Isotopes in geothermal prospecting: introduction

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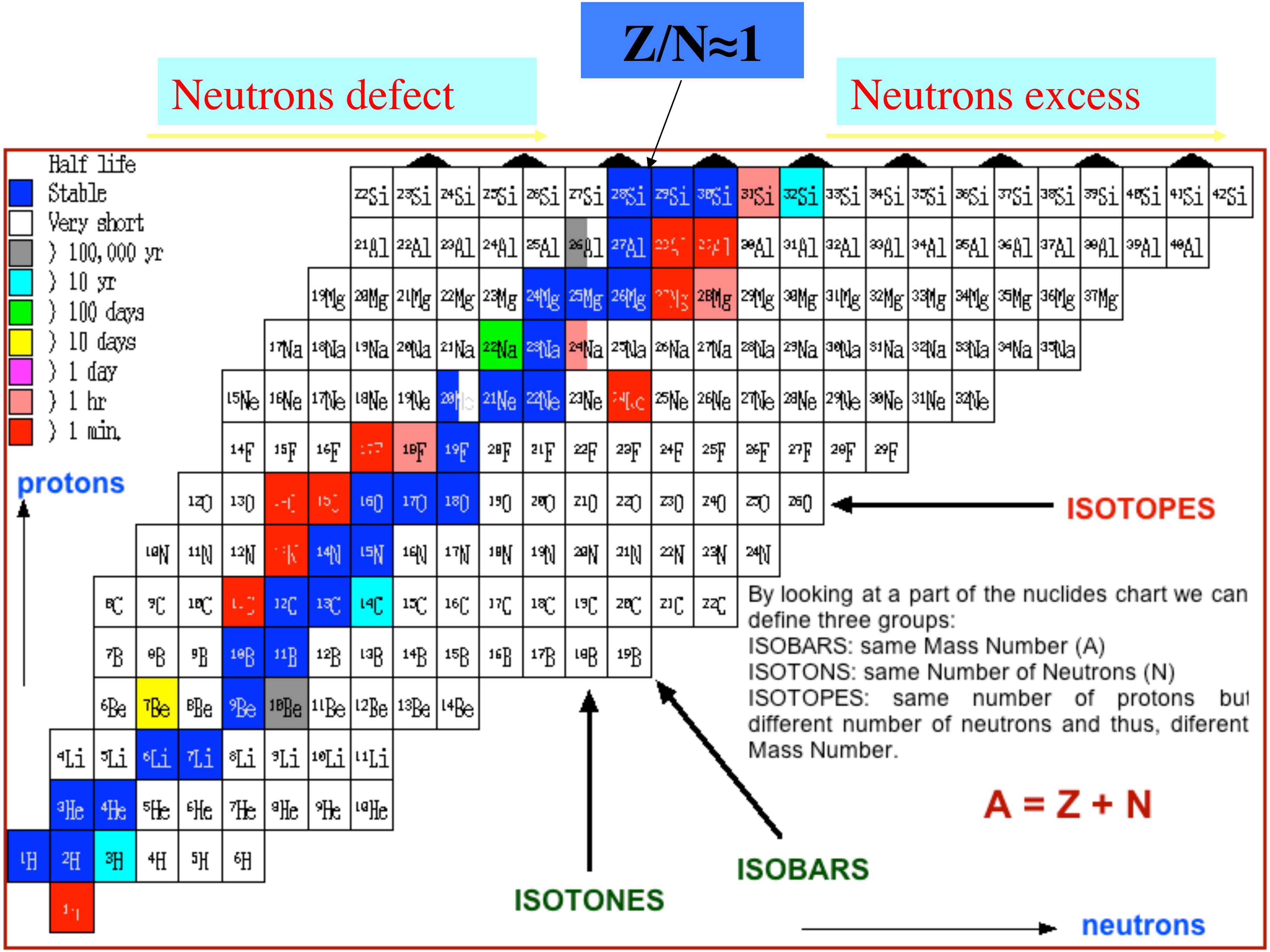


By looking at a part of the nuclides chart we can define three groups:

ISOBARS: same Mass Number (A)

ISOTONS: same Number of Neutrons (N)

ISOTOPES: same number of protons but different number of neutrons and thus, diferent Mass Number.

Some elements have both stable and radiogenic isotopes

i.e. for carbon: ^{12}C, ^{13}C, ^{14}C (unstable)

The elements involved in chemical reactions and/or physical processes "fractionate" isotopes.

e.g., in water boiling, ^{18}O will tend to stay in the liquid,
^{16}O will tend to move in the steam

The most used isotopic ratios in geothermics are:

$^{18}O/^{16}O$ and $^{2}H/H$ (for the origin of waters)

$^{3}H/H$ (for the age of geothermal fluids)

$^{13}C/^{12}C$ in CO_2 (for the origin of CO_2 and travertine)

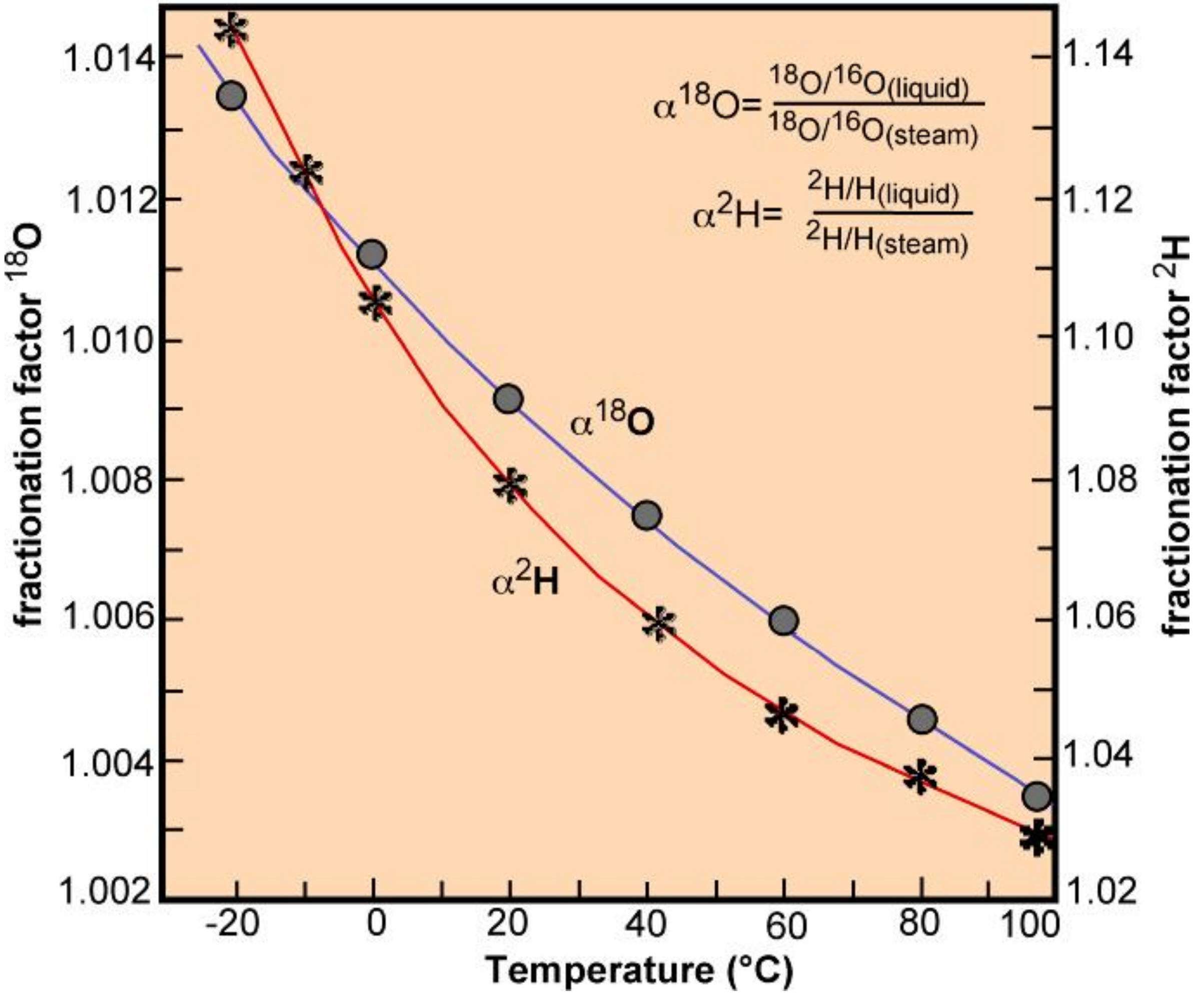
$^{13}C/^{12}C$ in CH_4 (for the origin of CH4 and geothermometry)

$^{3}He/^{4}He$ (for the very deep origin of the gas phase)

$^{15}N/^{14}N$ (for the origin of nitrogen)

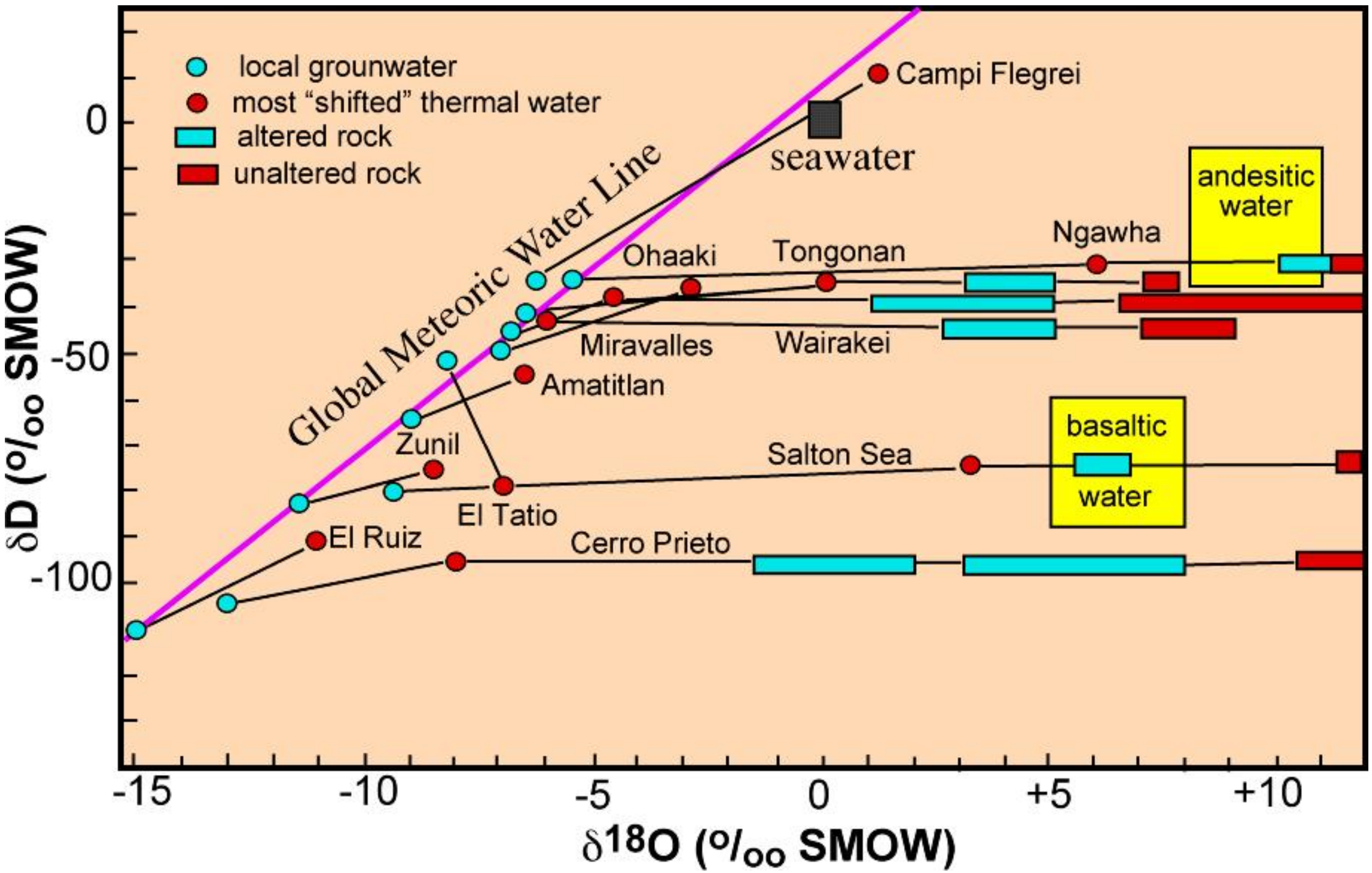
$^{35}S/^{34}S$ in H_2S, SO_4 (for the origin of sulfur)

fractionation factor for evaporation

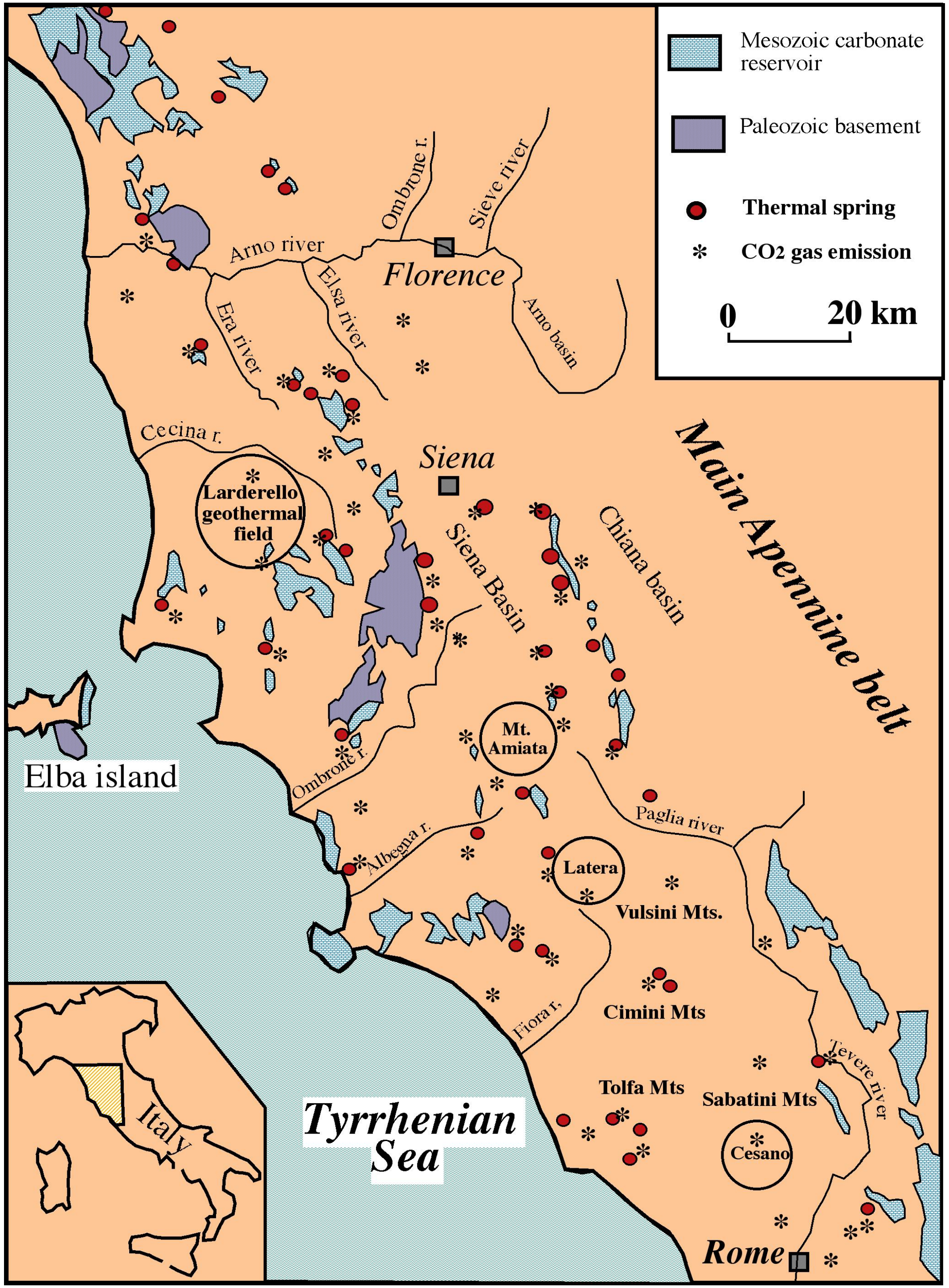


The fractionation factor is strongly dependent upon temperature

$\delta^{18}O$ in primary rocks, altered rocks and geothermal fluids (age of the system)

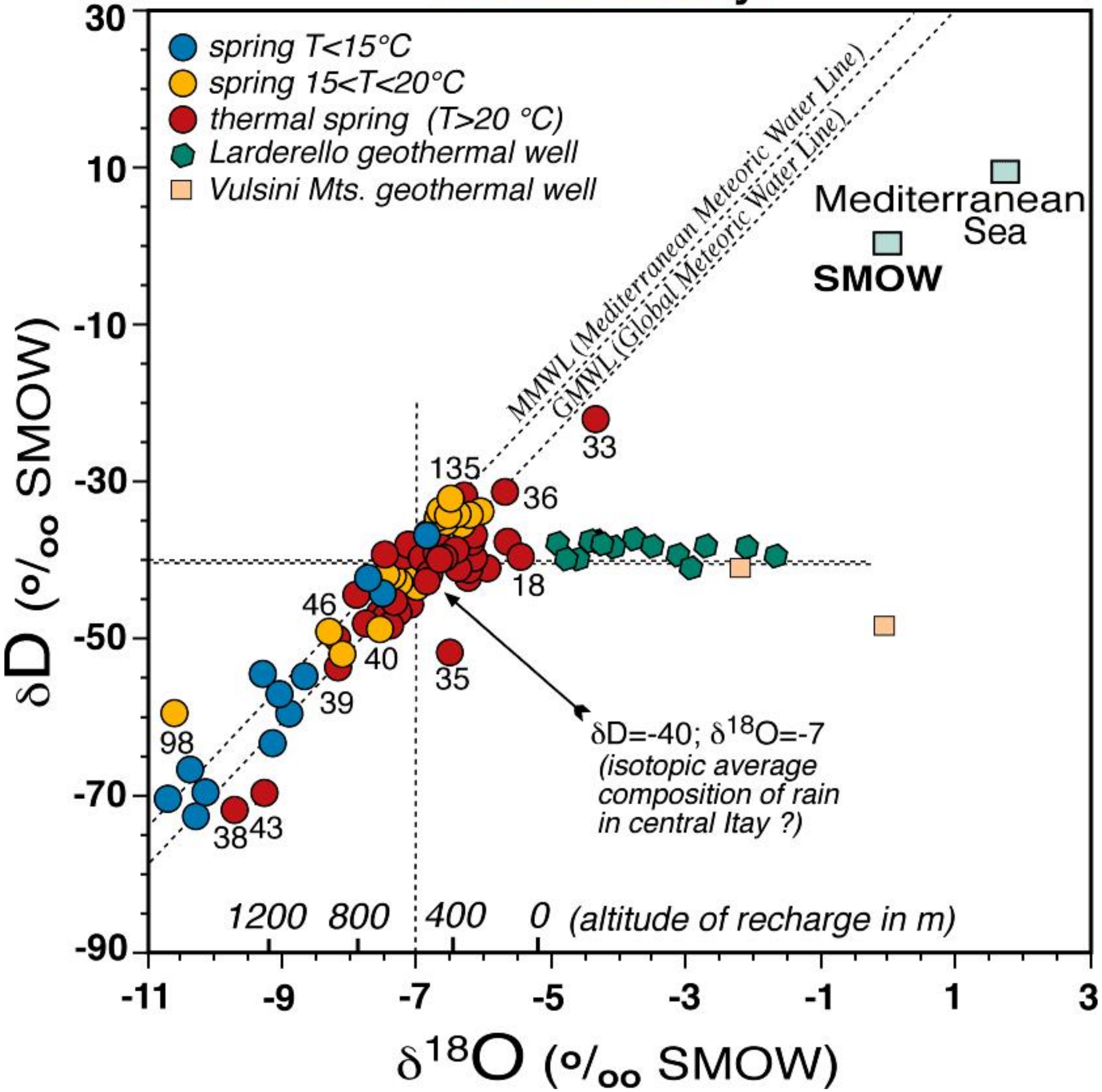


GMWL affected by 1) Altitude, 2) Latitude and 3) continental EFFECTS

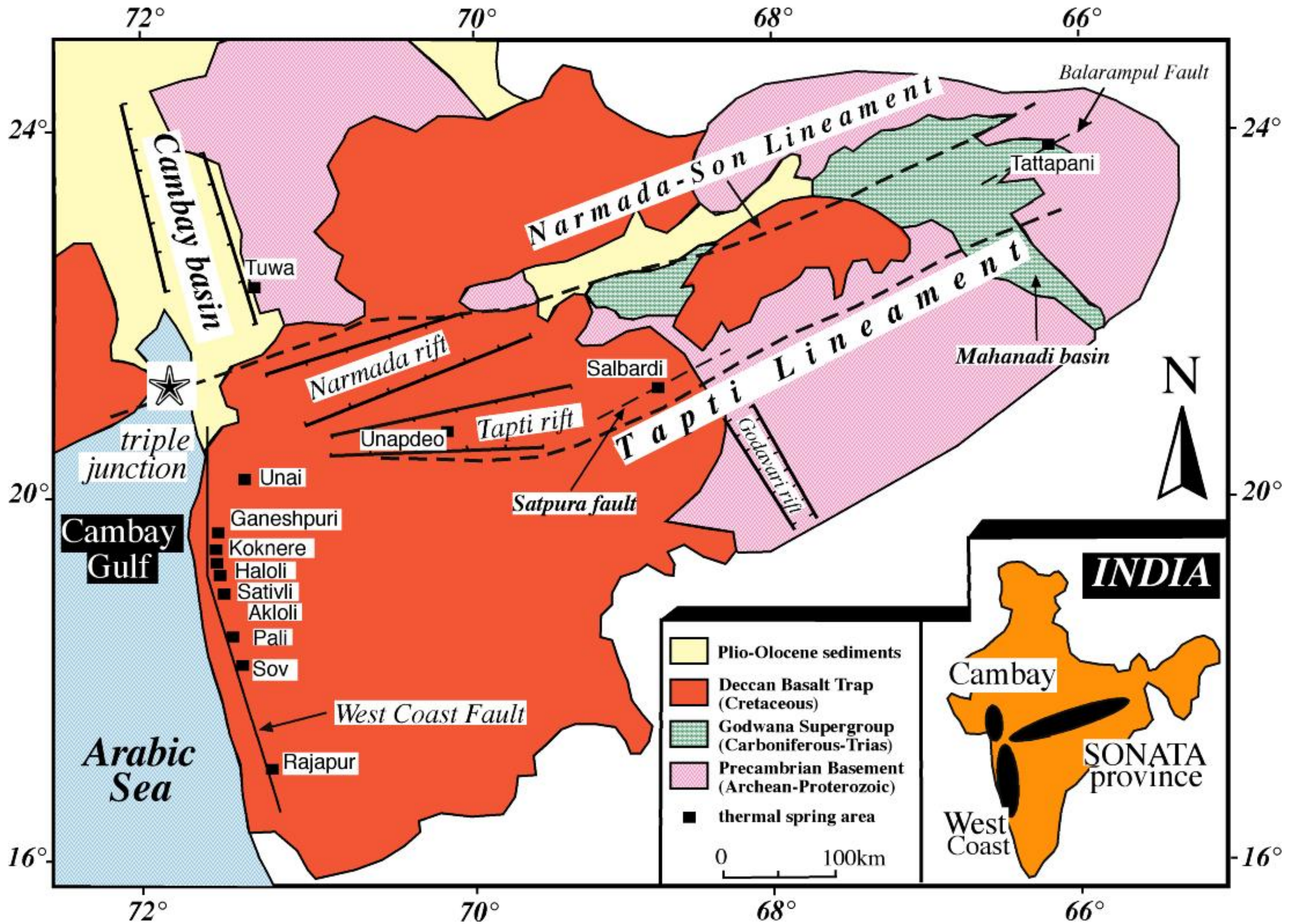


$\delta^{18}O$ and $\delta^{2}H$ in central Italy

central Italy

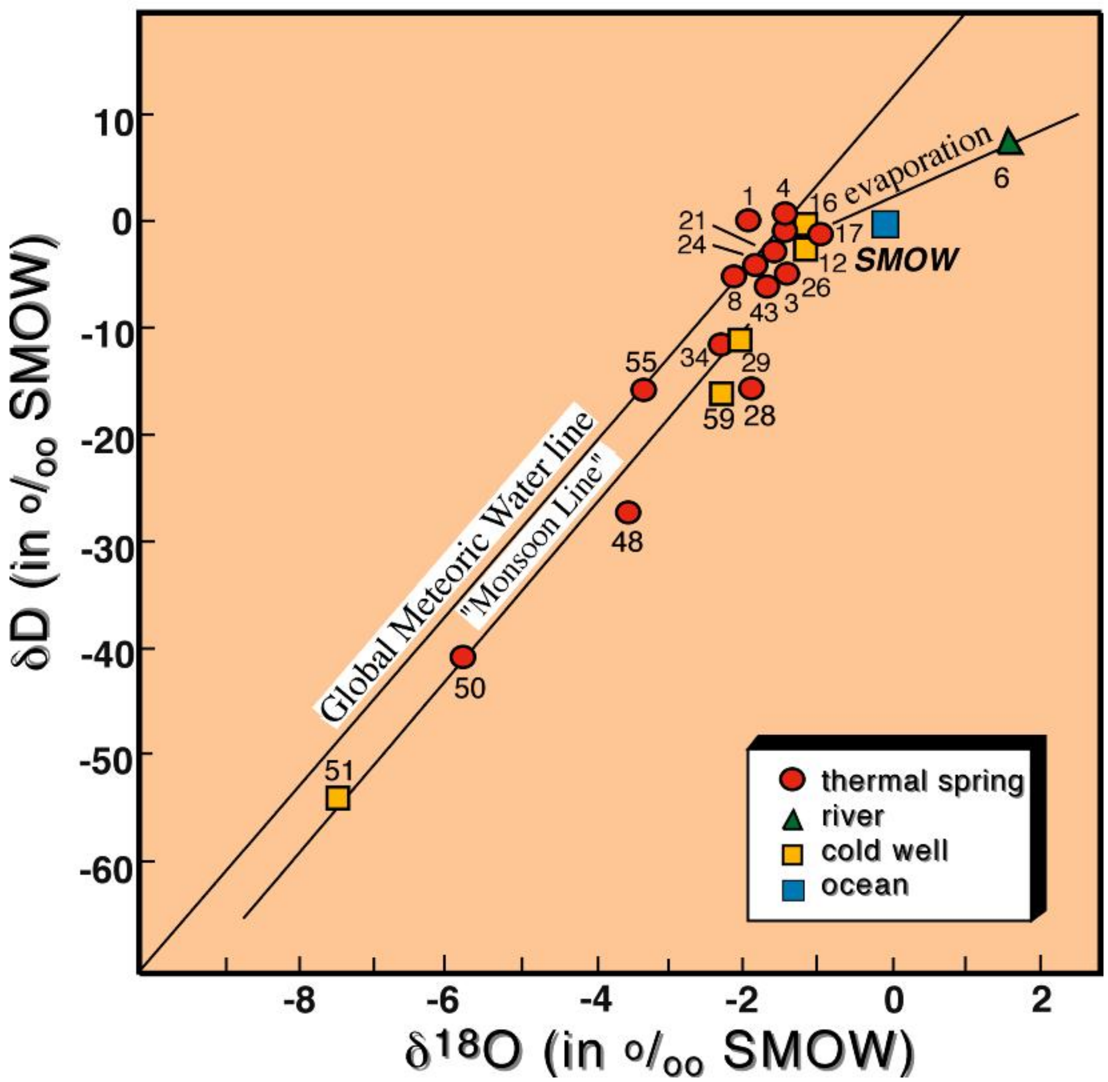


springs and geothermal fluids in central Italy

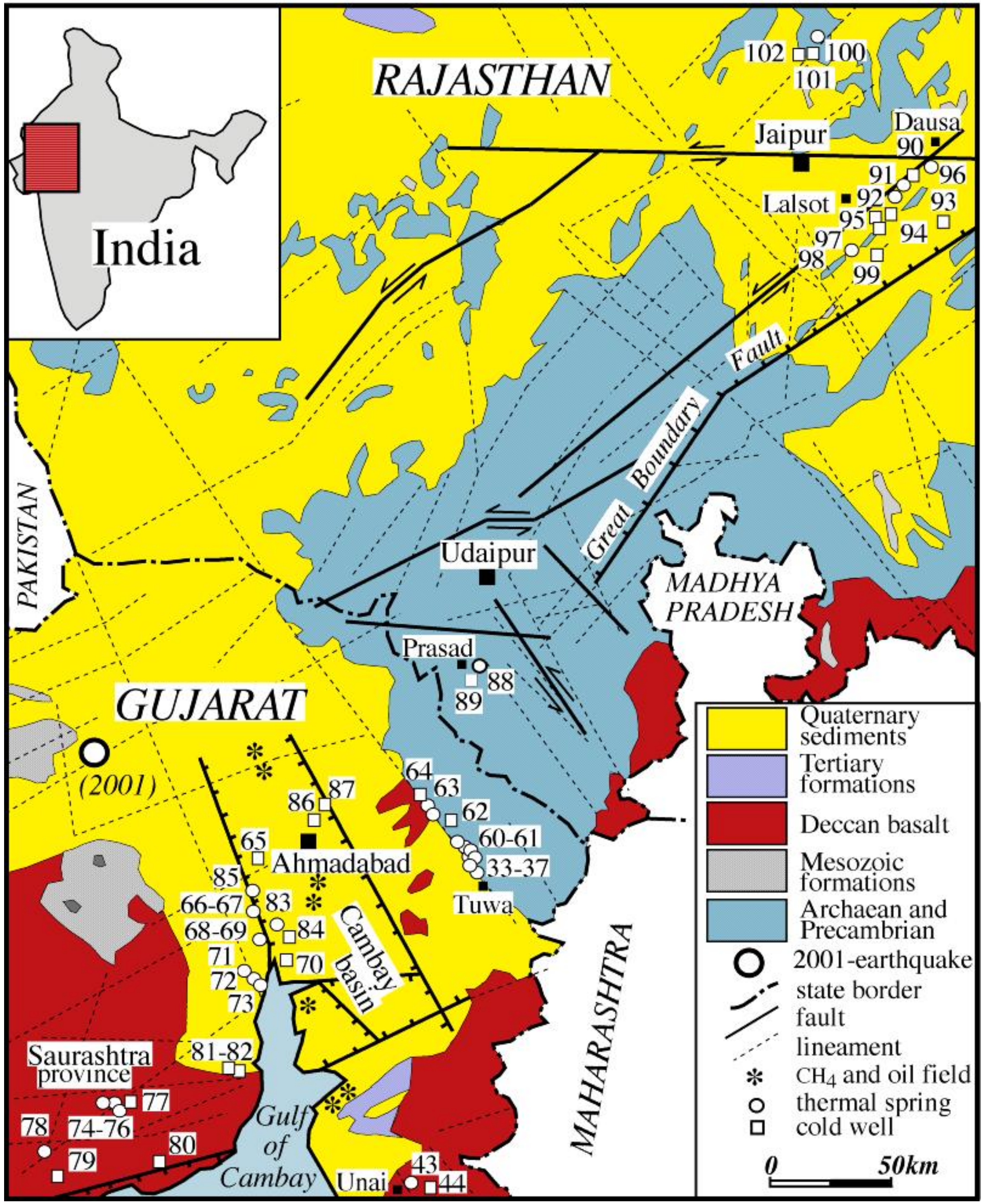


72°
70°
68°
66°
24°
20°
16°
Cambay basin
Tuwa
Narmada-Son Lineament
Balarampul Fault
Tattapani
Tapti Lineament
Mahanadi basin
N
Narmada rift
Tapti rift
Salbardi
Unapdeo
Satpura fault
Godavari rift
triple junction
Cambay Gulf
Unai
Ganeshpuri
Koknere
Haloli
Sativli
Akloli
Pali
Sov
West Coast Fault
Rajapur
Arabic Sea
Plio-Olocene sediments
Deccan Basalt Trap (Cretaceous)
Godwana Supergroup (Carboniferous-Trias)
Precambrian Basement (Archean-Proterozoic)
thermal spring area
0
100km
INDIA
Cambay
SONATA province
West Coast

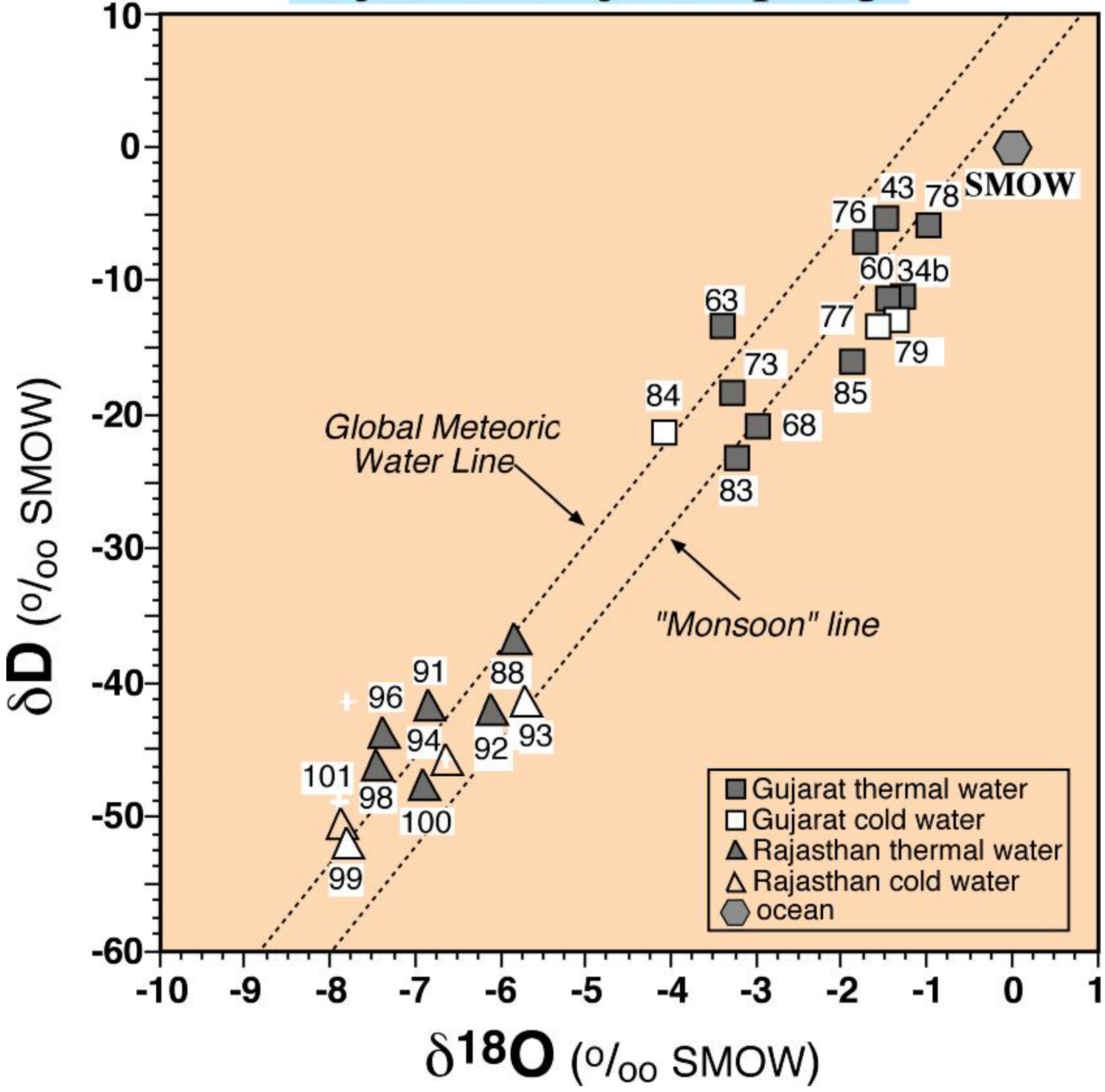
Peninsular India

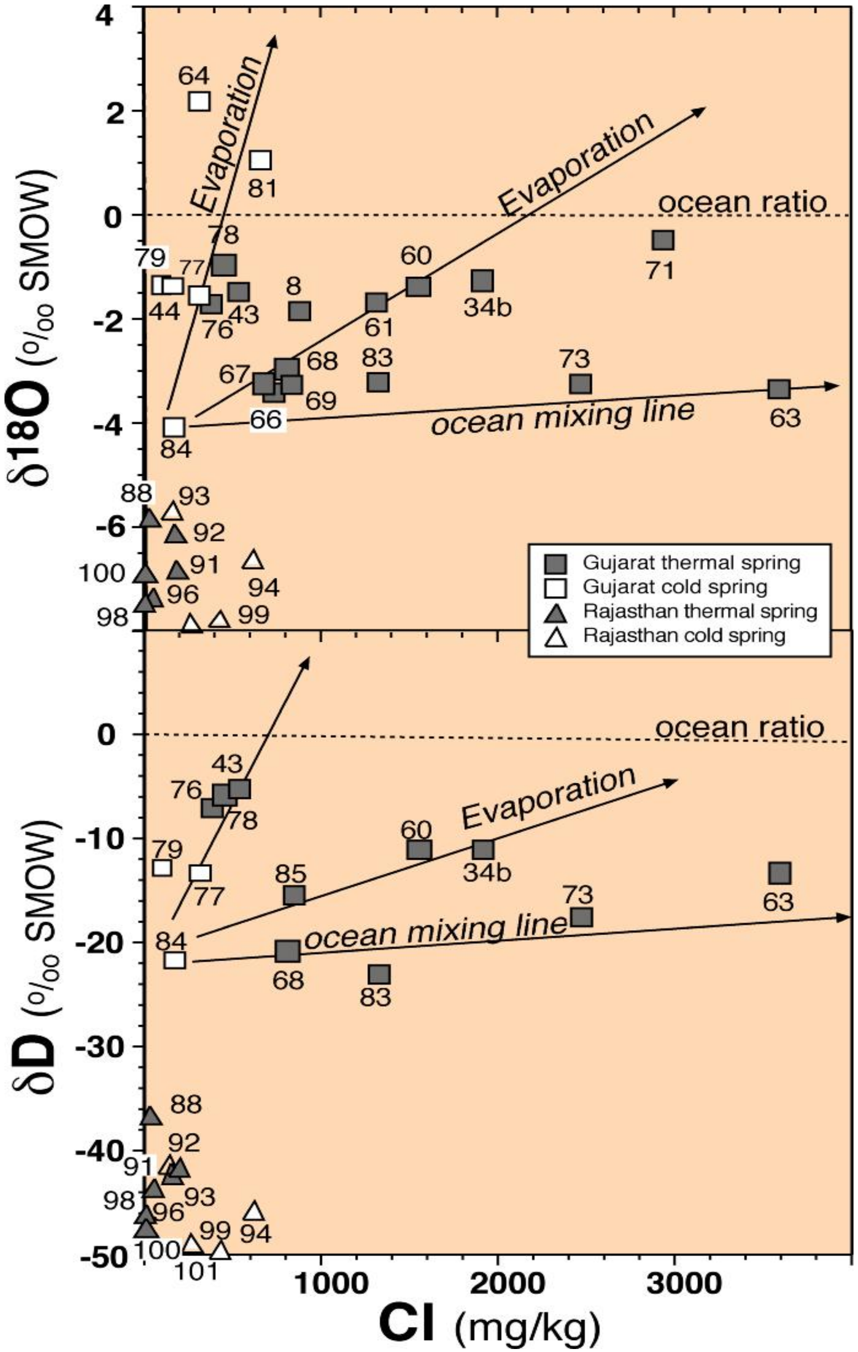


Geological map of Rajastan & Gujarat

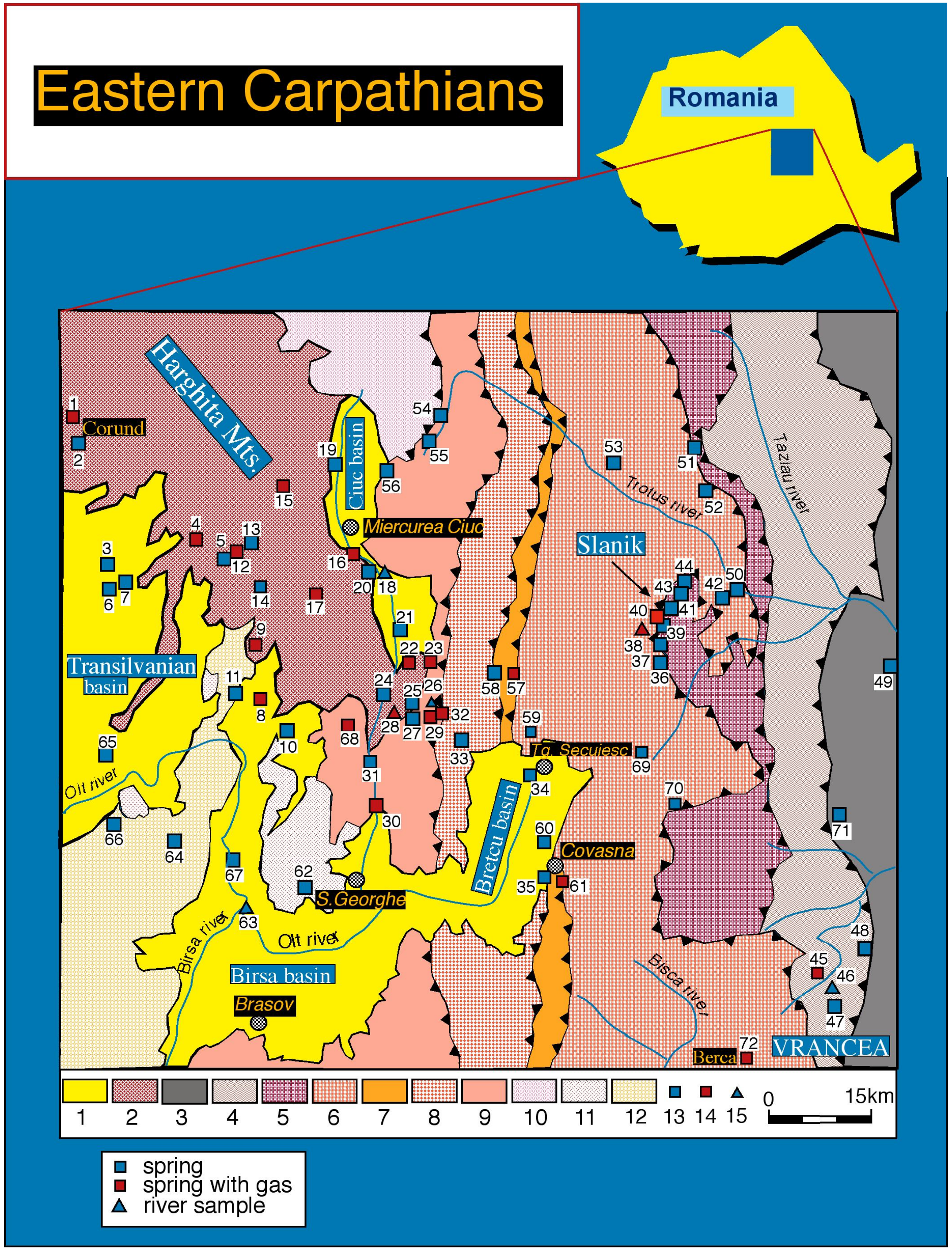


Rajastan-Gujarat springs

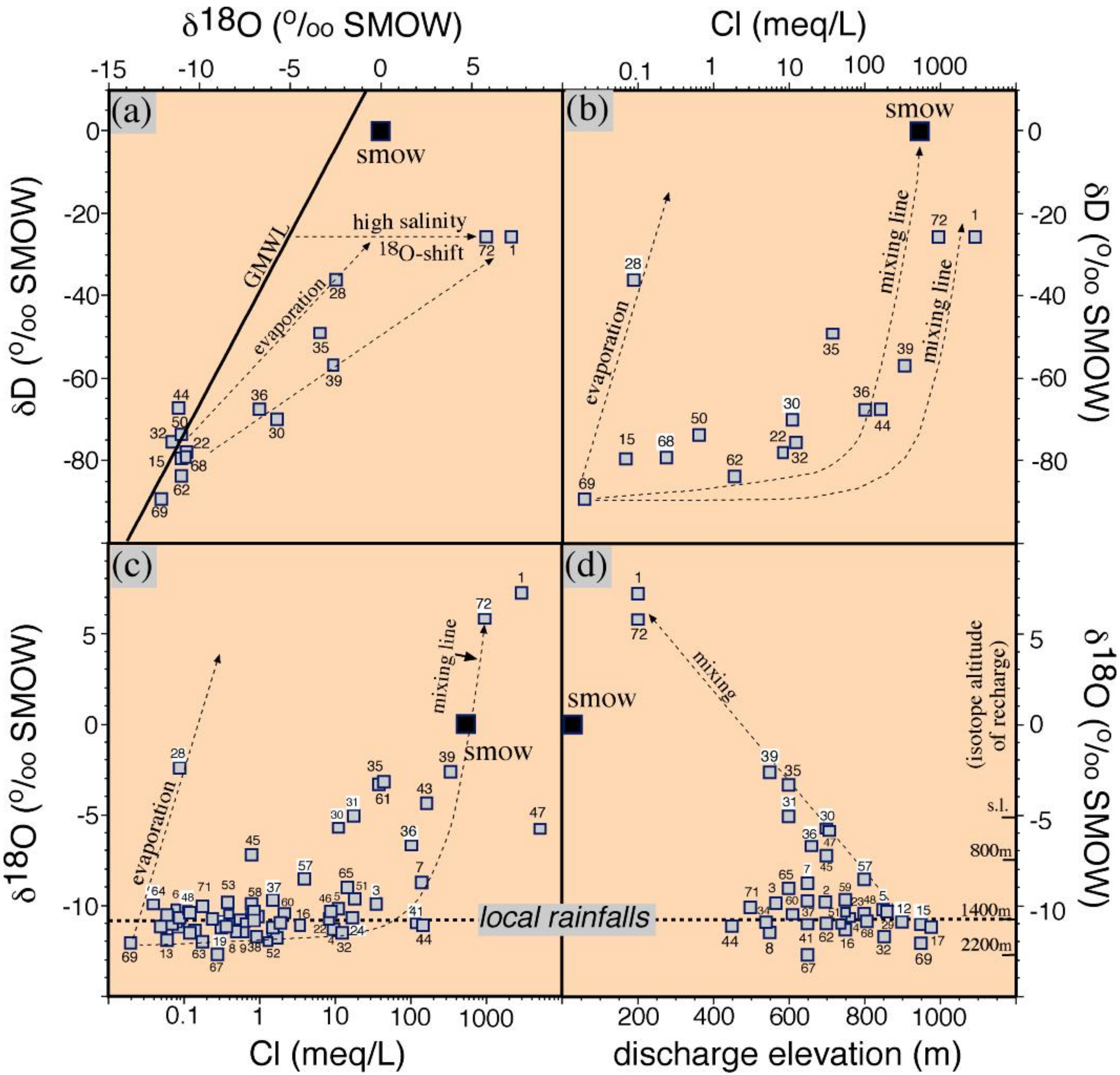




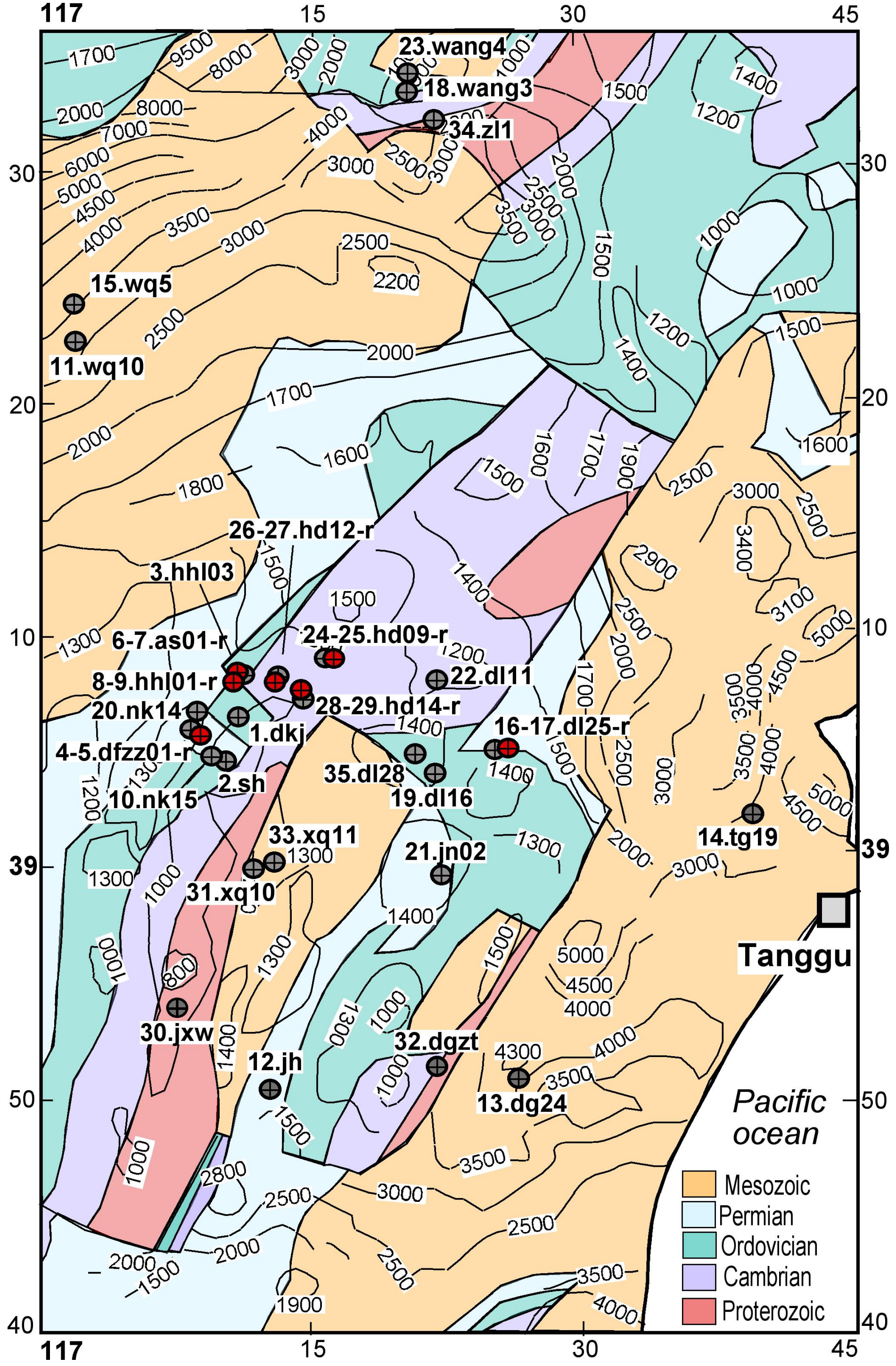
Mixing trends in Rajastan and Gujarat (India) springs



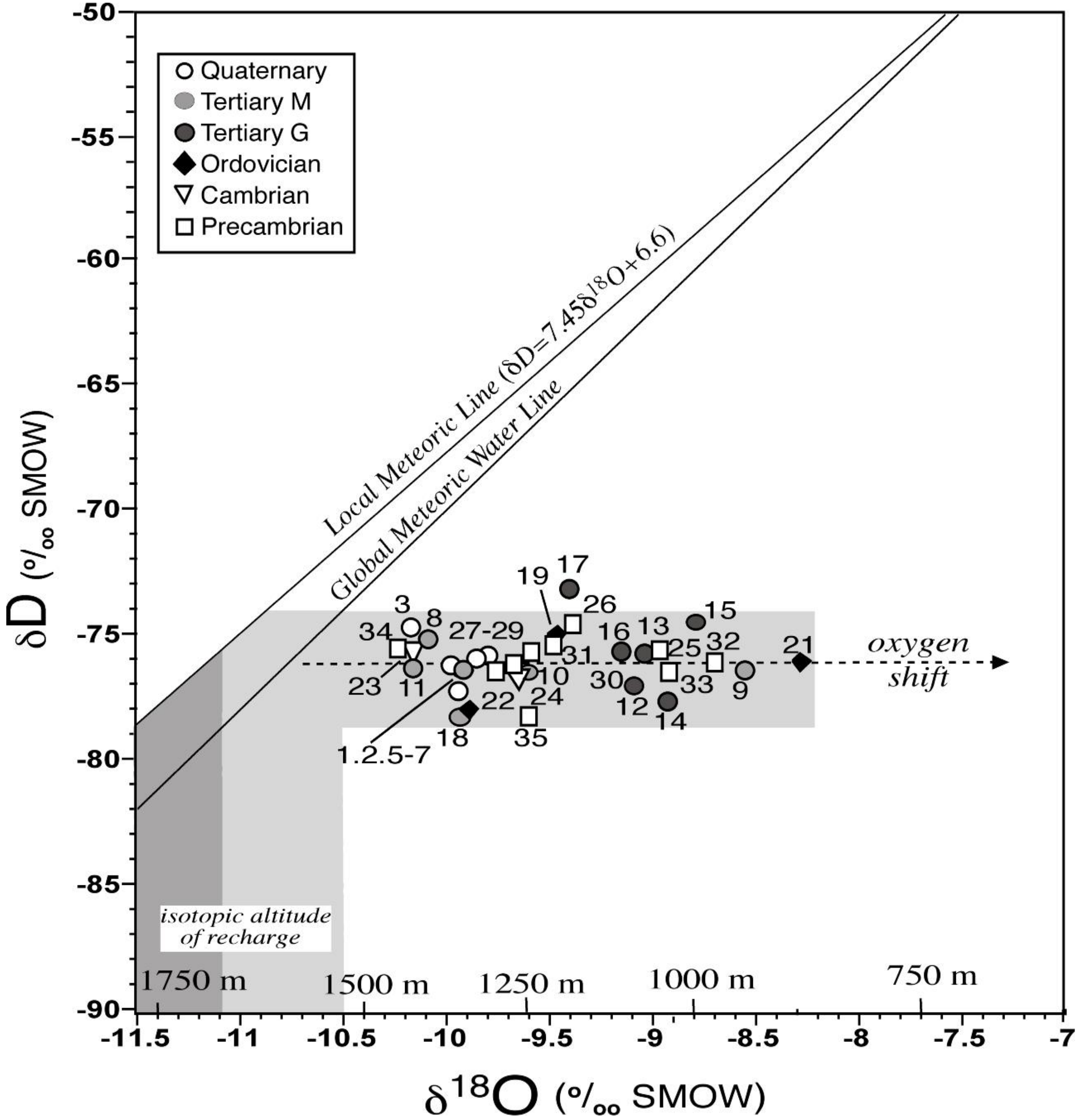
springs and CO_2 vents
In the Carpathian Range



water isotopes in the Carpathian Range (Romania)



Tianjin geothermal area (150 km W of Beijing on the Pacific coast)



well waters (50-100 °C)
from the Tianjin
geothermal field
(150 km E of Bejing)

General remarks on isotope geothermometry

CO_2, CH_4, H_2 and H_2O are always present in a geothermal system

relative distribution of isotopes between components is a function of temperature

any pair of compounds may constitute an isotopic geothermometer if equilibrium is attained in the reservoir

$$^{12}CO_2 + {}^{13}CH_4 = {}^{13}CO_2 + {}^{12}CH_4$$

$$CH_3D + H_2O = CH_4 + HDO$$

$$HD + CH_4 = H_2 + CH_3D$$

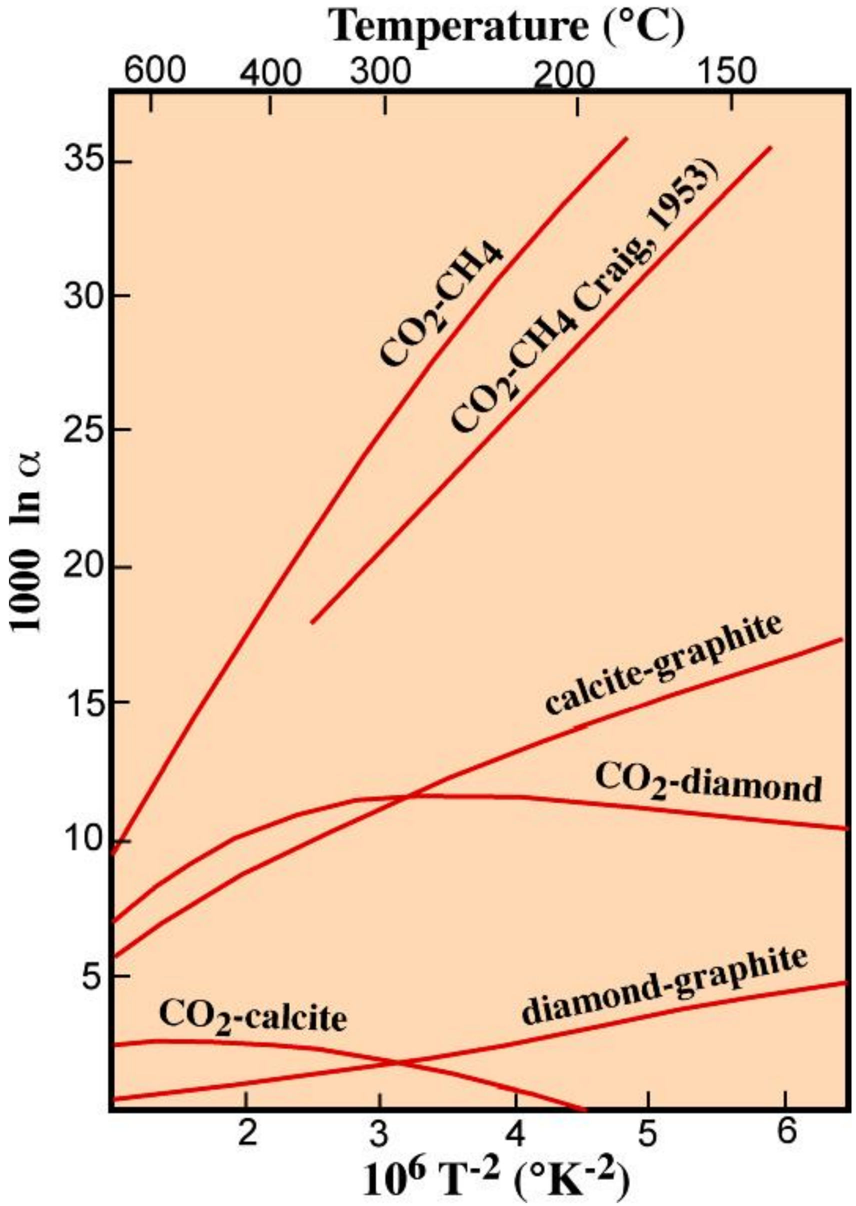
$$HD + H_2O = H_2 + HDO$$

$$C^{16}O_2 + H_2{}^{18}O = C^{16}O^{18}O + H_2{}^{16}O$$

$$S^{16}O_4{}^{2-} + H_2{}^{18}O = S^{16}O_3{}^{18}O^{2-} + H_2{}^{16}O$$

$$^{32}SO_4{}^{2-} + H_2{}^{34}S = {}^{34}SO_4{}^{2-} + H_2{}^{32}S$$

calculated isotopic fractionation factors for $^{13}C/^{12}C$ in the system calcite-CO_2-diamond-graphite-CH_4



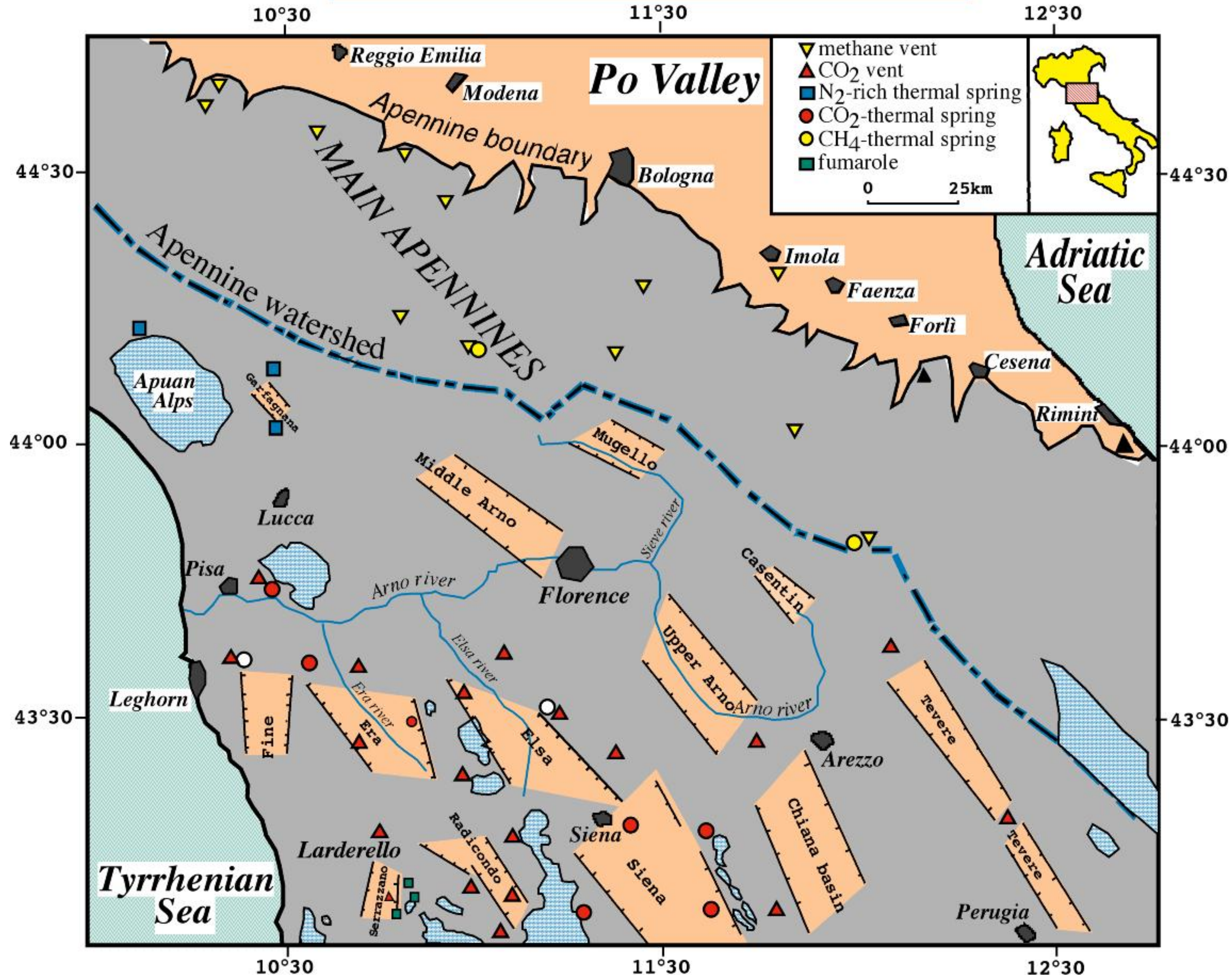
CO_2-CH_4 isotopic geothermometer

$$\boxed{{}^{13}CH_4 + {}^{12}CO_2 = {}^{13}CO_2 + {}^{12}CH_4}$$

$$T(°C) = -173 + (15790 / (1000 \ln\alpha + 9))$$

$$\alpha = \frac{\text{isotopic ratio in component 1}}{\text{isotopic ratio in component 2}}$$

Northern Apennines

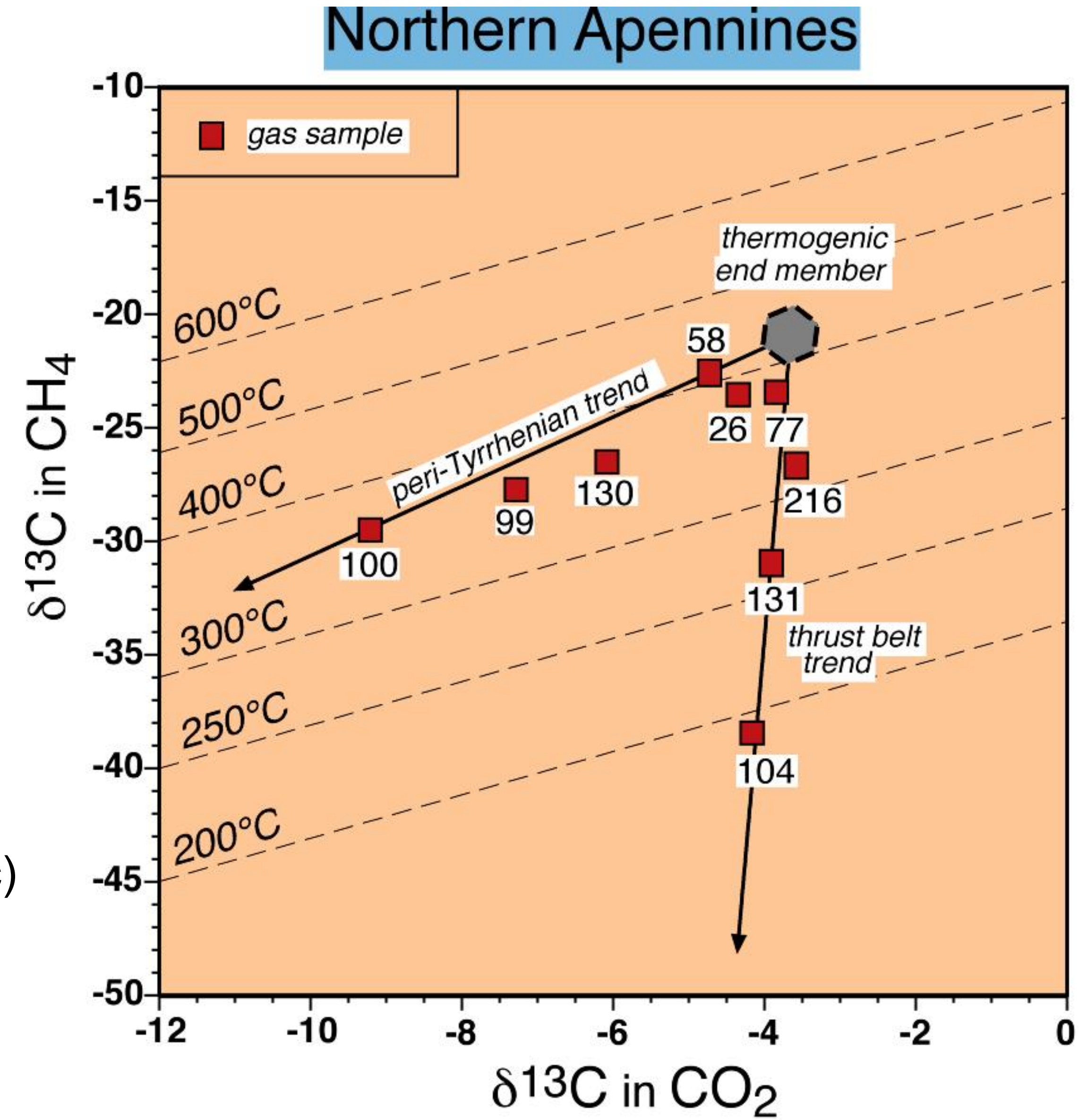


$\delta^{13}C$ in CO_2

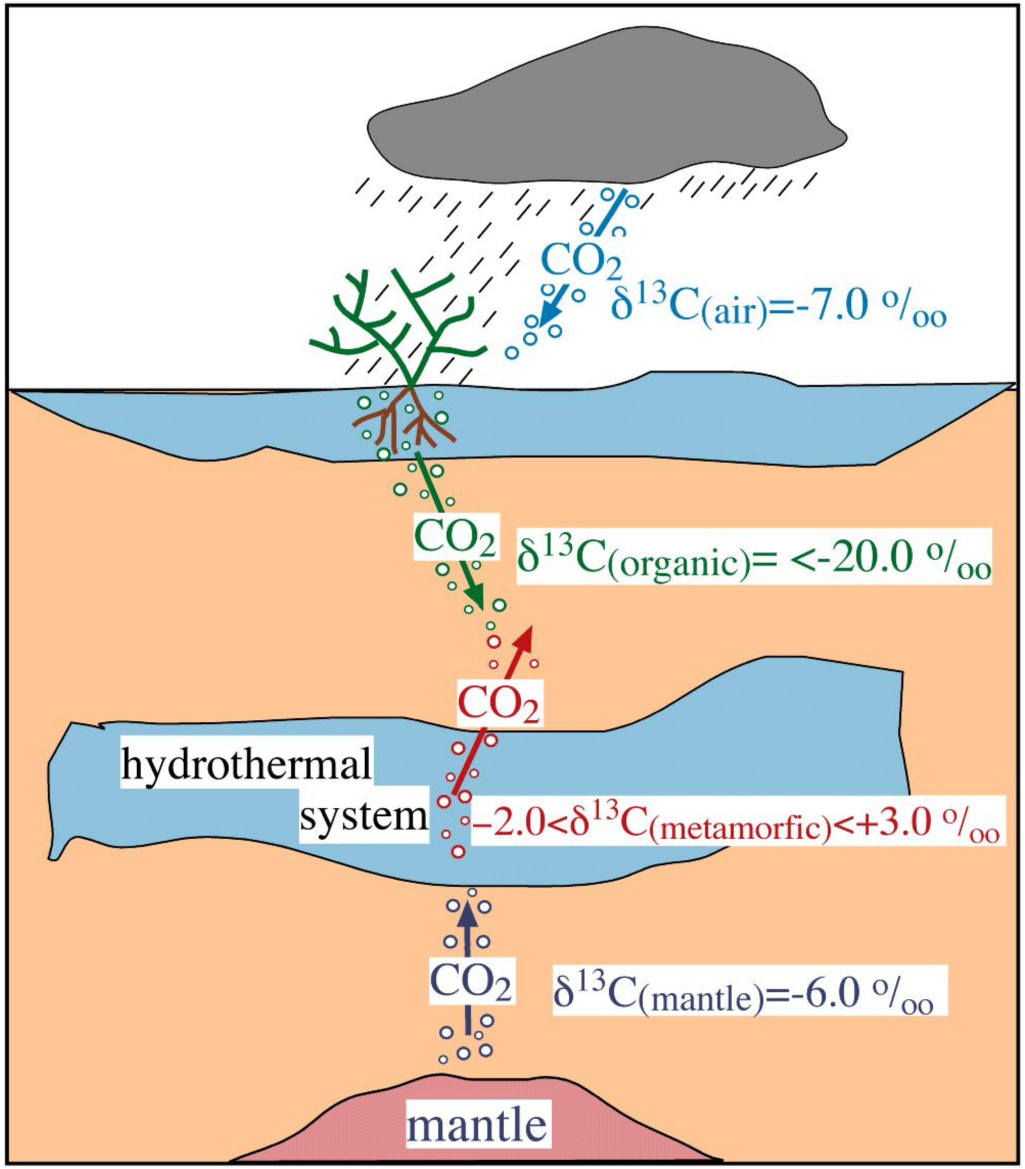
$\delta^{13}C<-20\ ^{o}/_{oo}$ (organic)
$-6 <\delta^{13}C<-4\ ^{o}/_{oo}$ (mantle)
$\delta^{13}C = -7\ ^{o}/_{oo}$ (atmosphere)
$-2< \delta^{13}C<+2\ ^{o}/_{oo}$ (limestone)

$\delta^{13}C$ in CH_4

$-35 <\delta^{13}C<-20\ ^{o}/_{oo}$ (thermogenic)
$-50< \delta^{13}C$ (biogenic)



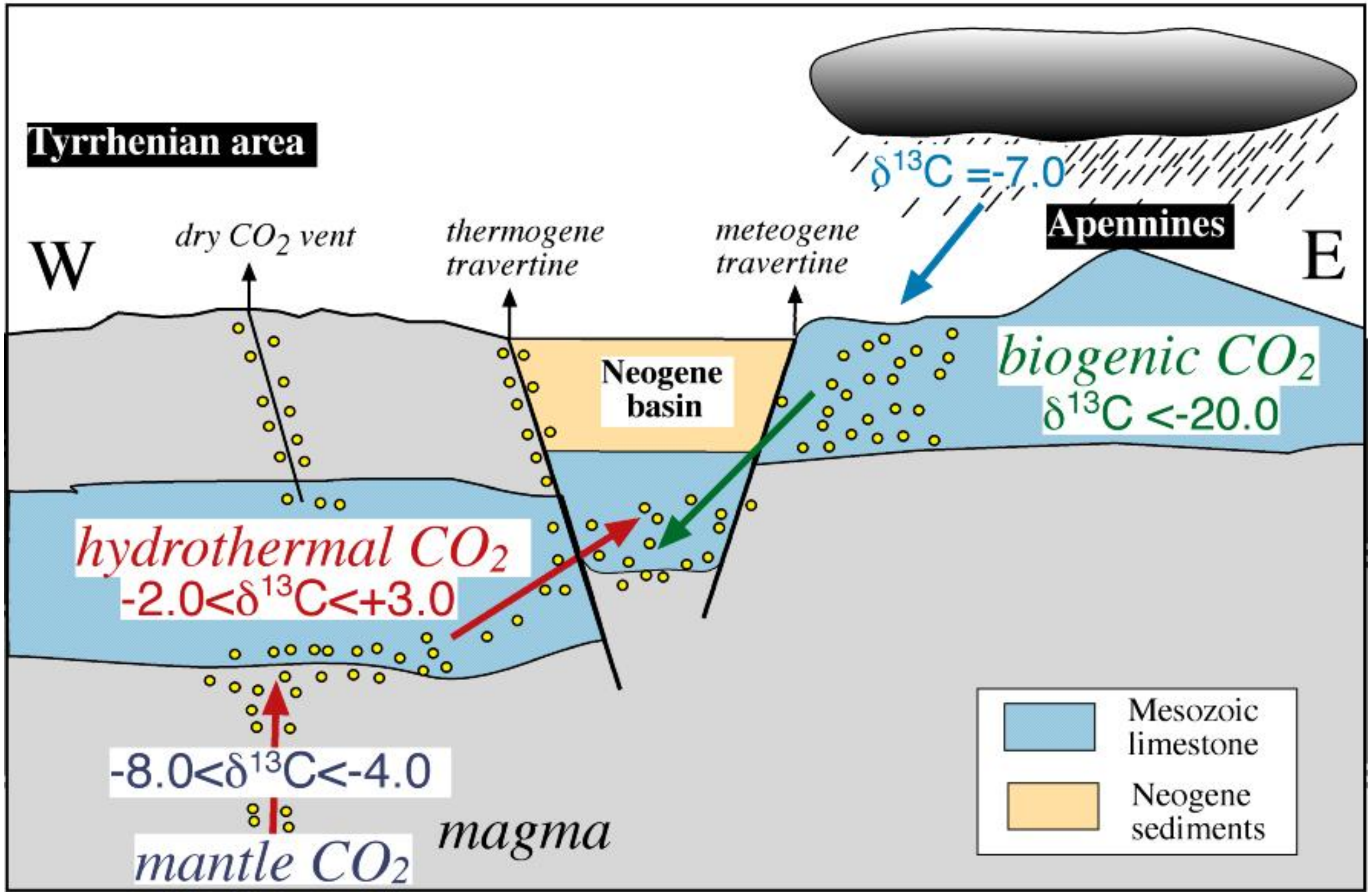
Multiple sources of CO_2

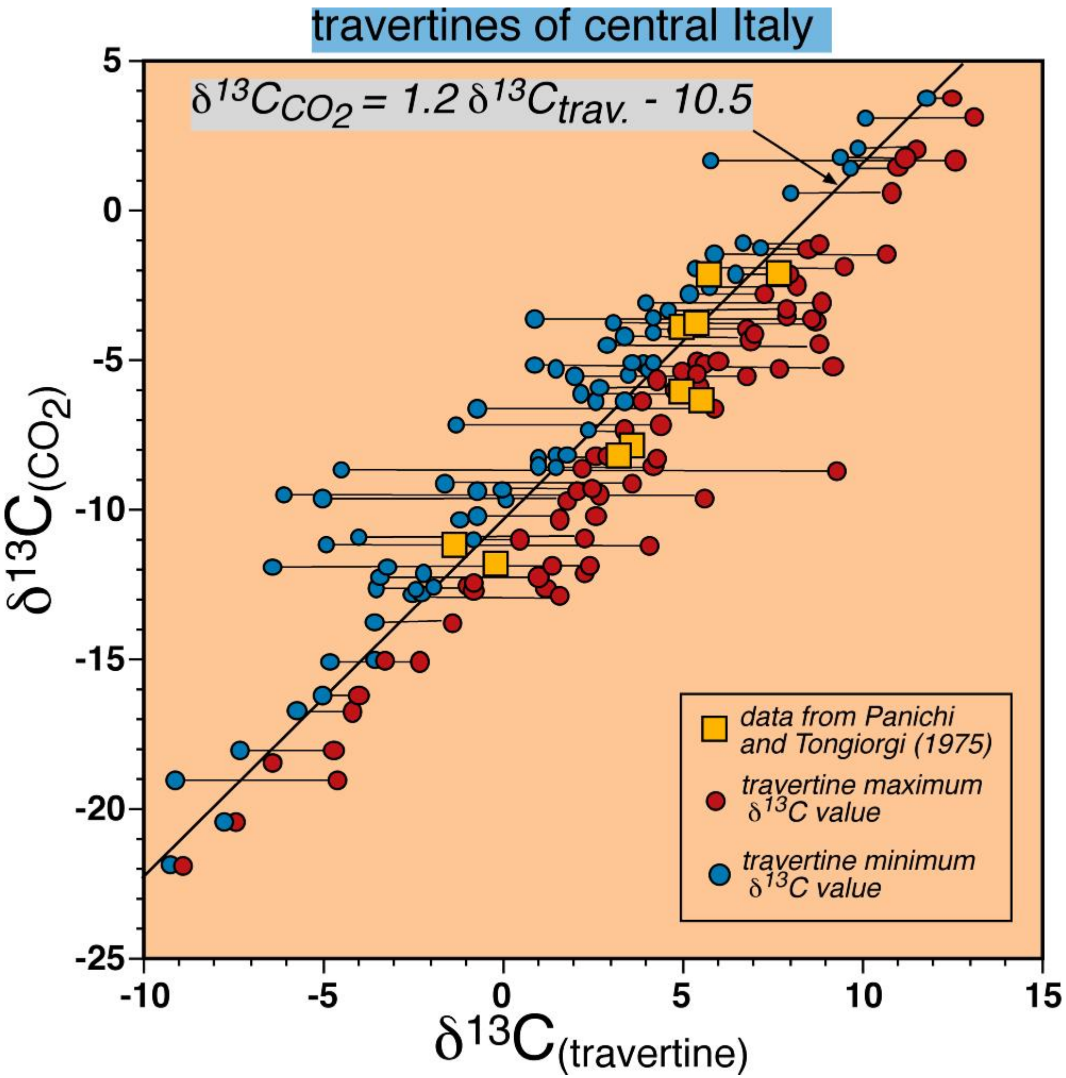


Multiple origin of CO_2 in central Italy having different isotopic signature (Minissale et al. 1997;2002).

Carbon isotopes and the origin of CO_2

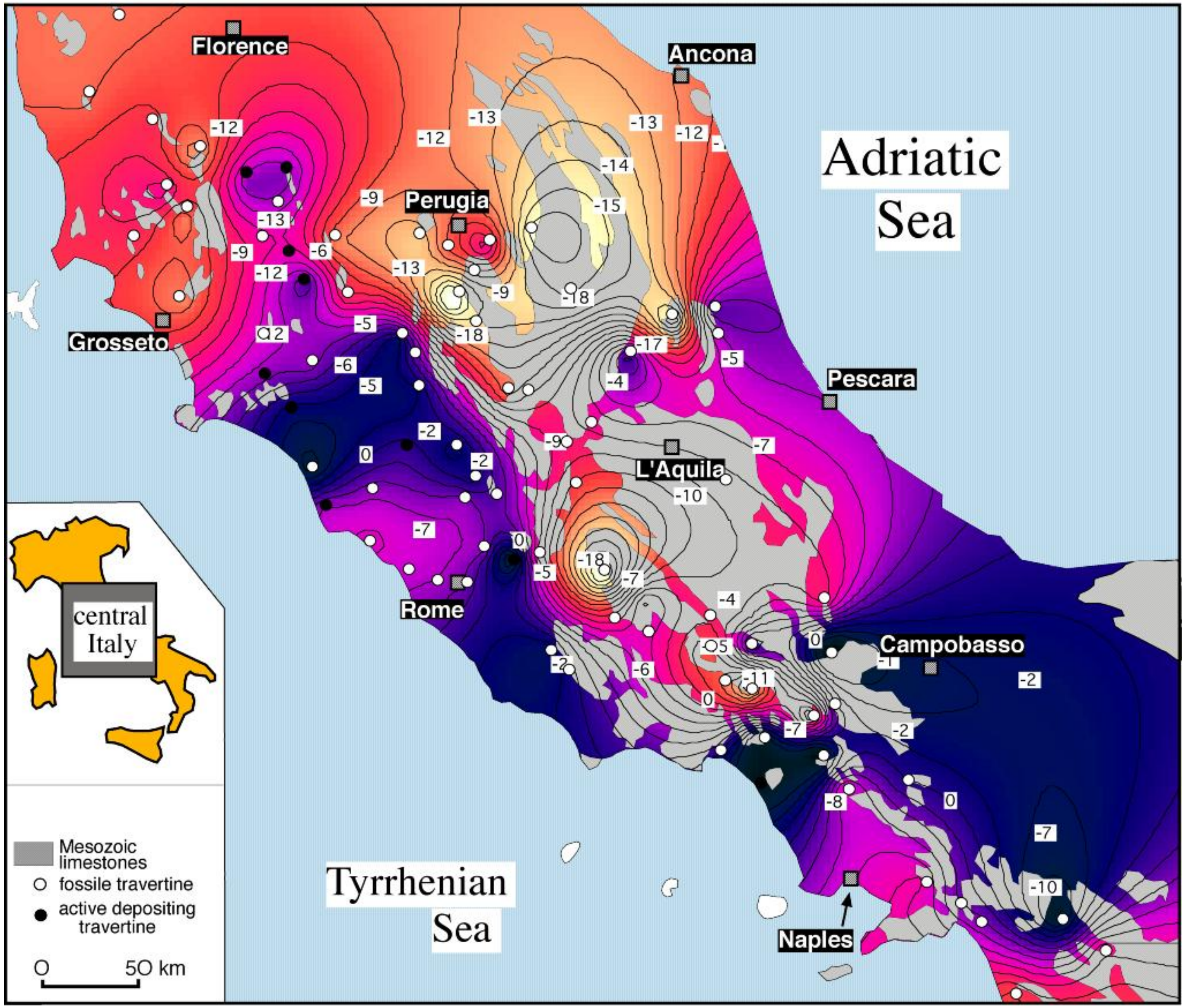
cross section of central Italy





travertines of central Italy
$\delta^{13}C_{CO_2} = 1.2\,\delta^{13}C_{trav.} - 10.5$
$\delta^{13}C_{(CO_2)}$
$\delta^{13}C_{(travertine)}$
data from Panichi and Tongiorgi (1975)
travertine maximum $\delta^{13}C$ value
travertine minimum $\delta^{13}C$ value
5
0
-5
-10
-15
-20
-25
-10
-5
0
5
10
15

isodistribution map of "re-built" mother CO_2 of travertine



The $^{3}He/^{4}He$ (R) is a powerful tectonic tool

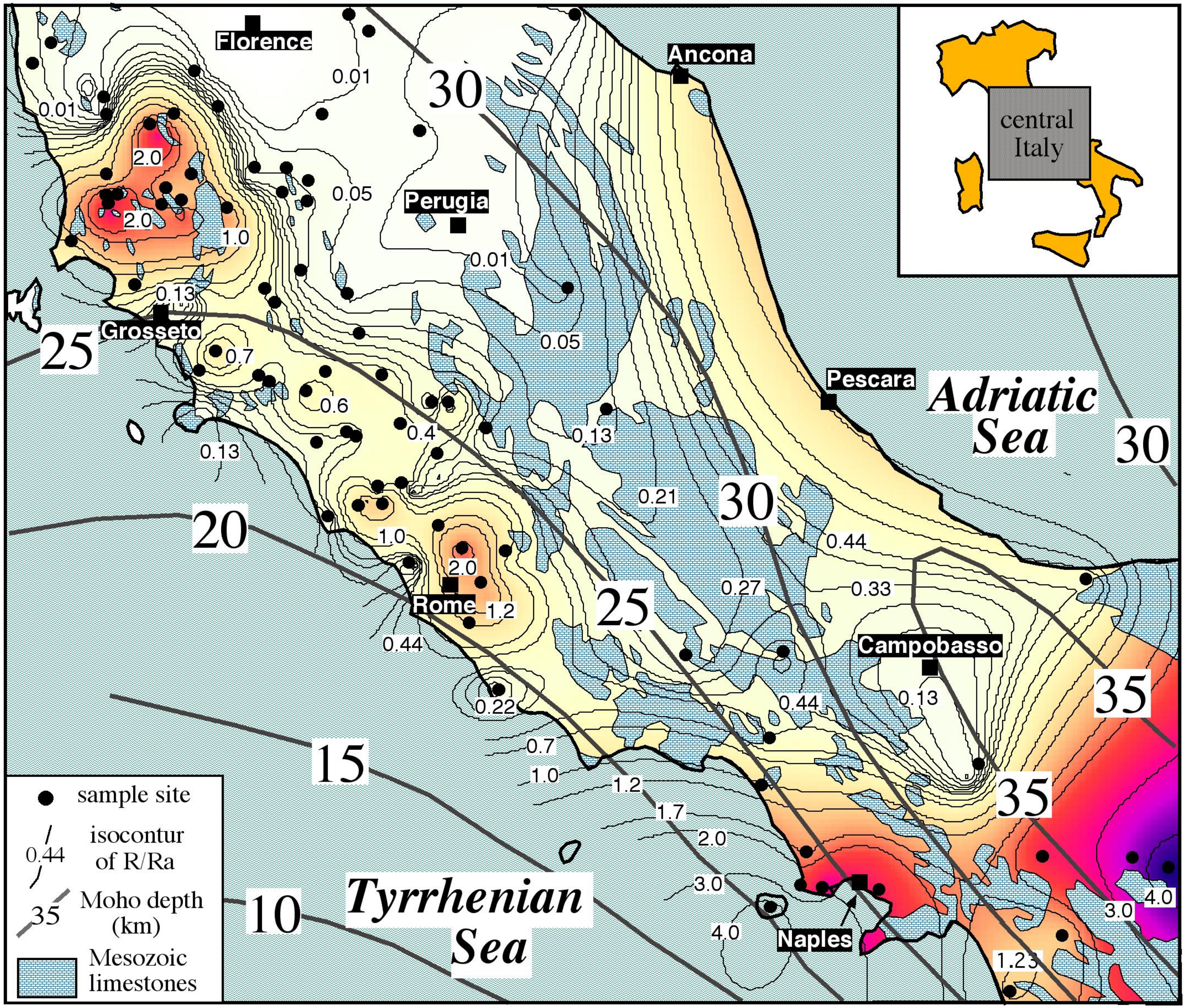
In air the $^{3}He/^{4}He$ (Ra) is 1,39 $*10^{-6}$

The ratio (R/Ra) in the mantle > 35

Because f radioactivity of U and Th and formation of α particles (^{4}He) the ratio (R/Ra) in the crust can be as low as 0.0001

The $^{3}He/^{4}He$ ratio can be used to trace the presence of mantle magmas and deep gases (San Andreas, Anatolian….faults)

Isocontour map of $^3He/^4He$ ratio in gas vents



Recent isotopic ratios (prevalently used for pollution)

e.g. $^{15}N/^{14}N$ in NO_3 for biological pollution
$^{15}N/^{14}N$ in NH_2 (ammine) after explosions
$^{35}Cl/^{37}Cl$ isotopes in perclorates for pollution
$^{11}B/^{10}B$ isotopes for paleo *p*H of ocean
$^{129}I/^{131}I$

etc.