Origin of high sulfate contents in the thermal waters of Kizildere and environs Western Anatolia, Turkey

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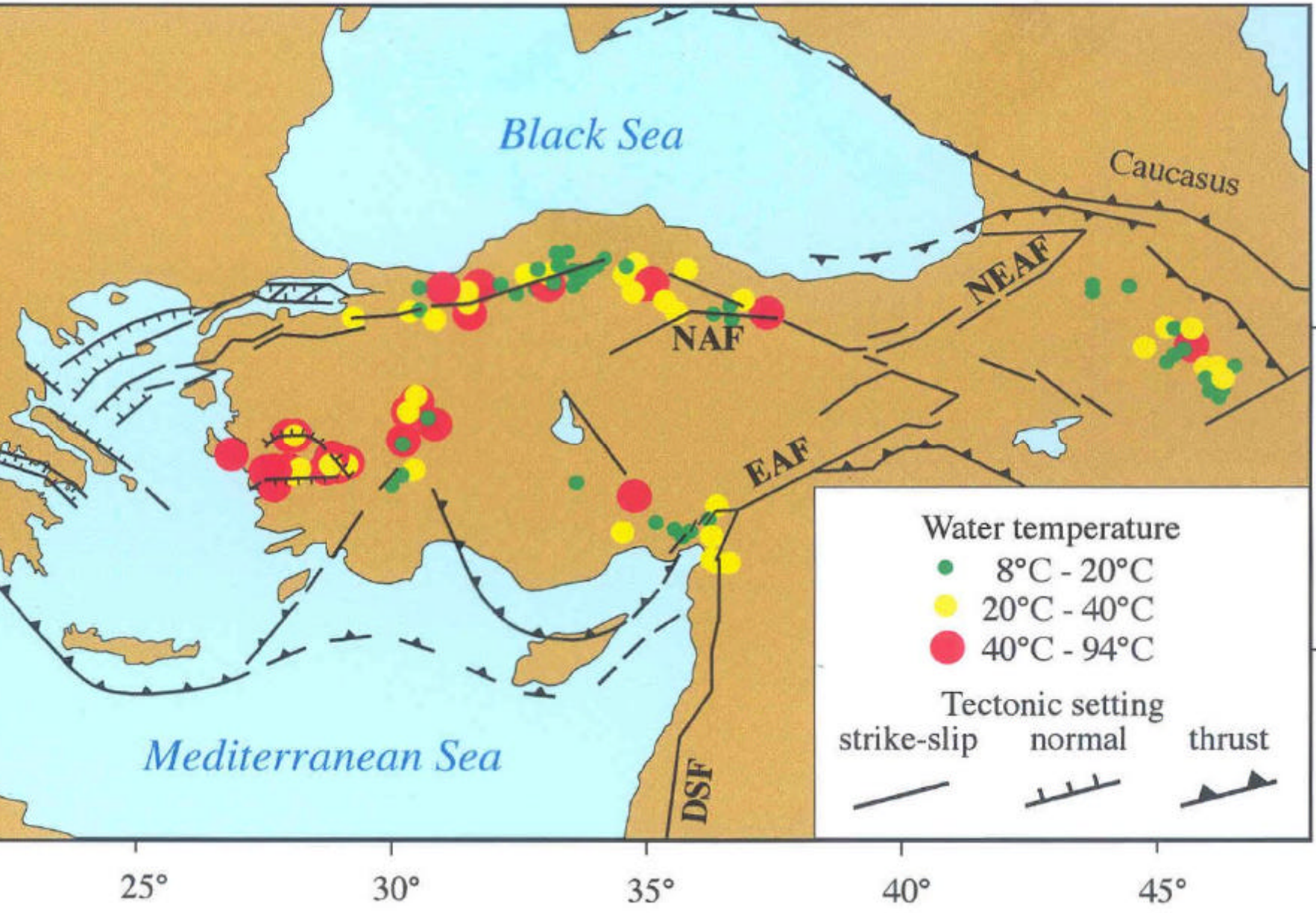
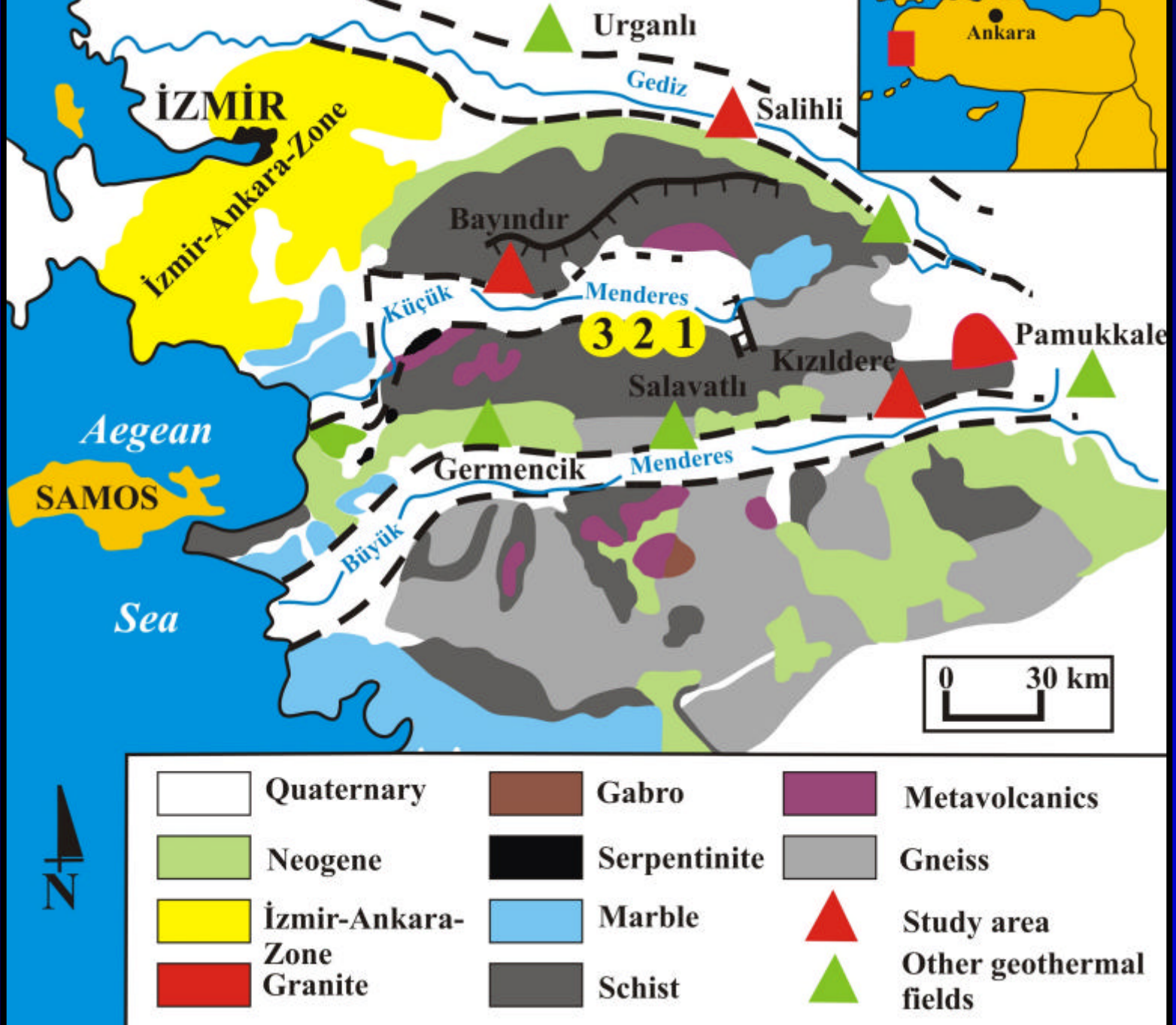
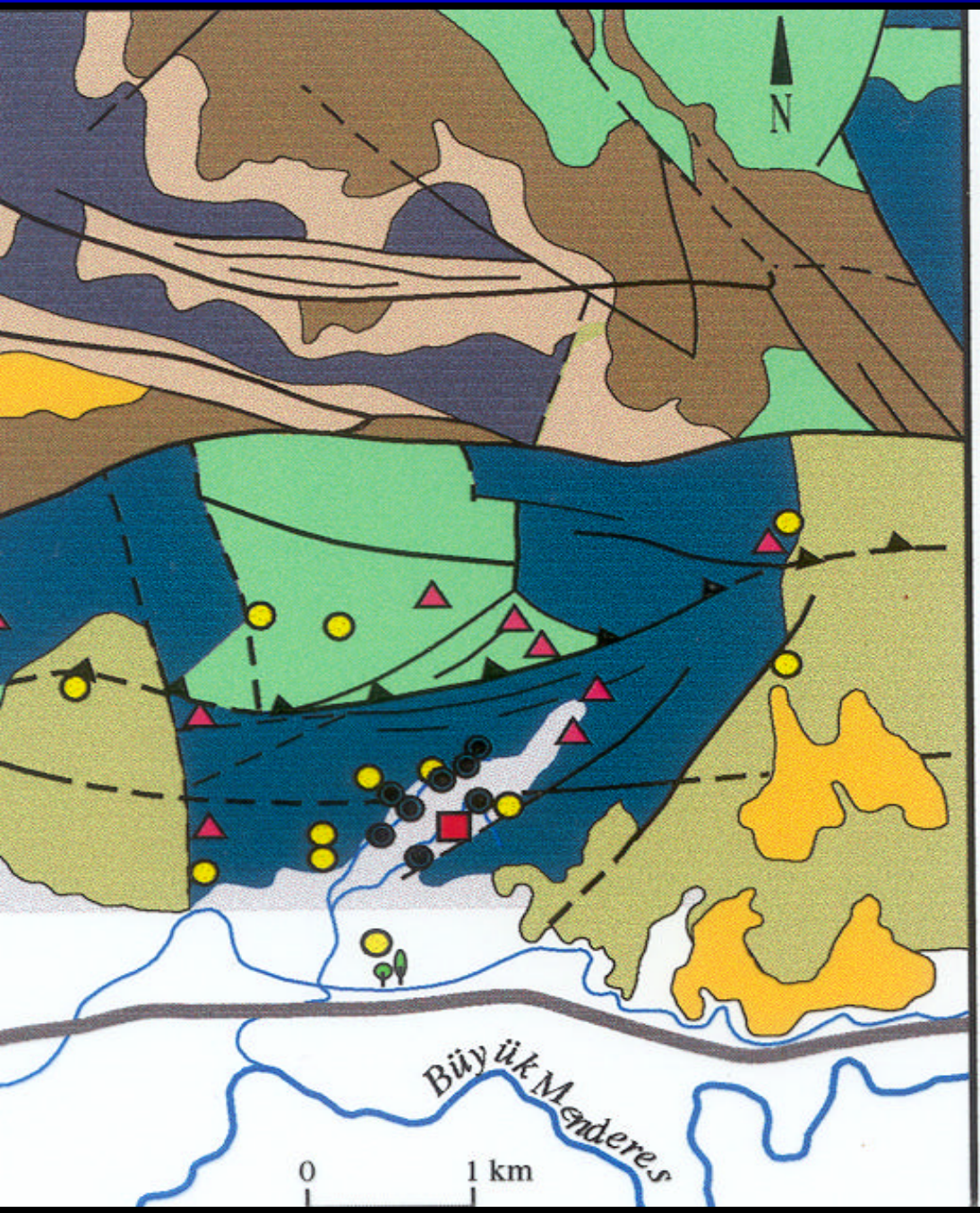

Black Sea
Caucasus
NEAF
NAF
EAF
DSF
Mediterranean Sea
Water temperature
8°C - 20°C
20°C - 40°C
40°C - 94°C
Tectonic setting
strike-slip
normal
thrust
25°
30°
35°
40°
45°
4
3


Ankara
Urganlı
Gediz
Salihli
İZMİR
İzmir-Ankara-Zone
Bayındır
Küçük
Menderes
3 2 1
Pamukkale
Kızıldere
Salavatlı
Aegean
SAMOS
Germencik
Menderes
Büyük
Sea
0 30 km
N
Quaternary
Neogene
İzmir-Ankara-Zone
Granite
Gabro
Serpentinite
Marble
Schist
Metavolcanics
Gneiss
Study area
Other geothermal fields

The aims of the study

- **Hydrogeological, hydrogeochemical, and isotope geochemical investigations to describe the origin, genesis, age, and thermodynamical reaction conditions of geothermal fluids in Kizildere and environs.**

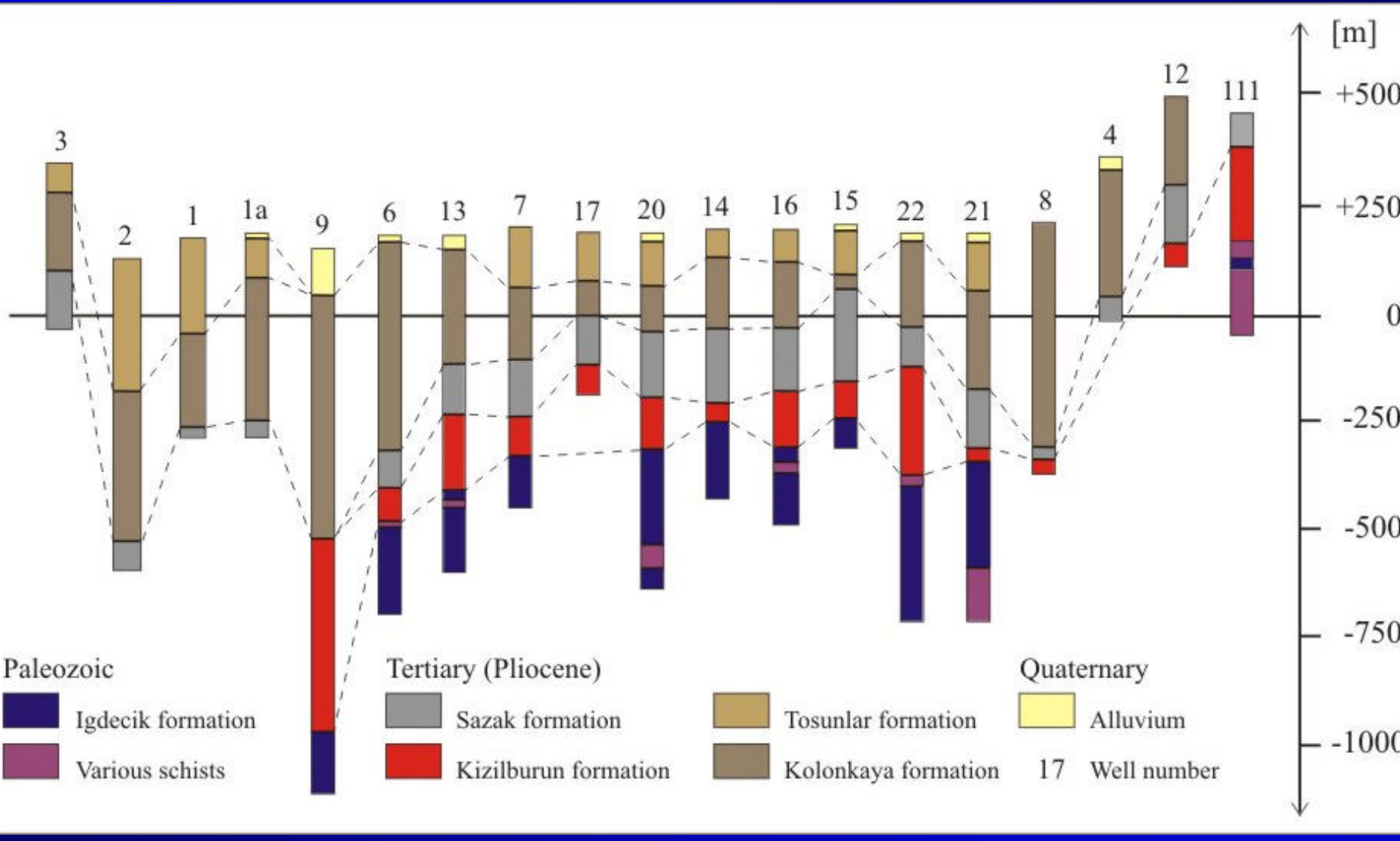
- **to elucidate the origin of high sulfate contents in thermal waters of Kizildere and environs in consideration of geochemistry and isotope geochemistry $\delta^{34}S$ and $\delta^{18}O$.**

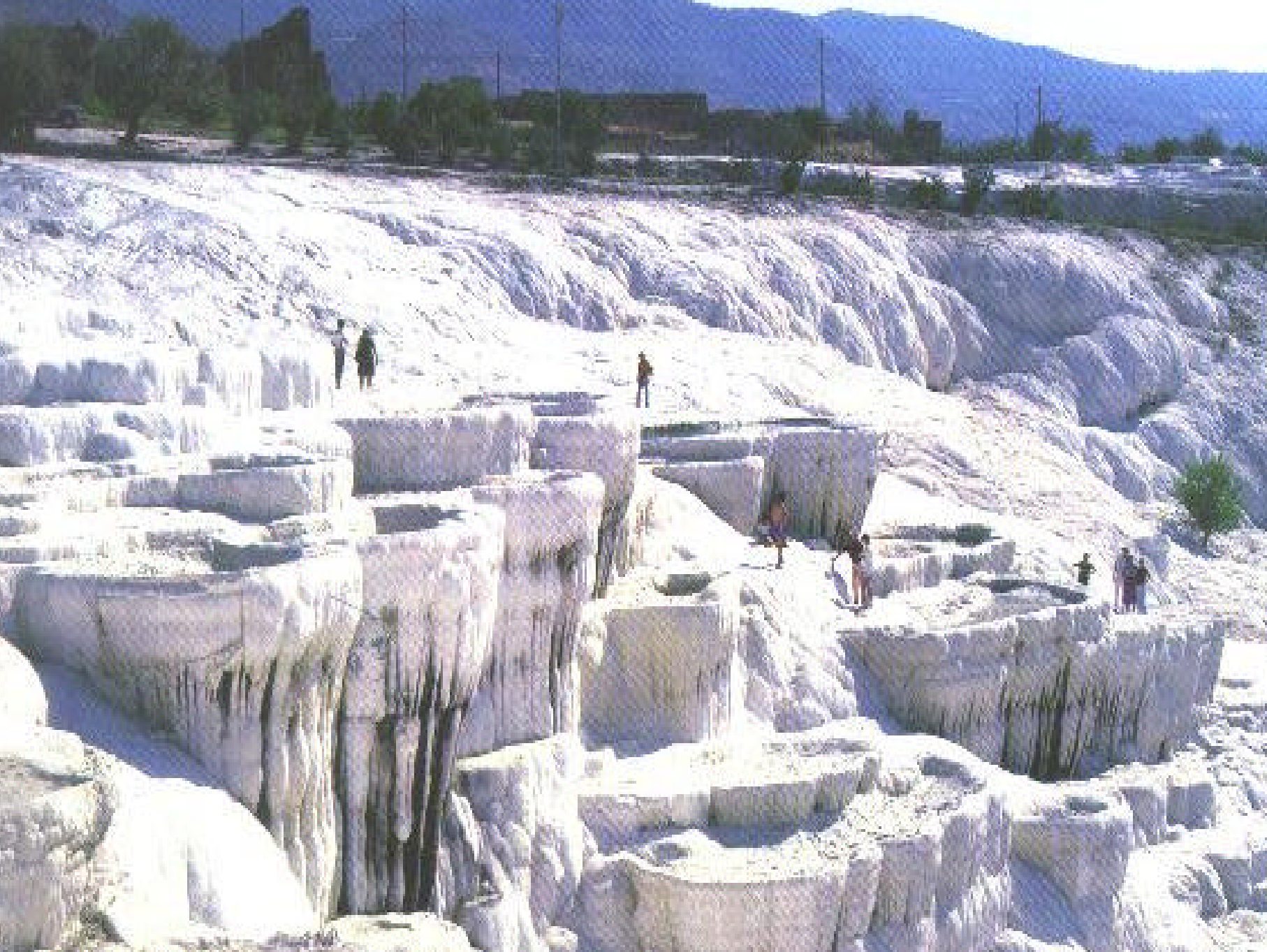


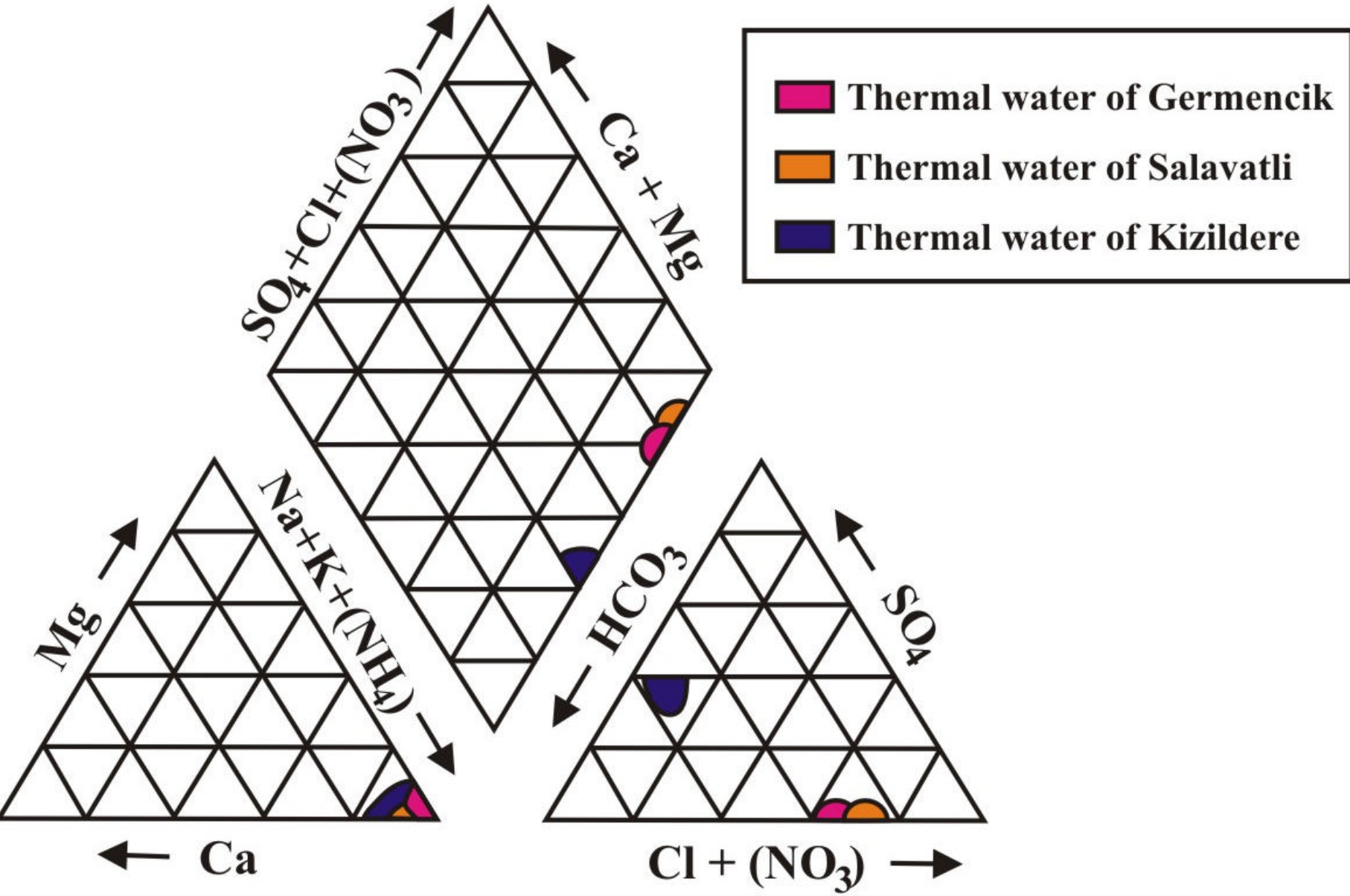
LEGEND

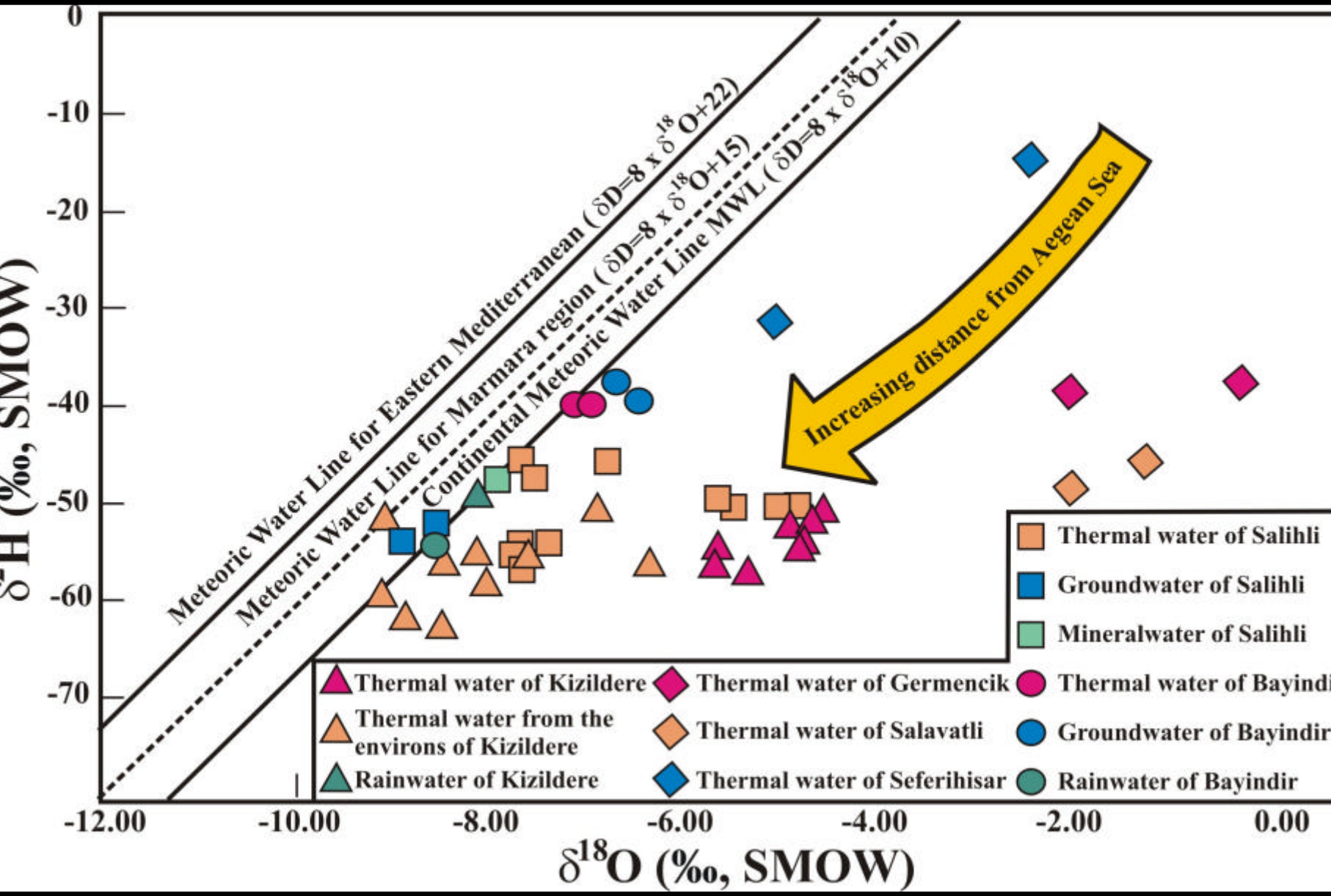
- Alluvium
- Cover of debris
- Tosunlar formation (Tt)
- Kolonkaya formation (Tko)
- Sazak formation (Ts)
- Kizilburun formation (Tk)
- Marble,Schist(Pmr)
- Schist,Quarzite (Pm)
- Boundary
- Fault
- Thrust
- Thermal water canal
- Greenhouses
- Outlet of thermal water and steams
- Prospection wells
- Production wells
- Geothermal power plant

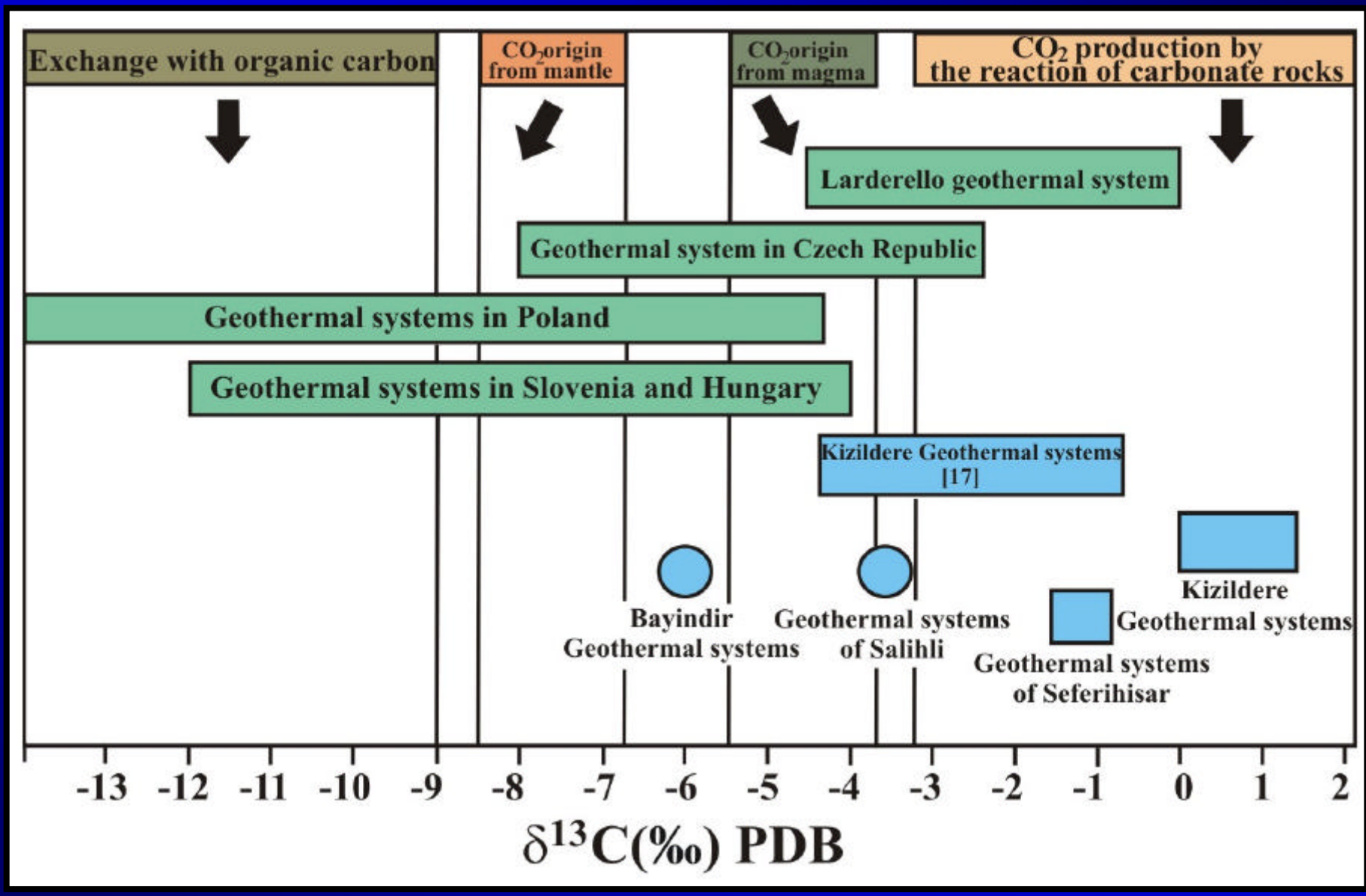
QUATERNARY
PLIOCENE
TERTIARY
PALEOZOICUM

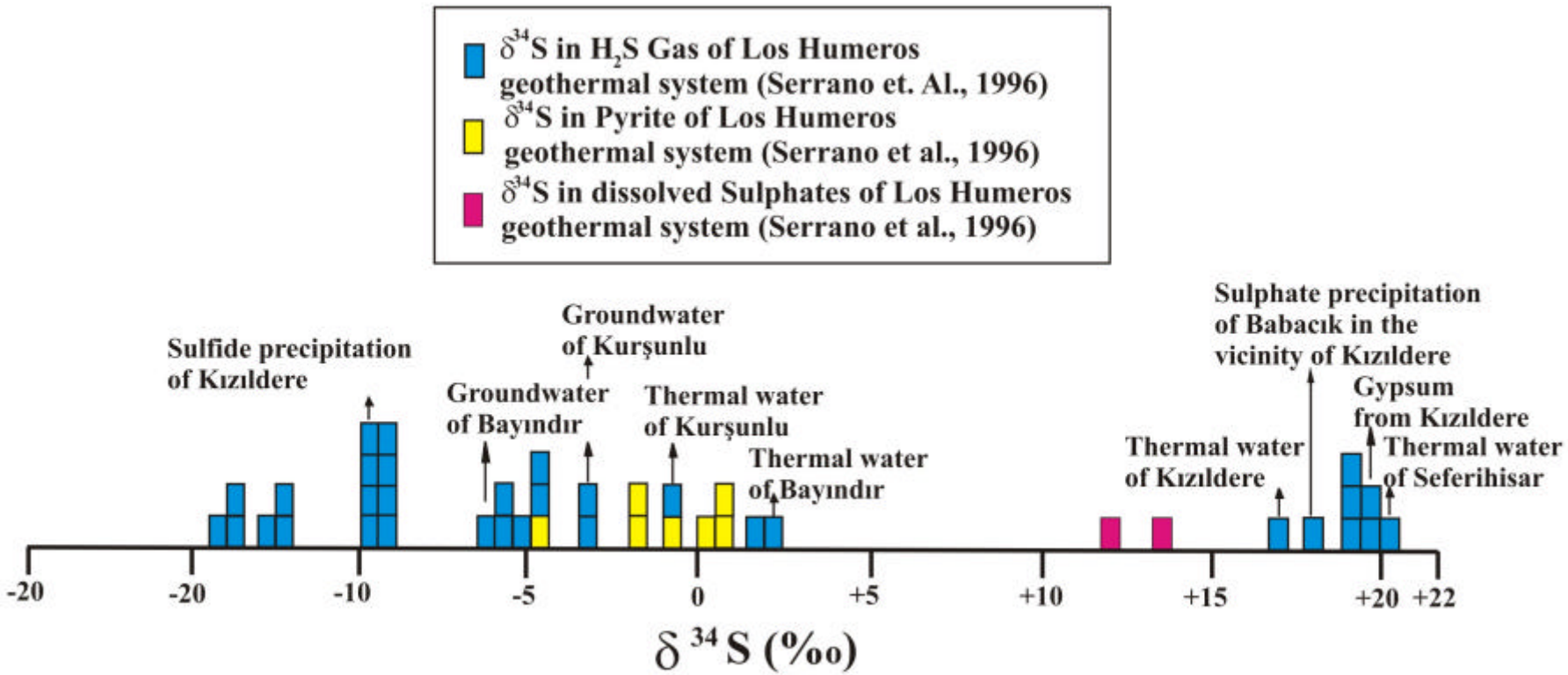

[m]
+500
+250
0
-250
-500
-750
-1000
3
2
1
1a
9
6
13
7
17
20
14
16
15
22
21
8
4
12
111
Paleozoic
Igdecik formation
Various schists
Tertiary (Pliocene)
Sazak formation
Kizilburun formation
Tosunlar formation
Kolonkaya formation
Quaternary
Alluvium
17 Well number

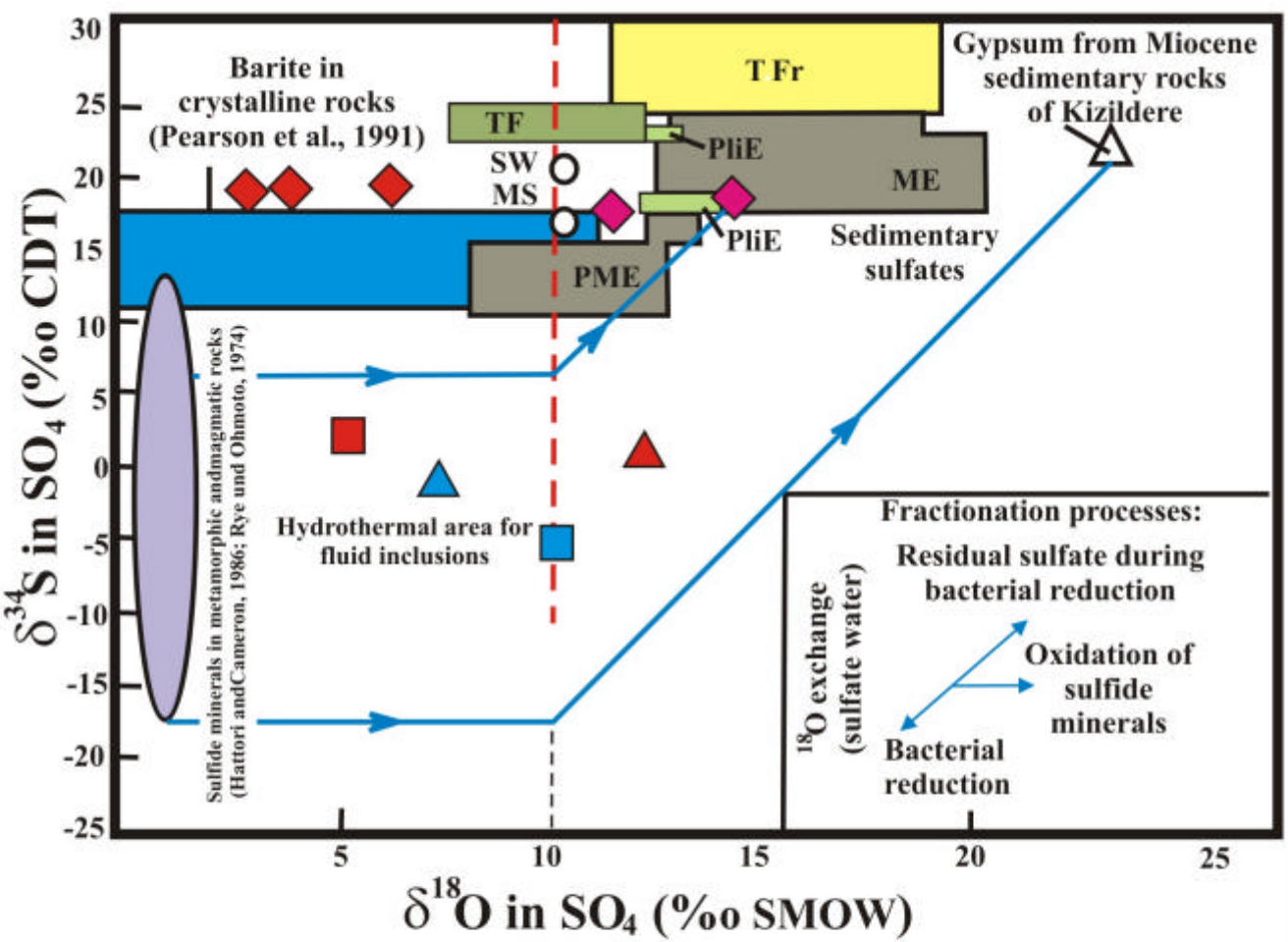



Thermal water of Germencik
Thermal water of Salavatli
Thermal water of Kizildere
SO4+Cl+(NO3)
Ca + Mg
Mg
Na+K+(NH4)
Ca
HCO3
SO4
Cl + (NO3)


Meteoric Water Line for Eastern Mediterranean (δD=8 x δ18O+22)
Meteoric Water Line for Marmara region (δD=8 x δ18O+15)
Continental Meteoric Water Line MWL (δD=8 x δ18O+10)
Increasing distance from Aegean Sea
Thermal water of Salihli
Groundwater of Salihli
Mineralwater of Salihli
Thermal water of Kizildere
Thermal water of Germencik
Thermal water of Bayindi
Thermal water from the environs of Kizildere
Thermal water of Salavatli
Groundwater of Bayindir
Rainwater of Kizildere
Thermal water of Seferihisar
Rainwater of Bayindir
0
-10
-20
-30
-40
-50
-60
-70
δ2H (‰, SMOW)
-12.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
δ18O (‰, SMOW)

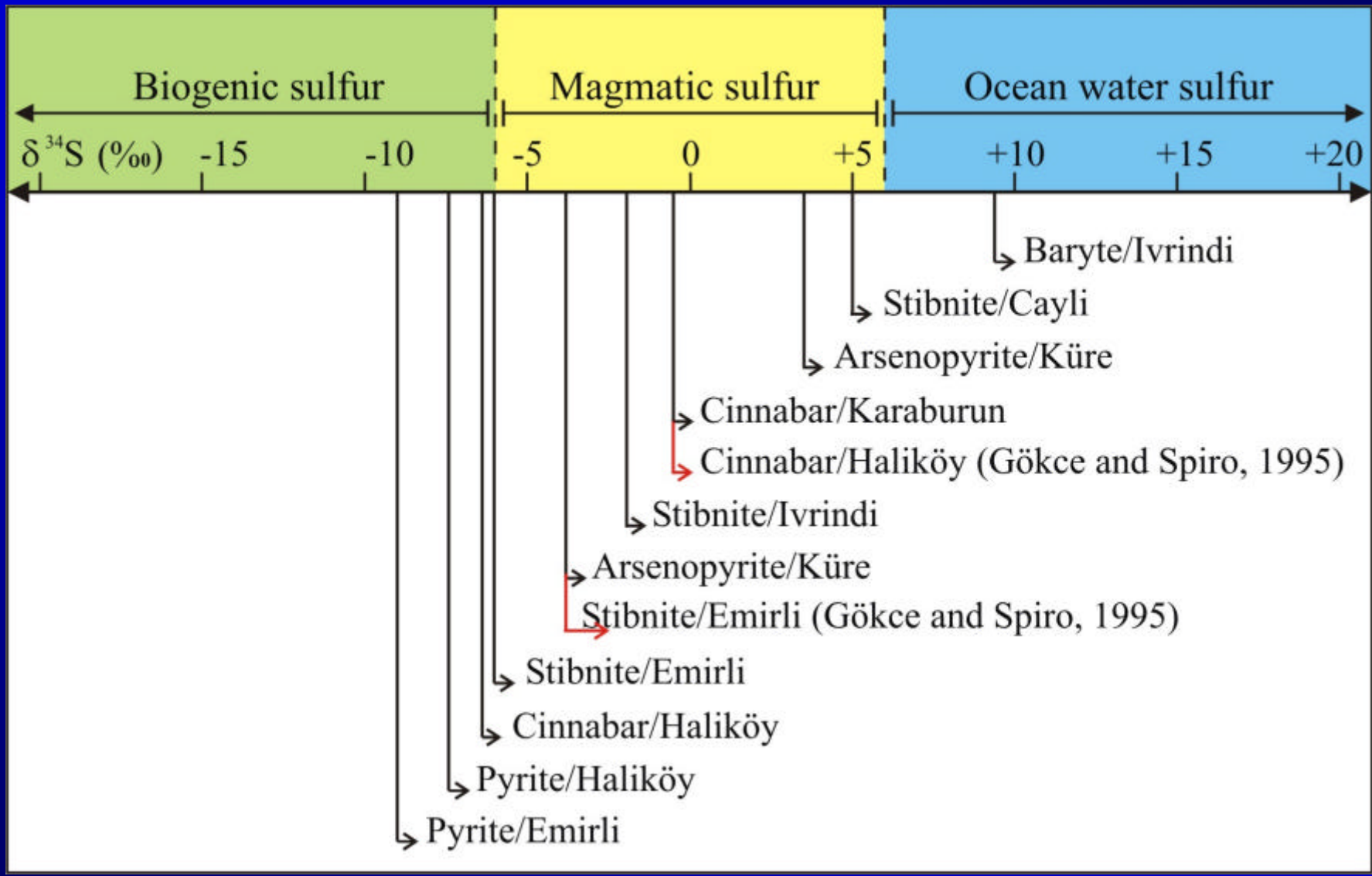

Exchange with organic carbon
CO_2 origin from mantle
CO_2 origin from magma
CO_2 production by the reaction of carbonate rocks
Larderello geothermal system
Geothermal system in Czech Republic
Geothermal systems in Poland
Geothermal systems in Slovenia and Hungary
Kizildere Geothermal systems [17]
Bayindir Geothermal systems
Geothermal systems of Salihli
Geothermal systems of Seferihisar
Kizildere Geothermal systems
-13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2
$\delta^{13}C$(‰) PDB

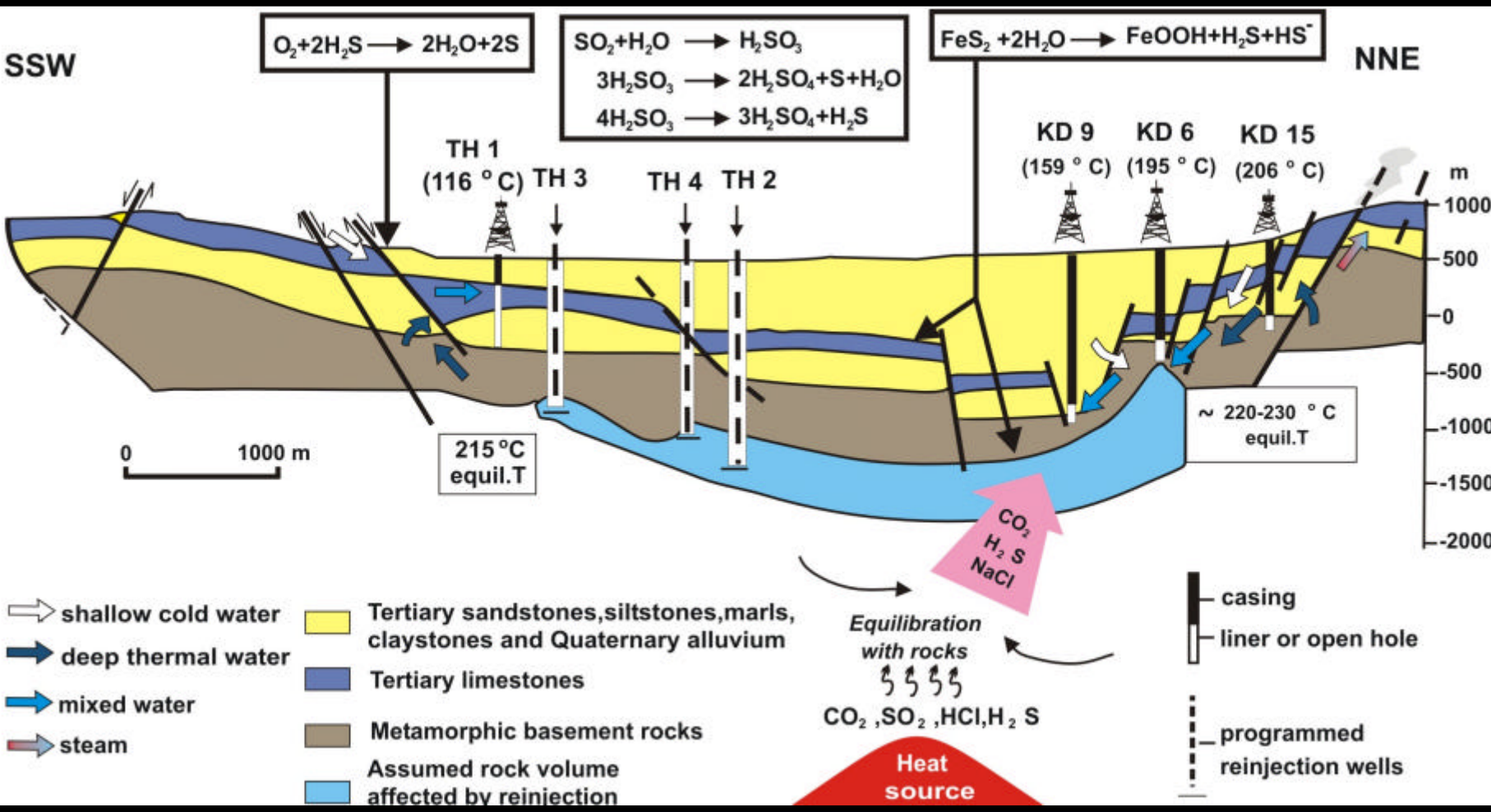

δ34S in H2S Gas of Los Humeros geothermal system (Serrano et. Al., 1996)
δ34S in Pyrite of Los Humeros geothermal system (Serrano et al., 1996)
δ34S in dissolved Sulphates of Los Humeros geothermal system (Serrano et al., 1996)
Sulfide precipitation of Kızıldere
Groundwater of Kurşunlu
Groundwater of Bayındır
Thermal water of Kurşunlu
Thermal water of Bayındır
Sulphate precipitation of Babacık in the vicinity of Kızıldere
Gypsum from Kızıldere
Thermal water of Kızıldere
Thermal water of Seferihisar
-20
-20
-10
-5
0
+5
+10
+15
+20
+22
δ 34 S (‰)



MS Marmara Sea
SW Sea water (Claypool et al., 1980)
TF Tertiary formation (water, Zak et al., 1980)
T Fr Tertiary formation (reduced water; Zak et al., 1980)
PliE Pliocene evaporites (Claypool et al., 1980)
ME Miocene evaporites (Claypool et al., 1980)
PME Paleozoic and Mesozoic evaporites (Claypool et al., 1980)

Sulfate precipitations of the
Groundwater of Salihli
Thermal water of Salihli
Groundwater of Bayindir
Thermal water of Bayindir
Thermal water of Kizildere
Thermal water of the environs of Kizildere


Biogenic sulfur
Magmatic sulfur
Ocean water sulfur
δ 34S (‰)
-15
-10
-5
0
+5
+10
+15
+20
Baryte/Ivrindi
Stibnite/Cayli
Arsenopyrite/Küre
Cinnabar/Karaburun
Cinnabar/Haliköy (Gökce and Spiro, 1995)
Stibnite/Ivrindi
Arsenopyrite/Küre
Stibnite/Emirli (Gökce and Spiro, 1995)
Stibnite/Emirli
Cinnabar/Haliköy
Pyrite/Haliköy
Pyrite/Emirli


SSW
NNE
$O_2+2H_2S \rightarrow 2H_2O+2S$
$SO_2+H_2O \rightarrow H_2SO_3$
$3H_2SO_3 \rightarrow 2H_2SO_4+S+H_2O$
$4H_2SO_3 \rightarrow 3H_2SO_4+H_2S$
$FeS_2+2H_2O \rightarrow FeOOH+H_2S+HS^-$
TH 1
(116 ° C)
TH 3
TH 4
TH 2
KD 9
(159 ° C)
KD 6
(195 ° C)
KD 15
(206 ° C)
m
1000
500
0
-500
-1000
-1500
-2000
0
1000 m
215 °C
equil.T
~ 220-230 ° C
equil.T
CO_2
H_2S
NaCl
Equilibration
with rocks
CO_2 ,SO_2 ,HCl,H_2S
Heat
source
shallow cold water
deep thermal water
mixed water
steam
Tertiary sandstones,siltstones,marls,
claystones and Quaternary alluvium
Tertiary limestones
Metamorphic basement rocks
Assumed rock volume
affected by reinjection
casing
liner or open hole
programmed
reinjection wells

CONCLUSIONS

- Due to various facts and existence of $\delta^{34}S$ and $\delta^{18}O$ in sulfate precipitations, it might be concluded that sulfure in the thermal field of Kizildere and environs reachs in terms of volatile components (H_2S, SO_2) the metamorphic and magmatic rocks, precipitates as sulfide minerals, later on, and/or encounter transformation to sulfate in the thermal water reservoir by disproportionation. The magmatic origin of sulfur can be corroborated by the ratios of $\delta^{13}C$ and $\delta^{11}B$ as well as by $\delta^{34}S$ in sulfide minerals of epithermal sulfide mineralizations.

- The gypsum occurrences in Pliocene sedimentary rocks and pyrite ore minerals can be added as a second source of SO_4^{2-} in thermal waters of Kizildere and environs.