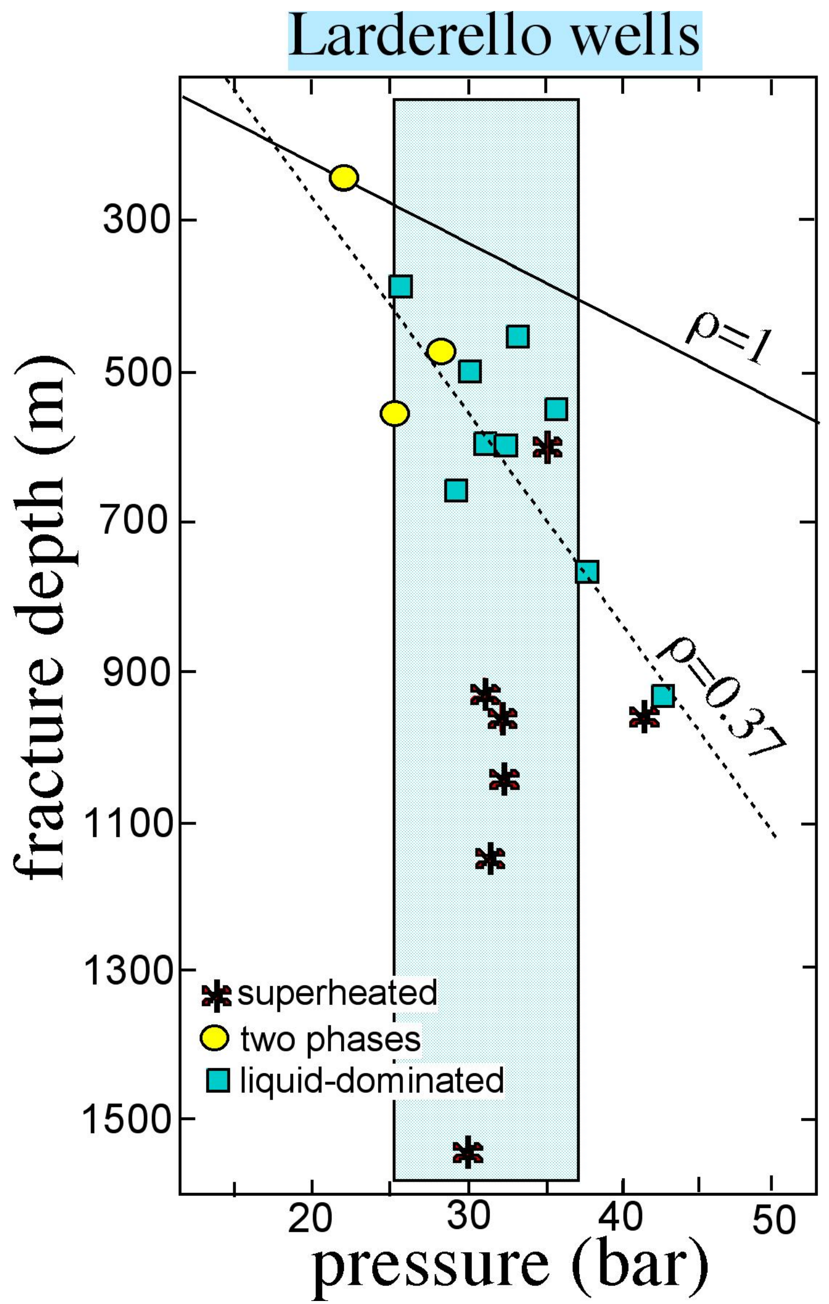
Water levels at the boundary of the field ?



Is this a boiling brine???

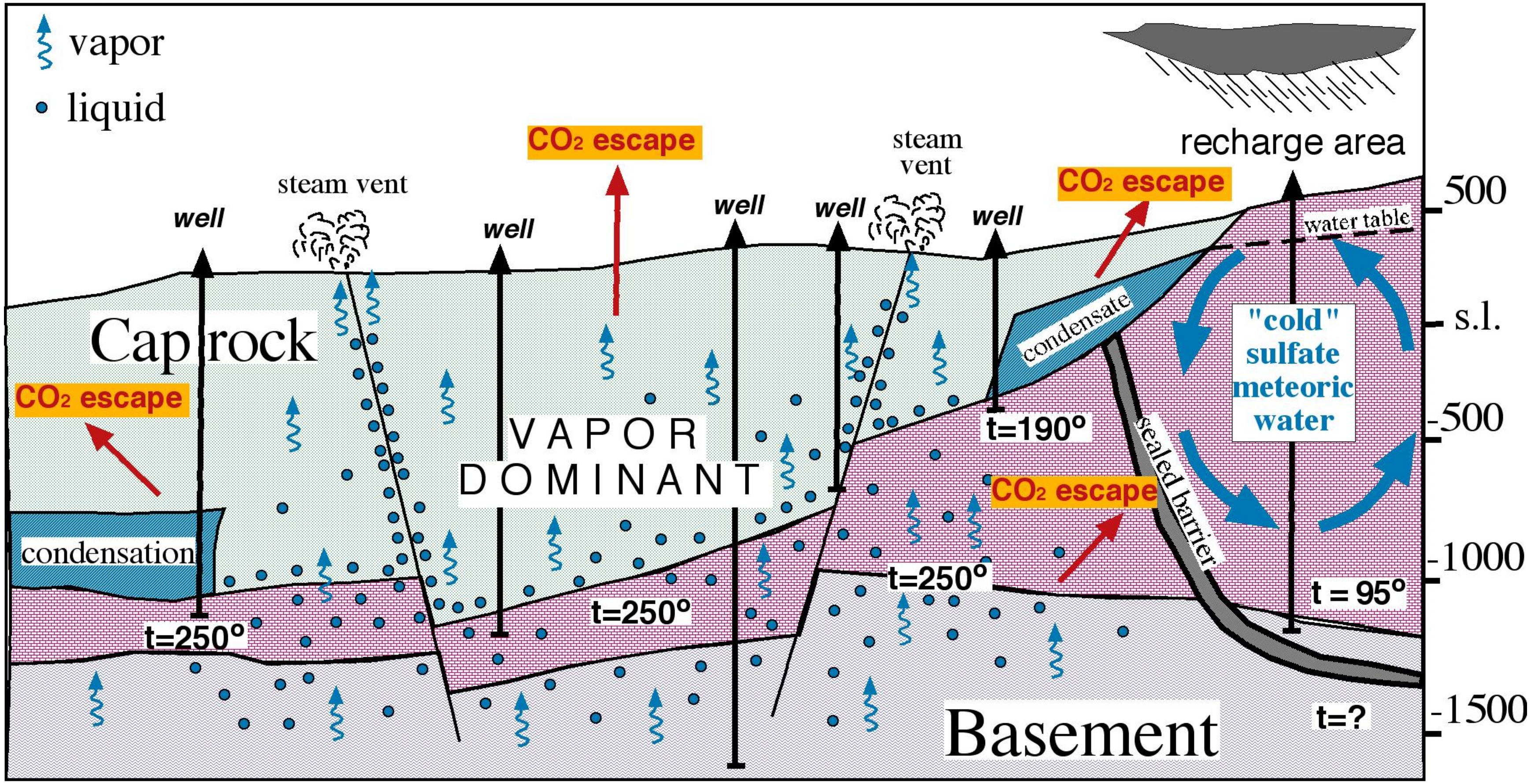
Chemistry of liquid around Larderello



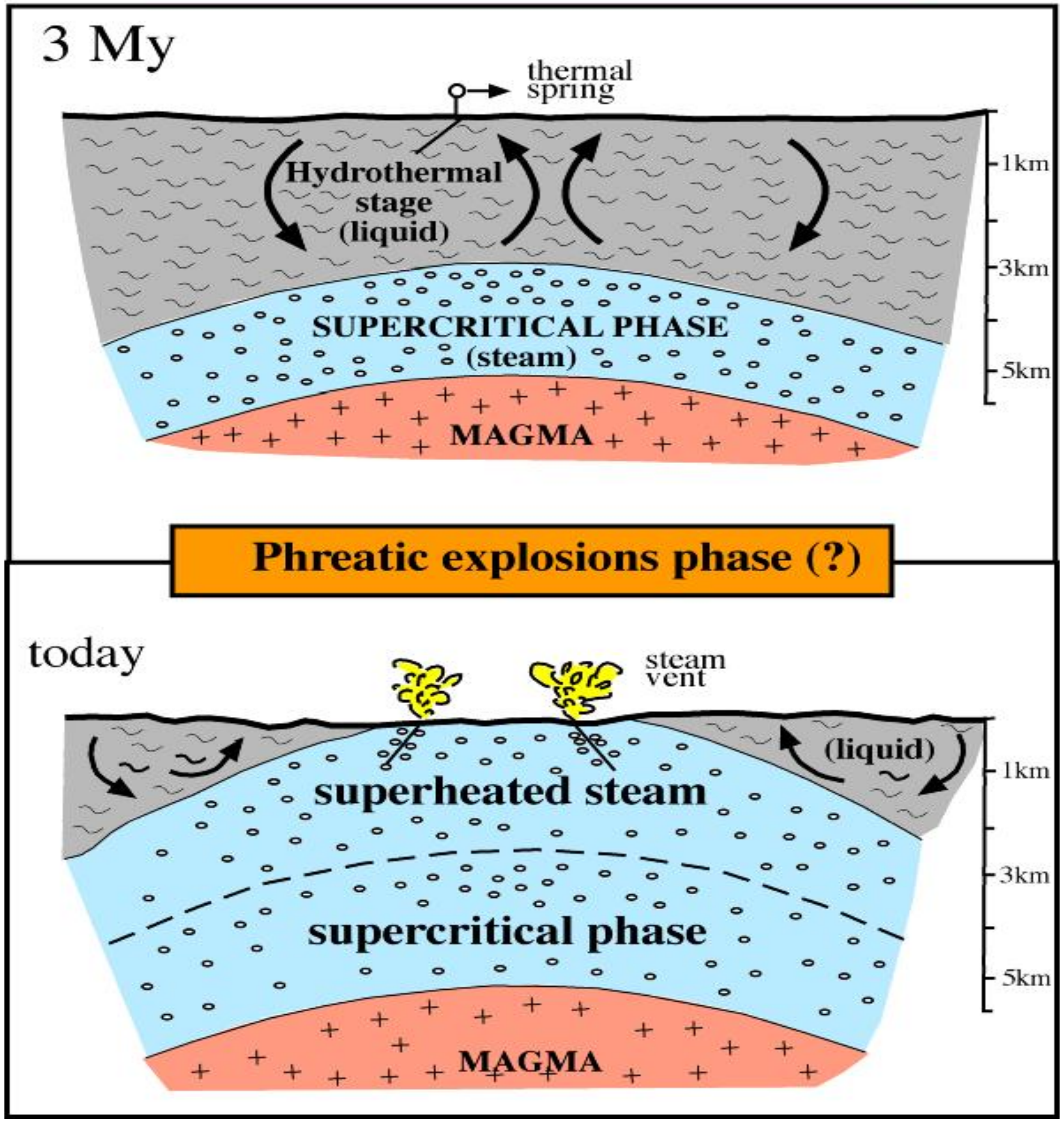


Larderello wells
fracture depth (m)
pressure (bar)
300
500
700
900
1100
1300
1500
20
30
40
50
ρ=1
ρ=0.37
superheated
two phases
liquid-dominated

conceptual section of the Larderello geothermal field



evolution in the last 3Ma



Conclusions

1) Larderello is in a sort of equilibrium state: fluid under production is balanced by fluid entering the system

2) The present liquid boundary (having a chemical composition very variable) of the field is mostly a steam condensation zone

3) The southern liquid boundary has a suspended aquifer having steam beneath (this was confirmed by drillings in the 90's)

4) Probably, a boiling Na-Cl brine is missing (or is very very deep)

5) The natural state of the field was stem-dominated ("pneumatolhitic phase"), typical of (sub)-volcanic fumaroles

The Mt. Amiata

Was discovered by chance in the ‘50s by a drilling for the prospection of mercury by the local mining company.

To the hot gas (at Bagnore: SW of the volcano) was added water to convince the Larderello ltd. to invest money in the area

In the ‘60s a campaign with shallow wells (30-70 m deep) to measure the thermal gradient discovered the area of Piancastagnaio (SE of the volcano)

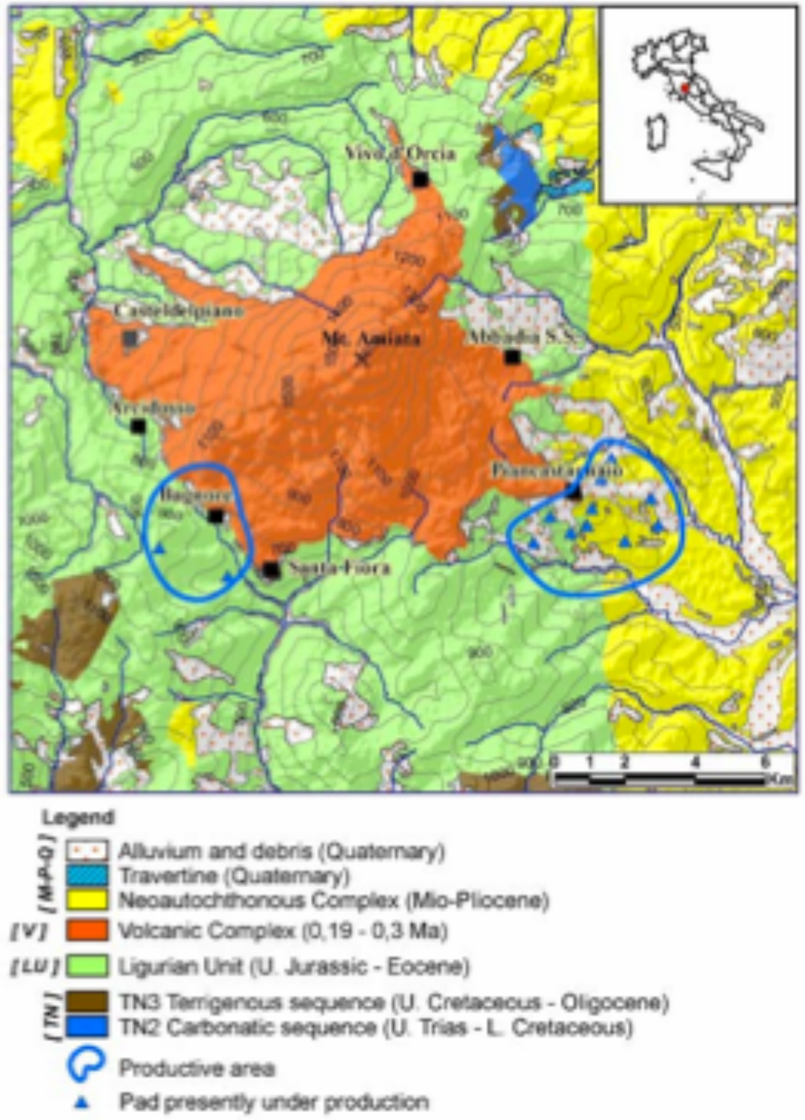
Comparing Larderello vs Mt. Amiata

Similarities

1) Same geological environment
2) Similar bul lower heat flow (>300 mW/m^2)
3) Same reservoir and cap rock
4) Permeability by fractures
5) Same origin of heat from a cooling granite
6) Same low Moho depth
7) Fluids of meteoric origin
8) K horizon still present, but a little deeper

Differences

1) Superheated steam at Larderello; two phase in the limestone reservoir, liquid-dominated deep reservoir (>300 °C) at Mt Amiata
2) Two clearly separated reservoirs at Mt. Amiata
3) Fumaroles at larderello, many CO_2 vents and travertine deposits at Larderello



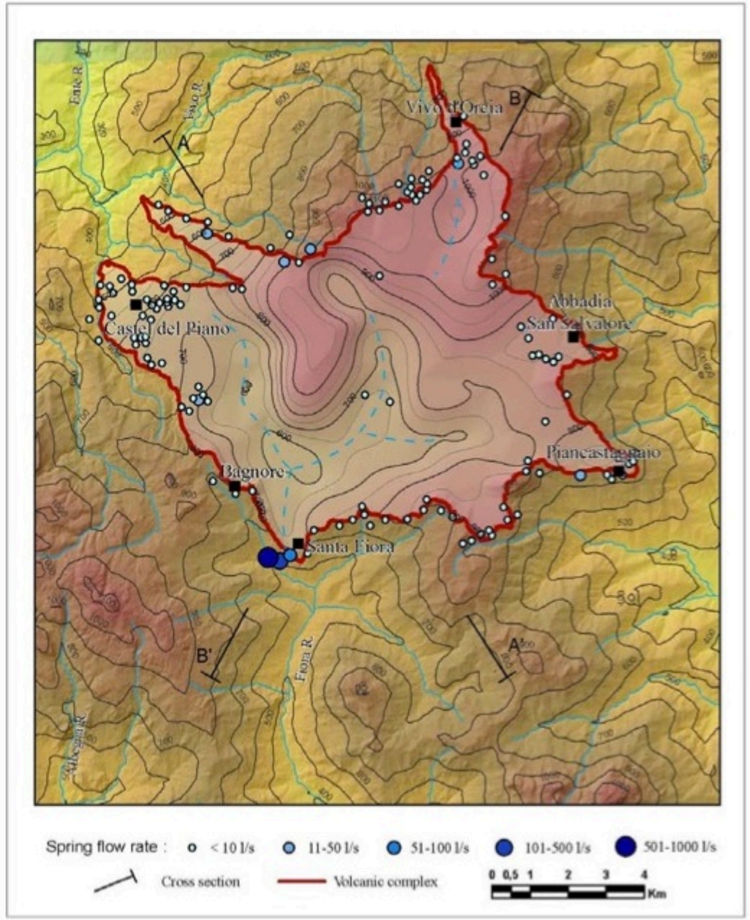


Figure 11: Base of the Vulcanic Complex superimposed on a DEM image.

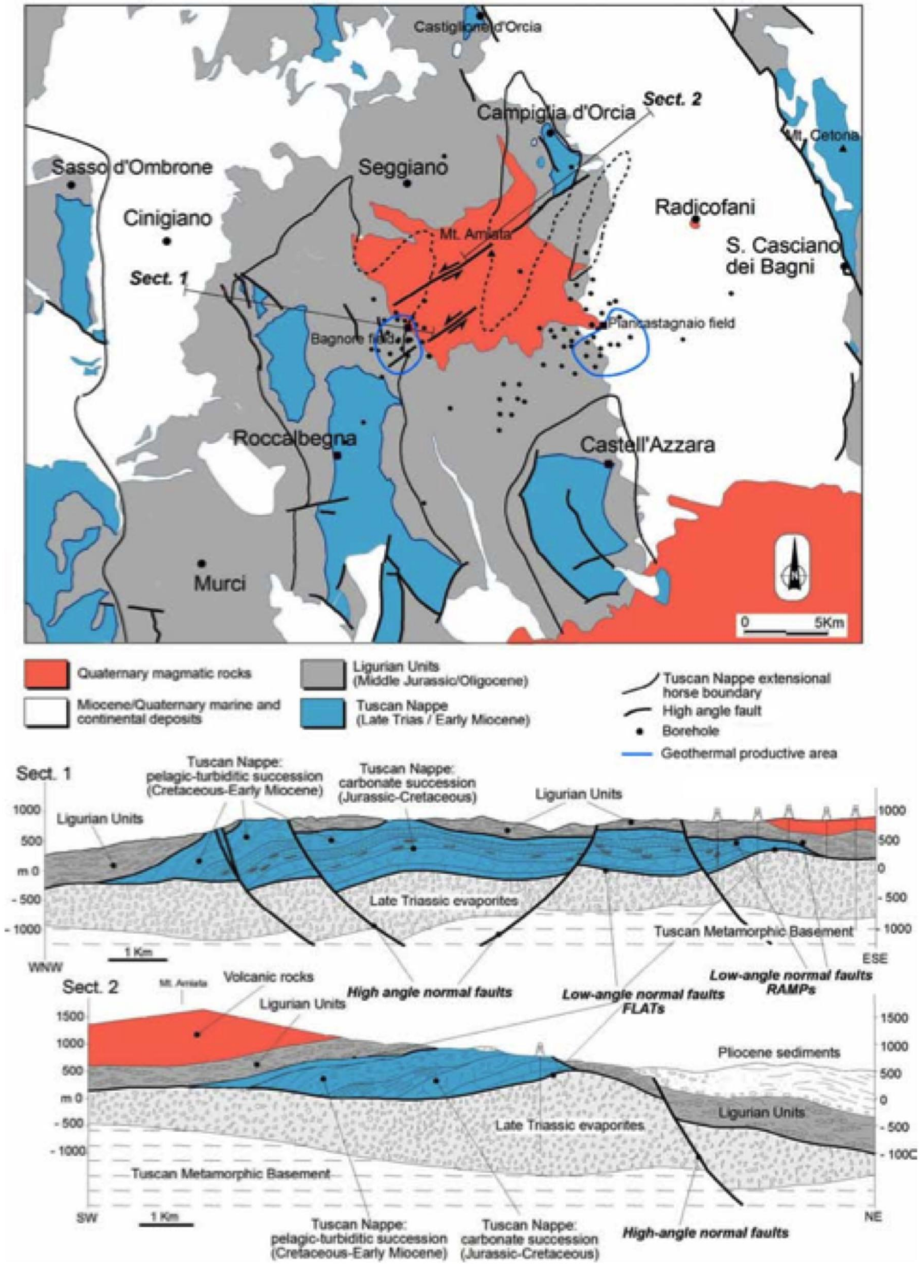
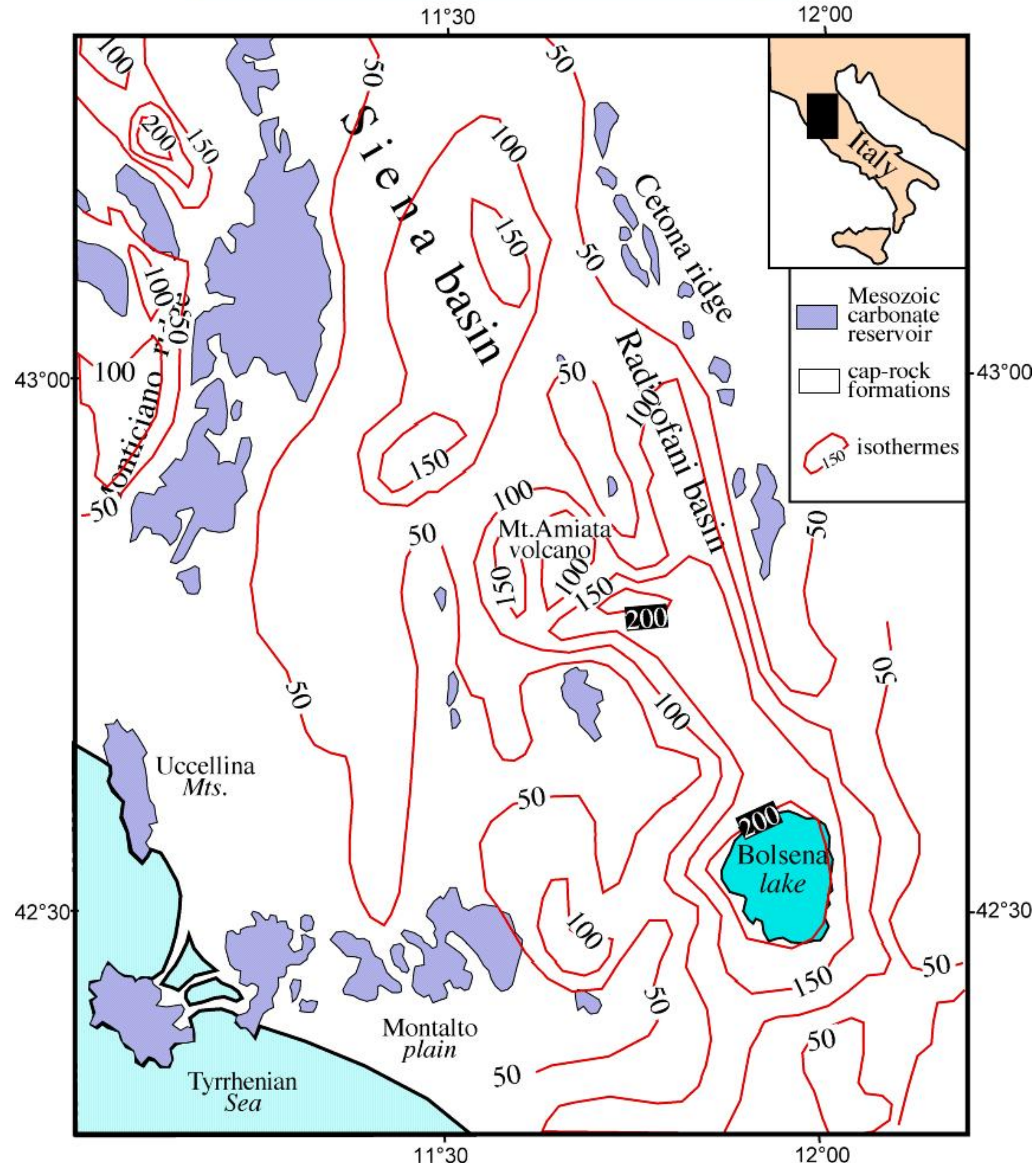


Figure 5: Tuscan Nappe geometry and geological sections across two main Tuscan Nappe geological bodies (from Brogi, 2008, modified).

Estimated temperature at the top of the carbonate formations in the Mt. Amiata region



Hydrology of Mt Amiata

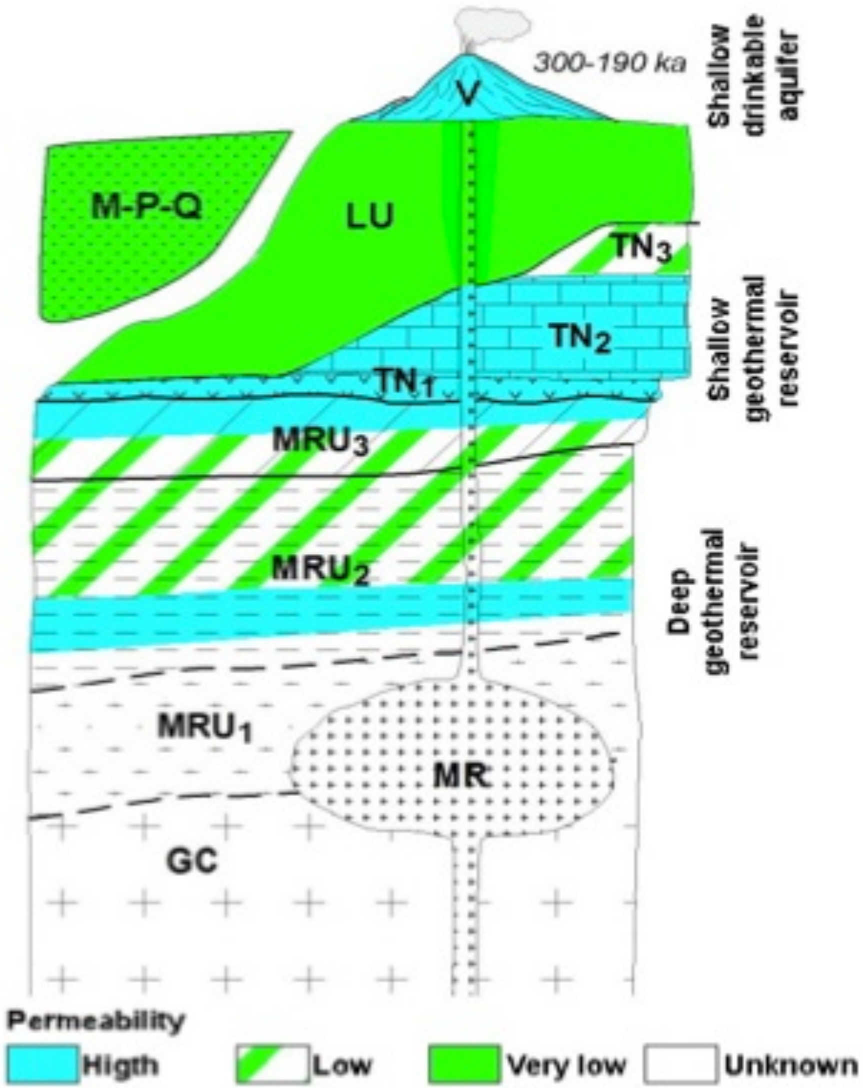
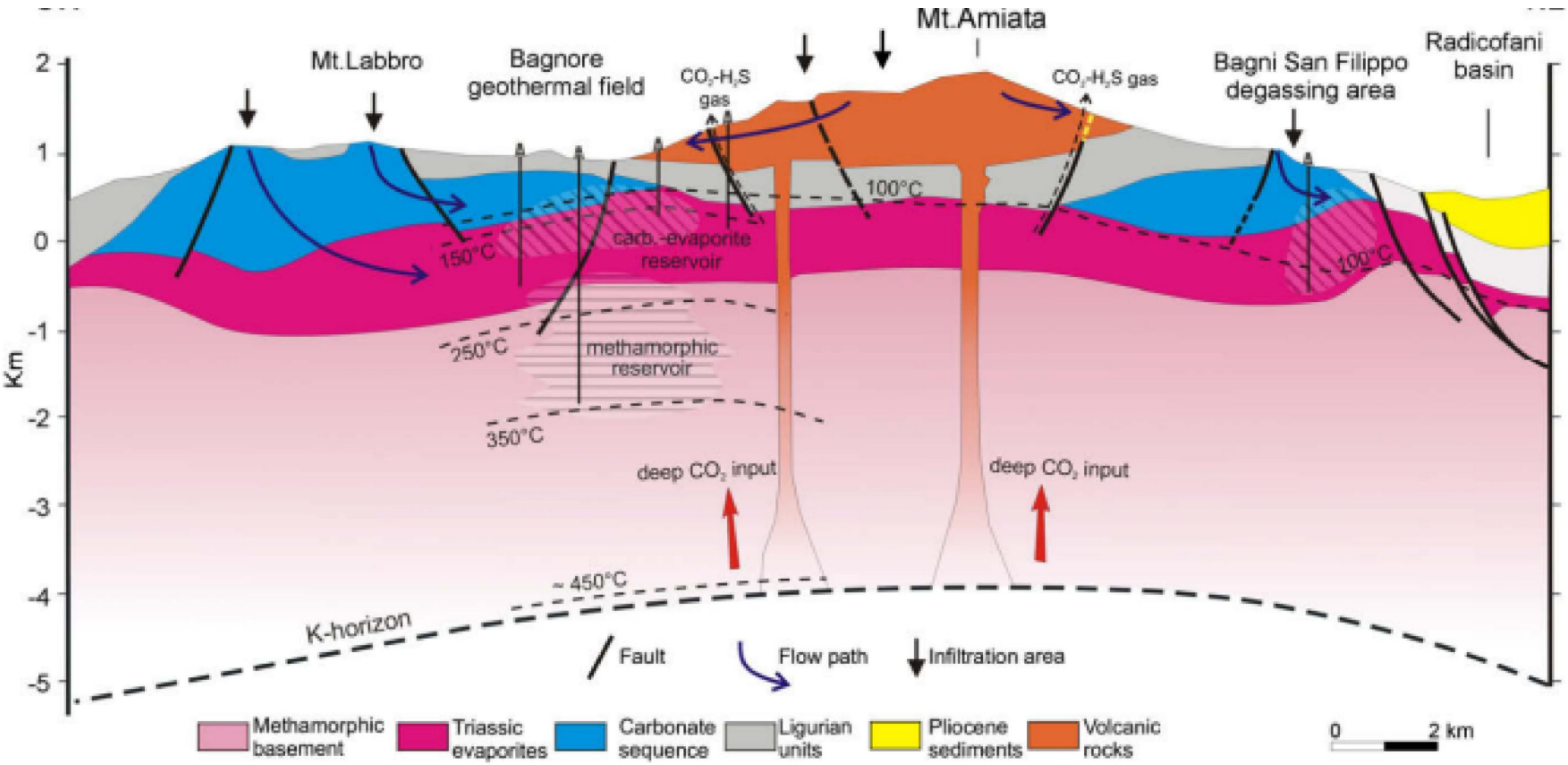


Figure 2: Geologic and hydrogeologic sketch (from Batini et al., 2003, modified).

V=vulcanics
MPQ=Mio-Quaternary sediments
LU=ligurids
TN=carbonate reservoir
MRU2-3=basament
MRU1=micaschists
GC=gneiss
MR=magmatic rocks



Mt.Amiata
Mt.Labbro
Bagnore
geothermal field
CO_2-H_2S
gas
CO_2-H_2S gas
Bagni San Filippo
degassing area
Radicofani
basin
2
1
0
-1
-2
-3
-4
-5
Km
100°C
150°C
carb.-evaporite
reservoir
100°C
250°C
methamorphic
reservoir
350°C
deep CO_2 input
deep CO_2 input
~ 450°C
K-horizon
Fault
Flow path
Infiltration area
Methamorphic
basement
Triassic
evaporites
Carbonate
sequence
Ligurian
units
Pliocene
sediments
Volcanic
rocks
0
2 km

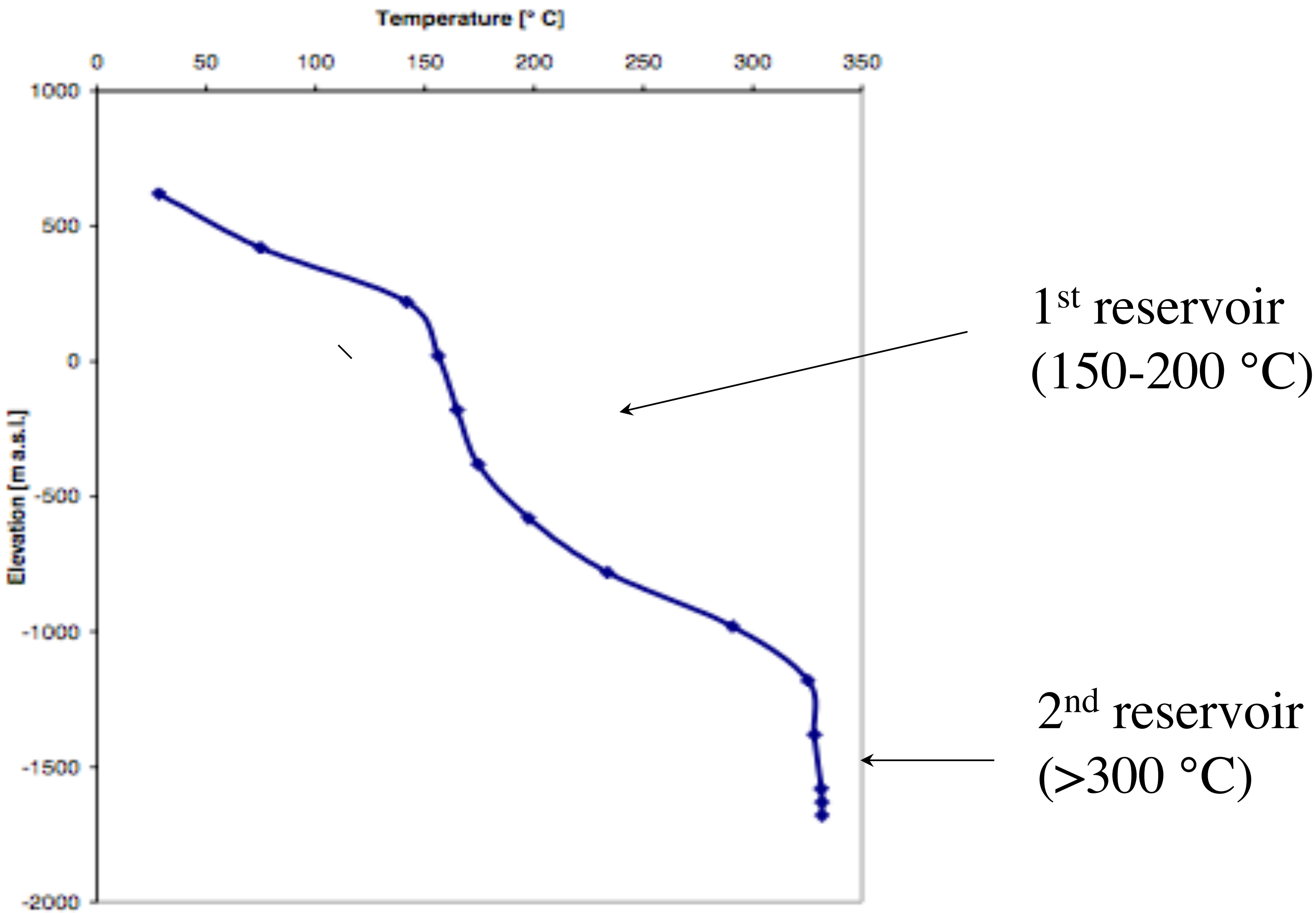


Figure 5: Typical temperature vs. elevation log in a geothermal well of the Mt. Amiata system.

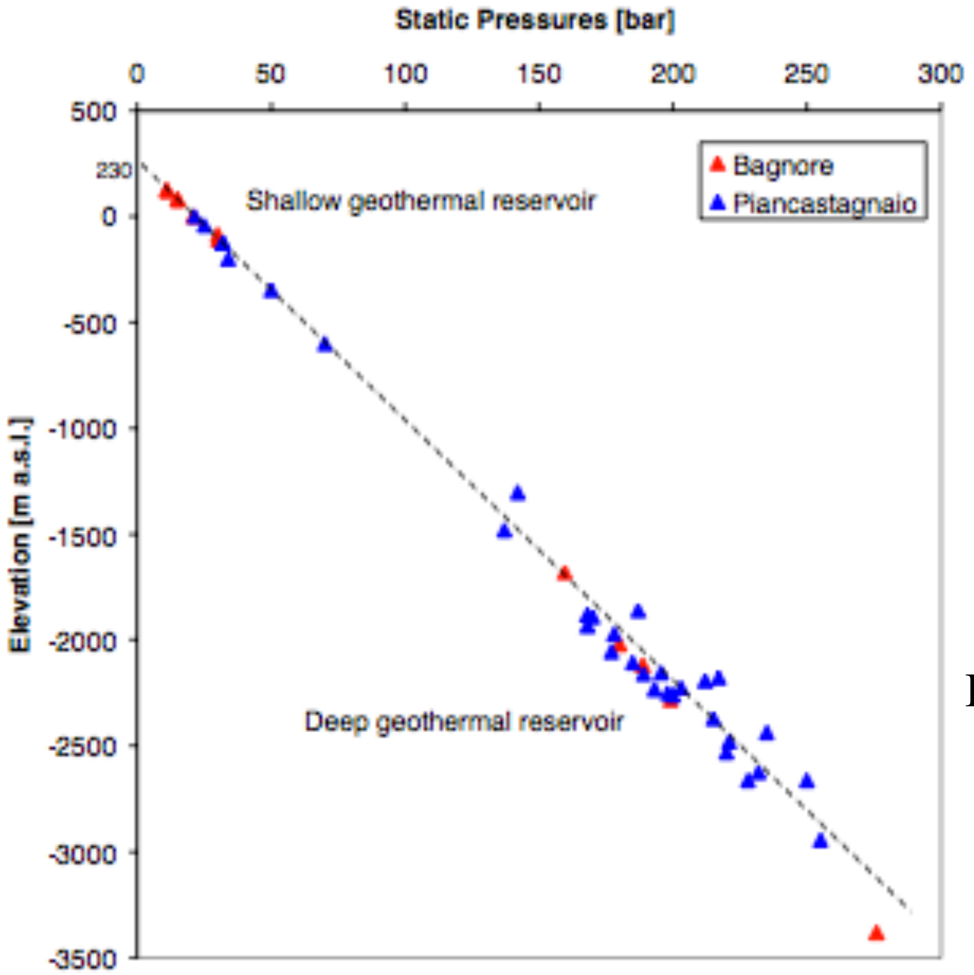


Figure 4: Static pressures vs. elevation in the Mt. Amiata geothermal system.

Whereas at Larderello fluids
are forced to move into the reservoir
Because of the low pressure of the system,
At Mt. Amiata there is a hydrostatica”

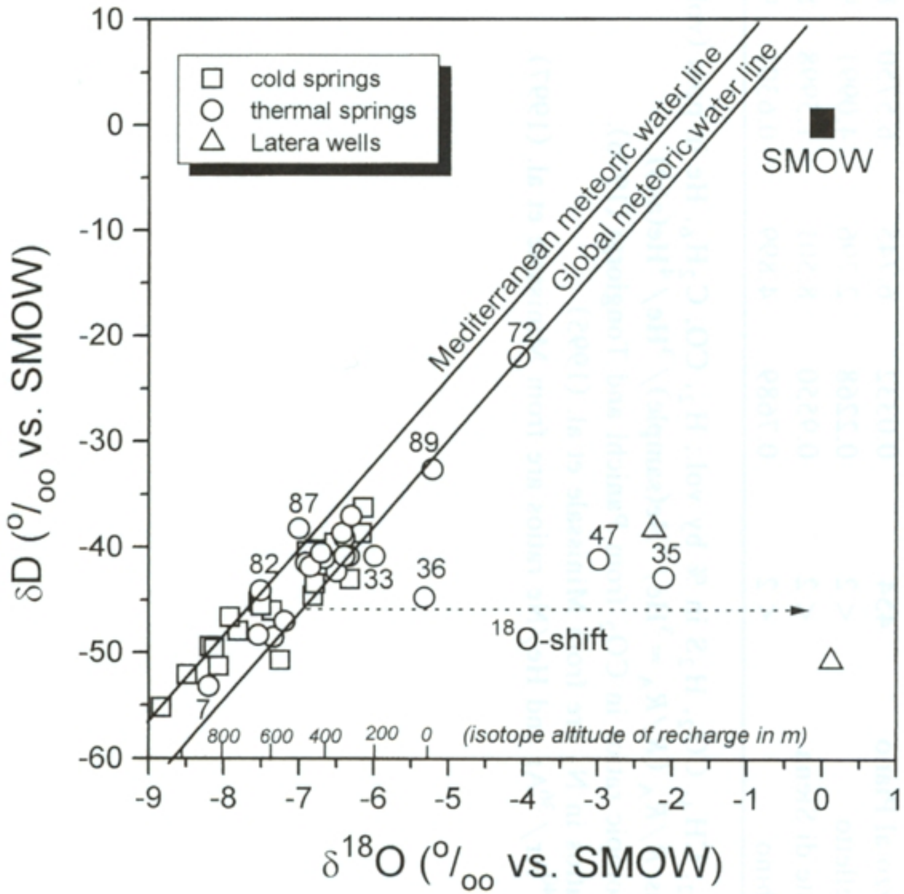
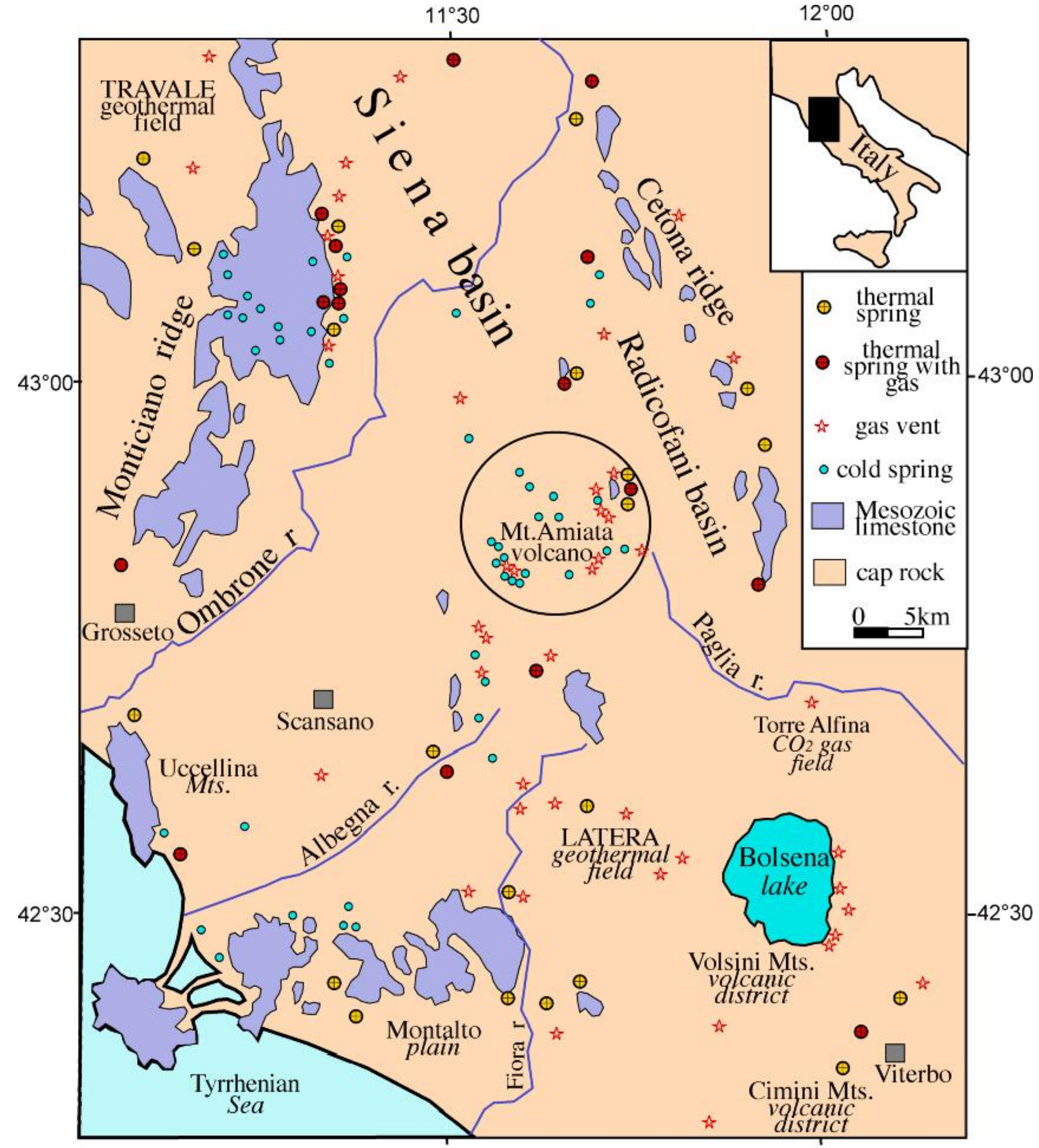
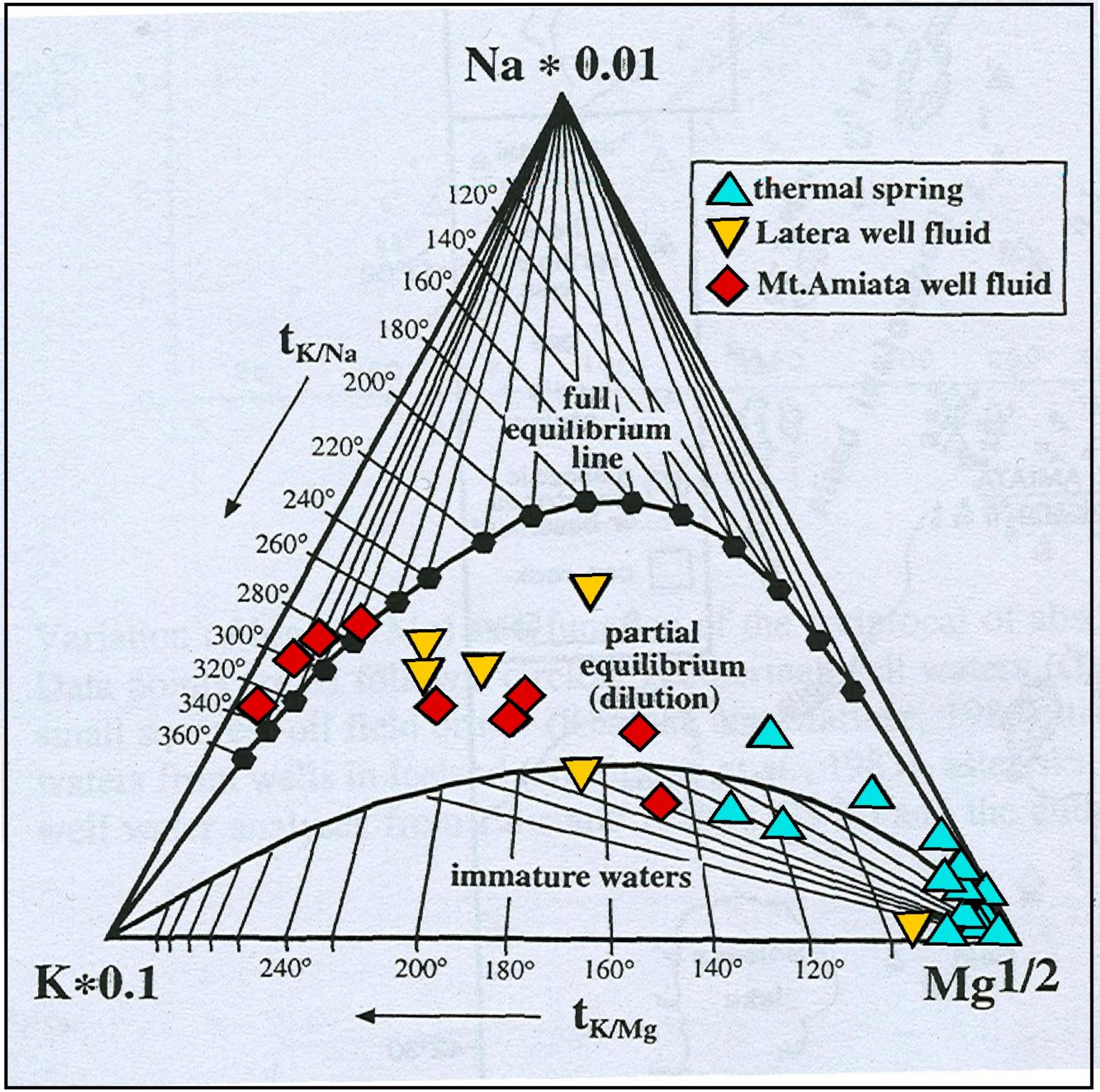


Fig. 9. $\delta^{18}O$ vs. δD diagram for some of the thermal and cold springs analysed. Isotopic values from the two Latera geothermal wells are from Battaglia et al. (1992).

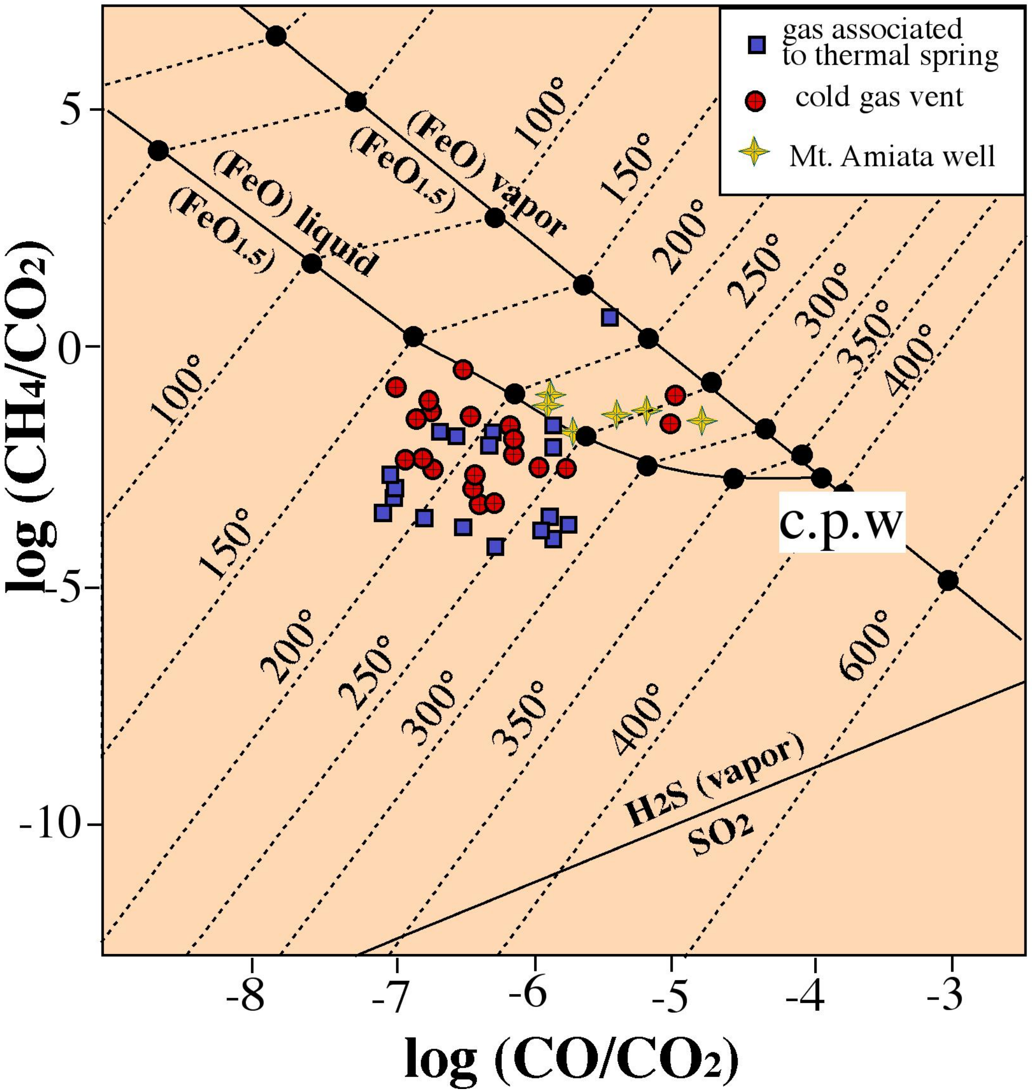
Meteoric recharge of the system


11°30
12°00
43°00
42°30
TRAVALE
geothermal
field
Siena basin
Cetona ridge
Radicofani basin
Monticiano ridge
Italy
thermal spring
thermal spring with gas
gas vent
cold spring
Mesozoic limestone
cap rock
0
5km
Mt.Amiata
volcano
Ombrone r.
Grosseto
Paglia r.
Torre Alfina
CO2 gas
field
Scansano
Uccellina
Mts.
Albegna r.
LATERA
geothermal
field
Bolsena
lake
Volsini Mts.
volcanic
district
Montalto
plain
Fiora r.
Tyrrhenian
Sea
Viterbo
Cimini Mts.
volcanic
district



Chemical relations between springs and wells

geothermometry in the gas phase



Chemical relations between springs and geothermal wells

$CH_4 + 2H_2O \Longleftarrow\Longrightarrow CO_2 + 3H_2$

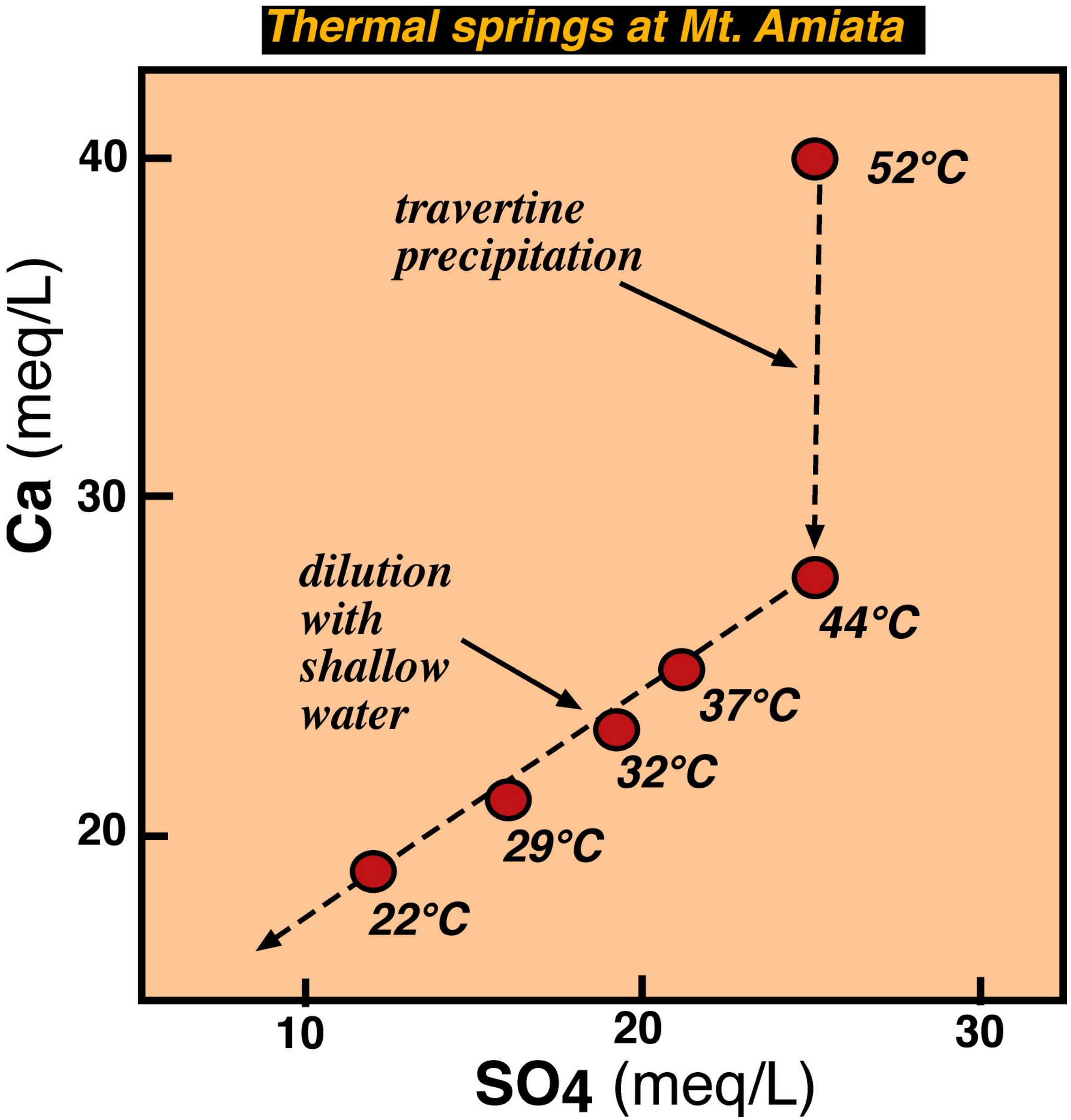
$CO + 0{,}5O_2 \Longleftarrow\Longrightarrow CO_2$

$FeO + 0.25\ O_2 \Longleftarrow\Longrightarrow FeO_{1.5} + 0.25\ e^-$

$H_2S + 2H_2O \Longleftarrow\Longrightarrow SO_2 + 6H + 6e^-$

Fosso bianco
Bagni S. Filippo

$Ca^{++} + 2HCO_3^{-} \text{-->}$
$CaCO_3 + CO_2 + H_2O$



If this process occurs underground the CO_2 split from solutions and this is the reason for the many CO_2 emissions at Mt. Amiata

Problemi aperti all’Amiata:

1) Interazione acquiferi superficiali/profondi: QUASI IMPOSSIBILE

2) L’alimentazione dei sistemi, sempre meteorica, è QUASI IMPOSSIBILE avvenga sulla verticale (self sealing)

3) A riprova di 1 e 2 c’è il fatto che nelle sorgenti termali c’è poco ammonio e poco boro

3) Hg, Sb, CO_2, NH_4, B, Rn…etc: in ambienti termalmente anomali sono molto mobili (meglio non mangiare i funghi delle aree minerarie e delle discariche)

4) L’inquinamento da mercurio forse è un problema più grave di quello generato dallo sfruttamento dell’energia geotermica