Cenni di limnologia

Orlando Vaselli – Franco Tassi
University of Florence, Italy

Limnology

- Term “limnology” derived from Greek word “limne” meaning pool, marsh, or lake
- The science arose from from lake investigation
- mid-1800s - Henry David Thoreau’s observations from Walden Pond (nice lake)

Limnology

- Gradually grew to encompass all inland waters
- Today includes standing water (*lentic* habitats) as well as running water (*lotic* habitats)

Physical Limnology

- Unique properties of water - important role in penetration, distribution of light, heat
- Water movements (waves, currents)
- Geology of basin (origin, morphology, leaching minerals)

Chemical Limnology

- Inorganic , organic compounds
- Closely allied to geology (leaching)
- Distribution often related to water movements

Biological Limnology

- Base is photosynthesis - *primary productivity*
- Regulated by, and may regulate, physical and chemical factors

Limnology

- Everything becomes interconnected
- Add in further complications resulting from human relations and impacts
- Very complicated science

Lake (limnic) ecosystems

- Origins and classifications
- Lakes as open systems
- Light and temperature
- Lake chemistry
- Primary productivity
- Secondary productivity
- Lake evolution
- Perturbations

Lake classification: geological origin

Lakes result from impoundment of water by:

- tectonic downwarping (e.g. Lake Victoria)
- tectonic faulting (e.g. Dead Sea)
- volcanic eruption (e.g. Crater Lake)
- landslide dams
- ice dams
- biotic dams (e.g. Beaver lake)
- glacial erosion (e.g. Lake Peyto)
- glacial deposition (e.g. Moraine Lake)
- river channel abandonment (e.g. Hatzic Lake)
- deflation

Lake classification: morphology

- Lake morphology (size, surface area and depth) largely determined by origin.
- Substrate (rocky, sandy, muddy, organic) initially determined by geological origin; thereafter by inputs.

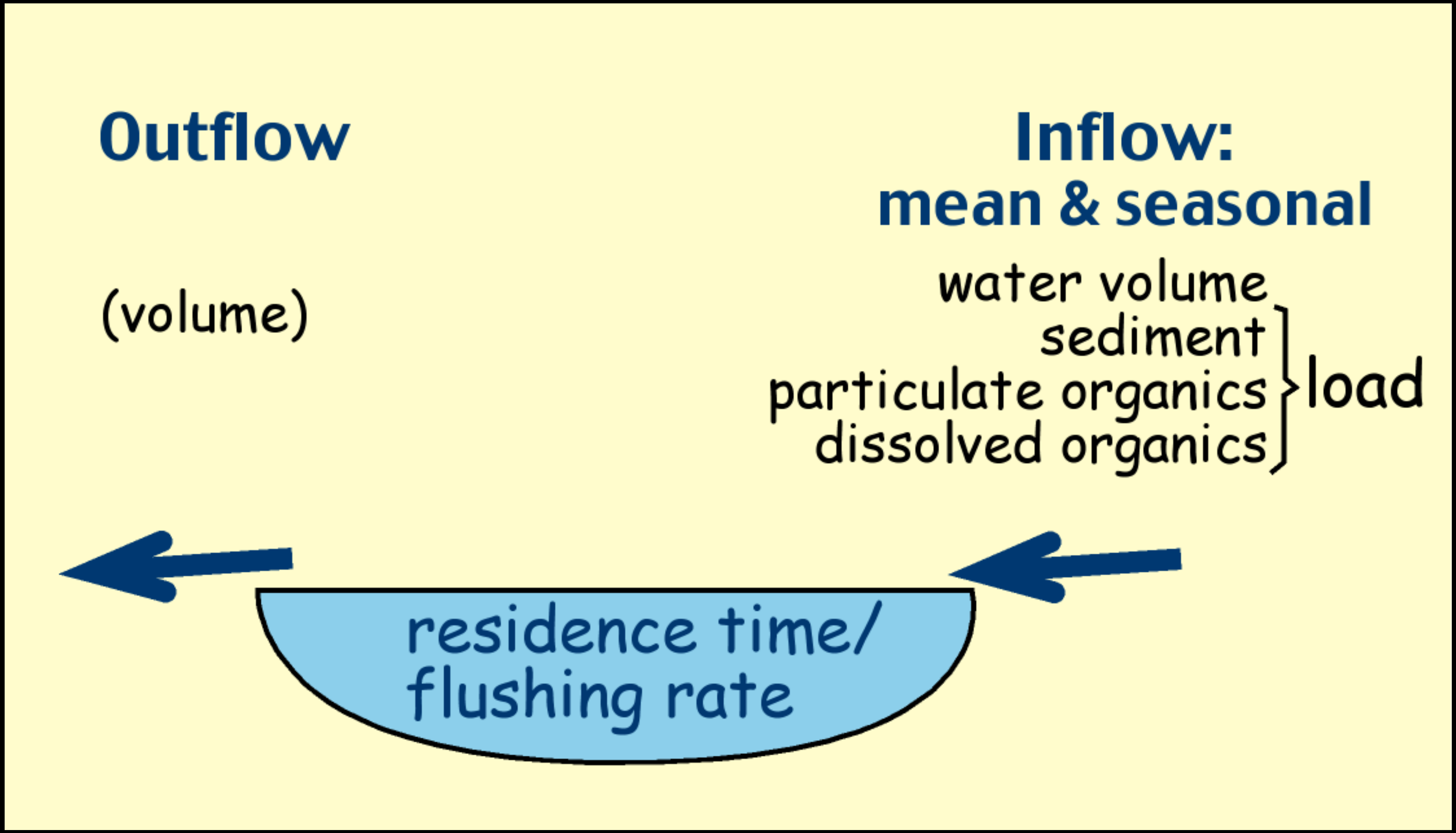
Lake classification: hydro-regime

- Open lakes have outflow streams.
- Closed lakes are found in endorheic basins in arid areas; e.g Lake Eyre (Australia): shallow lake forms in La Niña years (e.g. 2000), usually persists for 1 year. Never overflows - lake sits at 15m below sea level.

Types

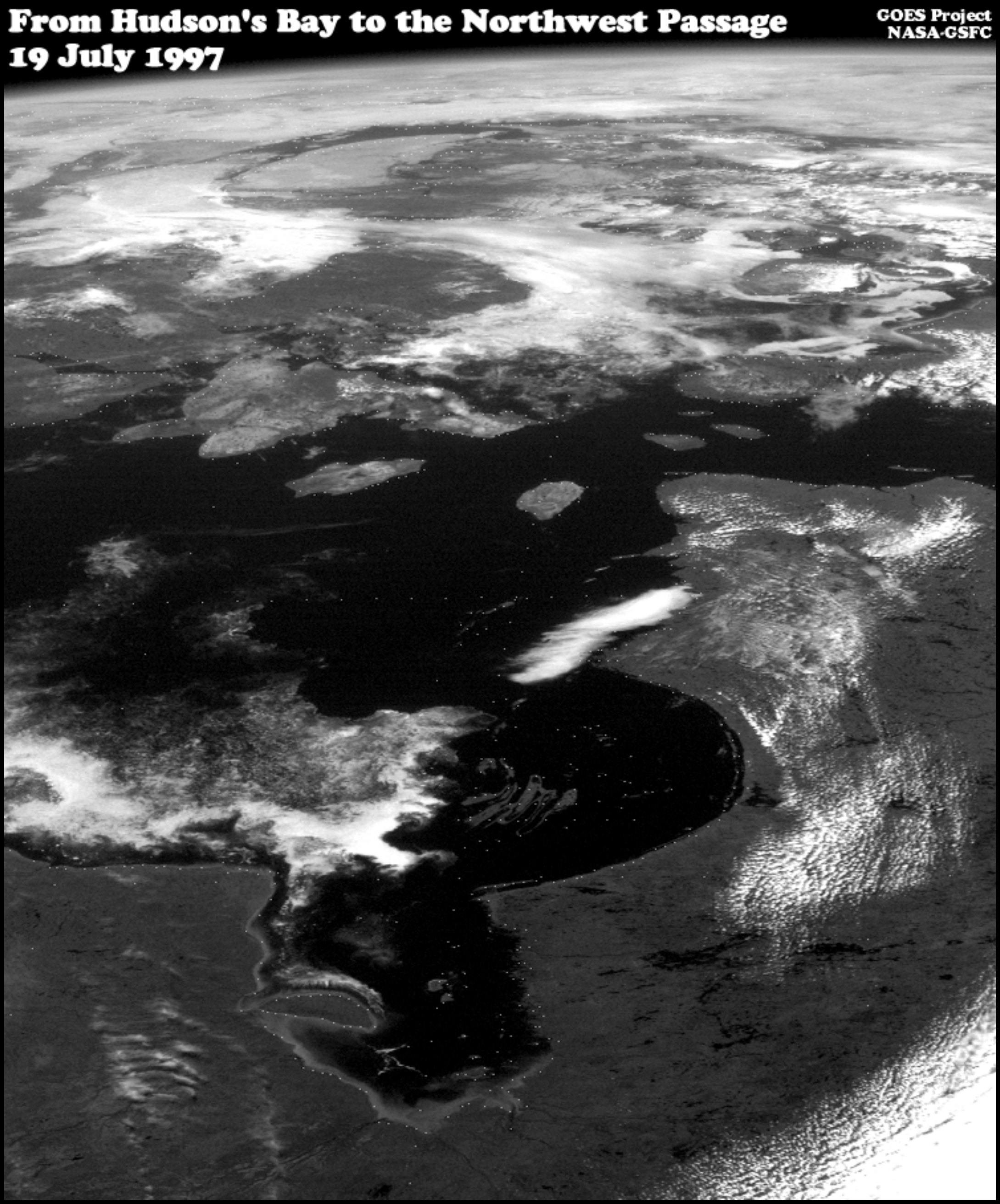
- Open
  - has outflow of water
  - Ppt + inflow = Evap + outflow
    - clastic sedimentation common
- Closed
  - no major outflow
  - inflow > Evap
  - chemical sedimentation may dominate due to concentration of ions
- Perennial
  - inflow from at least 1 perennial stream
  - rarely dry up
- Ephemeral
  - salt-pan basins
  - dry up seasonally; fed by springs, runoff, groundwater
  - Salts important ephemeral deposits
    - salts are bedded

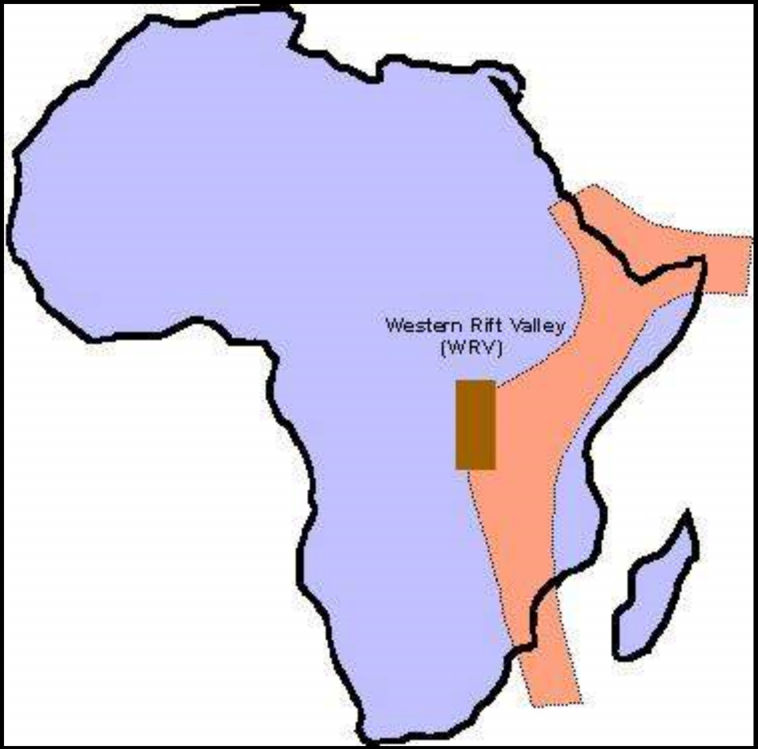
Lakes as open systems



Origins

- Formation
  - Meteors- Hudson Bay
  - glacial processes (ice damming, etc)-Glacial Lake Missoula
  - wind drives accumulation of sands
  - oxbow lakes
  - tectonics (Large lakes)
    - Rift valleys (Lake Tanganika)
    - Subsiding intracontinental regions (Chad)


From Hudson's Bay to the Northwest Passage
19 July 1997
GOES Project
NASA-GSFC


Western Rift Valley
(WRV)

Camas Prairie Ripple Marks/Mark Alan Wilson

Debris field below Grand Coulee... boulder on left is 5 feet tall. Mark Alan Wilson

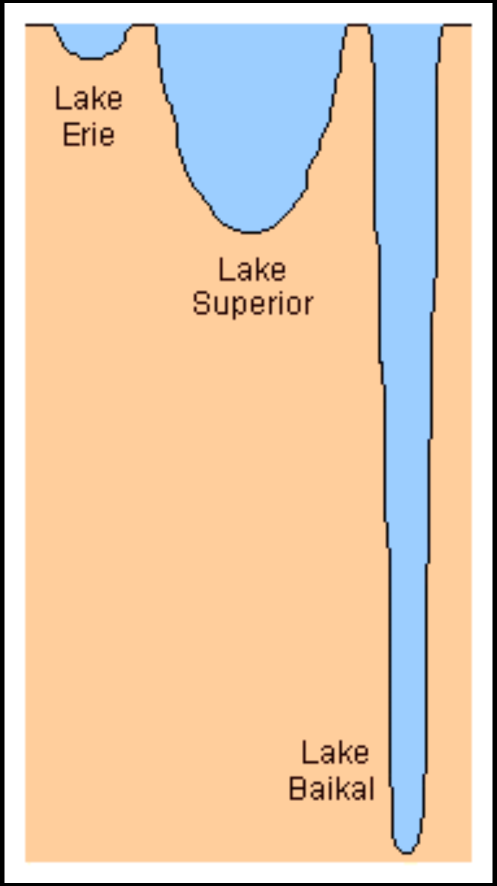
Size

- Ponds to Caspian Sea
  - Caspian Sea
    - saline lake-1.2%
    - 371,000 km^2
    - maximum depth of about 980m
  - Great Lakes
    - ~ 1/4 to 1/8 of size of Caspian
- Shallow to deep
  - Lake Baikal
    - 1700m

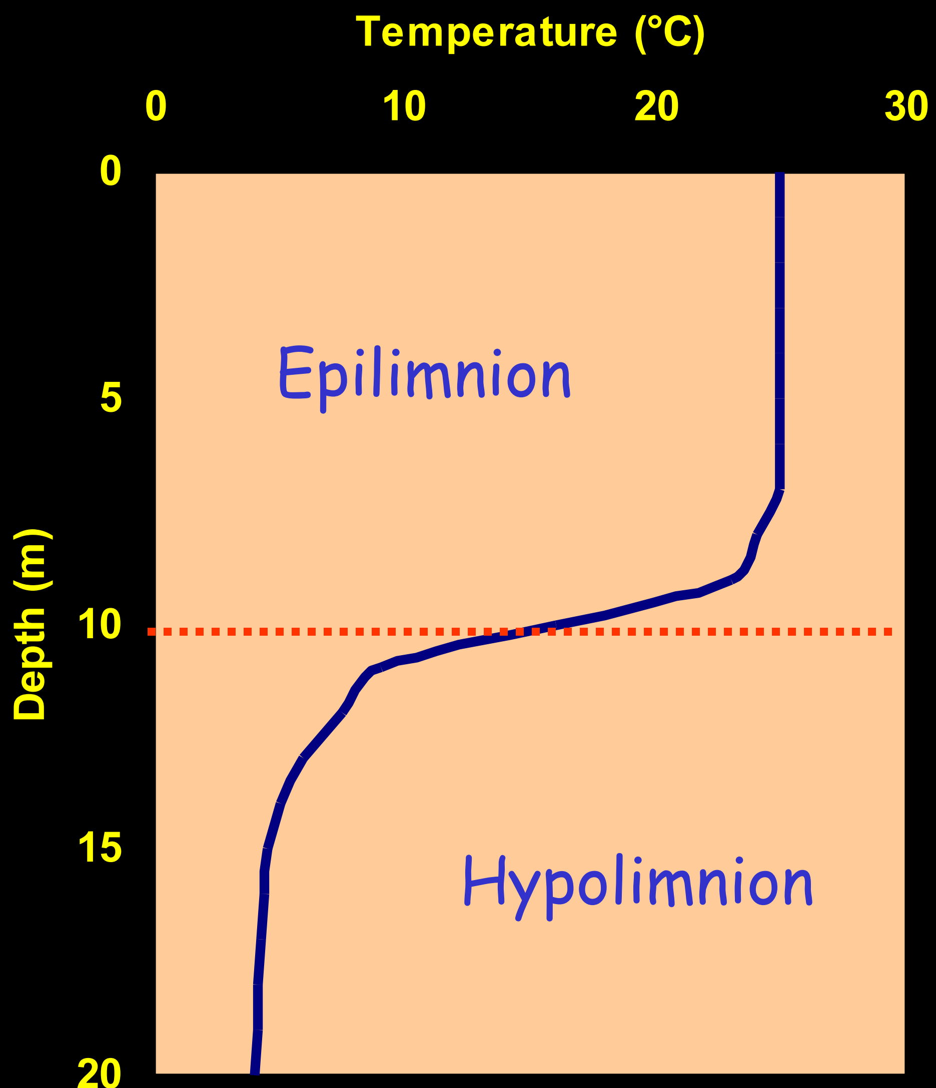
Caspian Sea

The northern part of the Caspian freezes during the winter, in harsh winters, the whole northern area of the sea is covered with ice. Ice can occur in the southern regions of the sea in December and January. In mild winters, ice forms in shoals in the shallow areas near the coast.

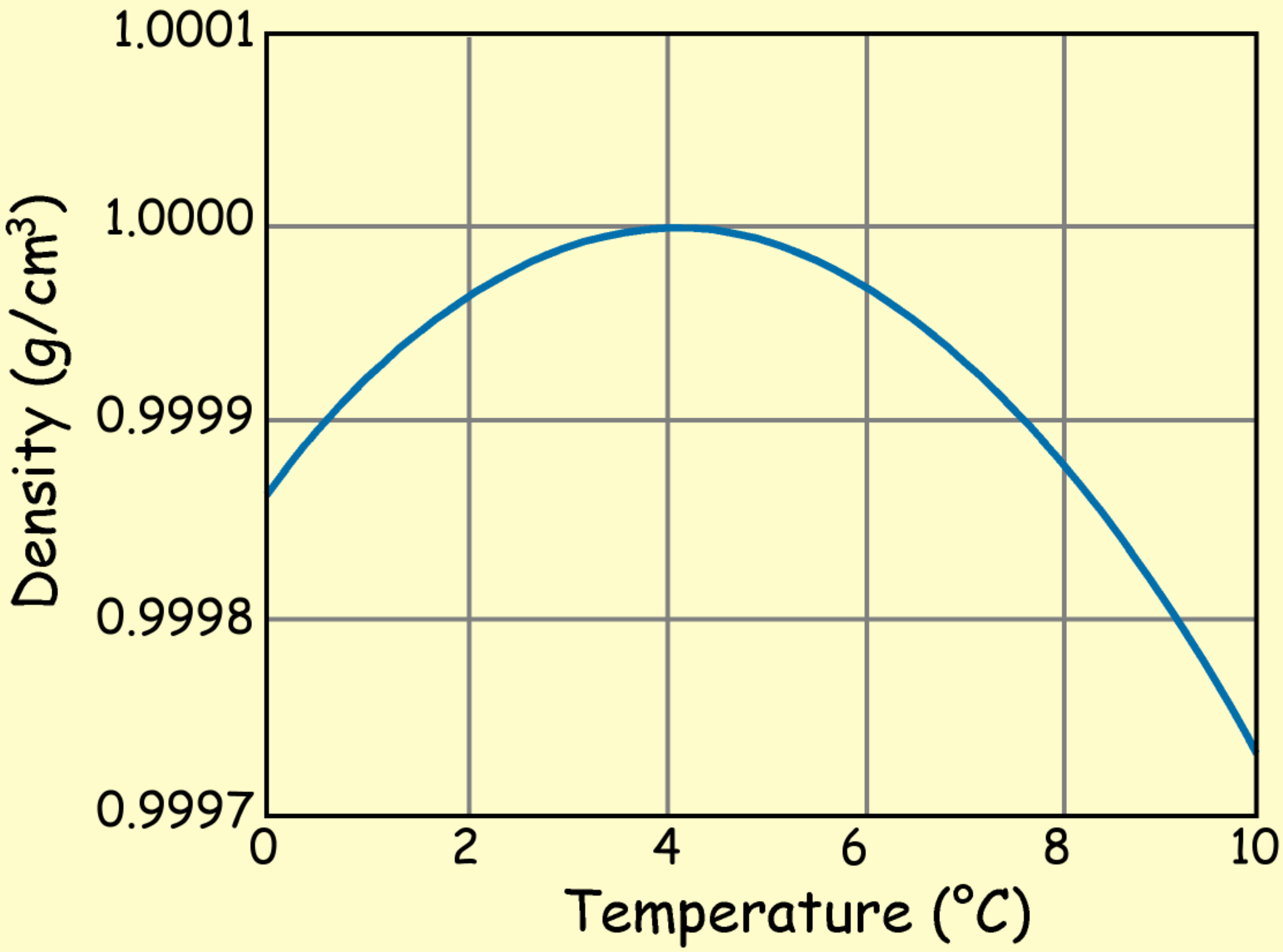
Lake Baikal



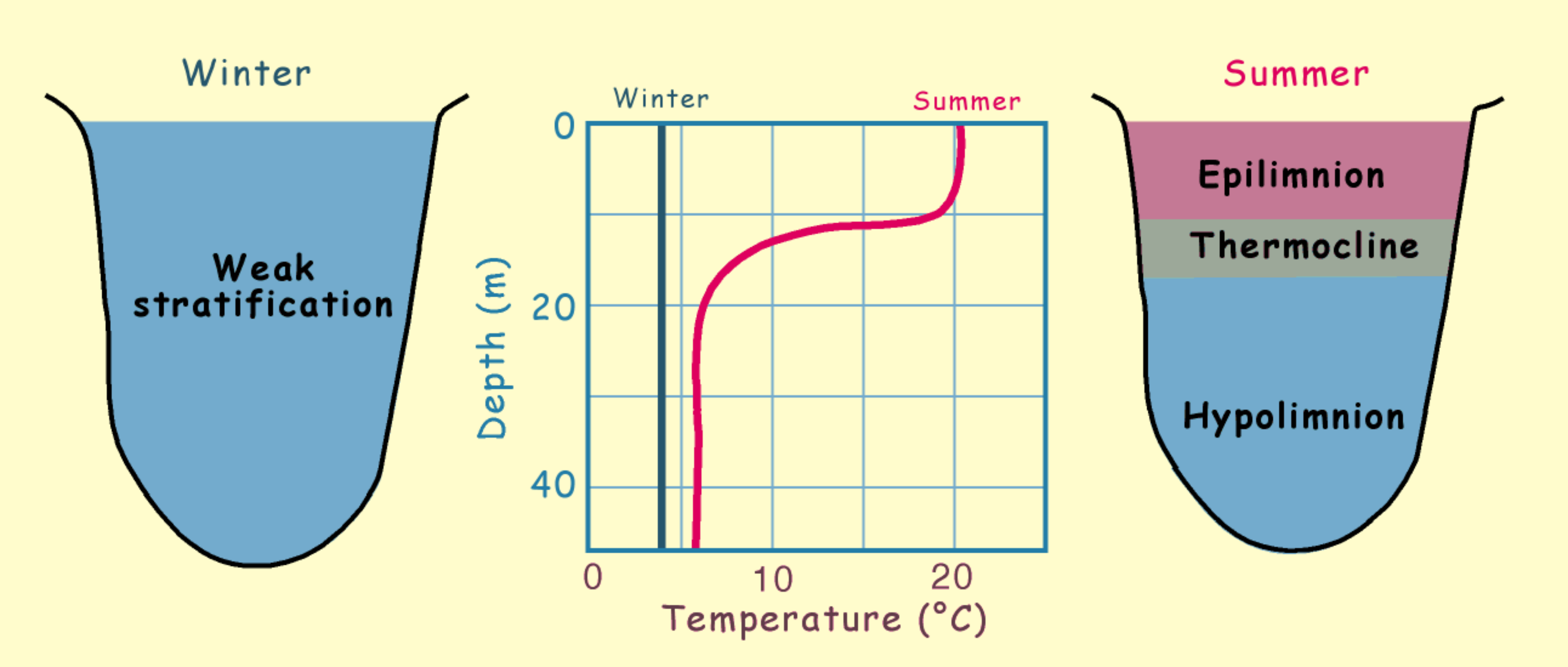
Thermal Stratification



Thermal stratification of lakes: the physical properties of water



Thermal stratification of temperate lakes



Seasonal Stratification

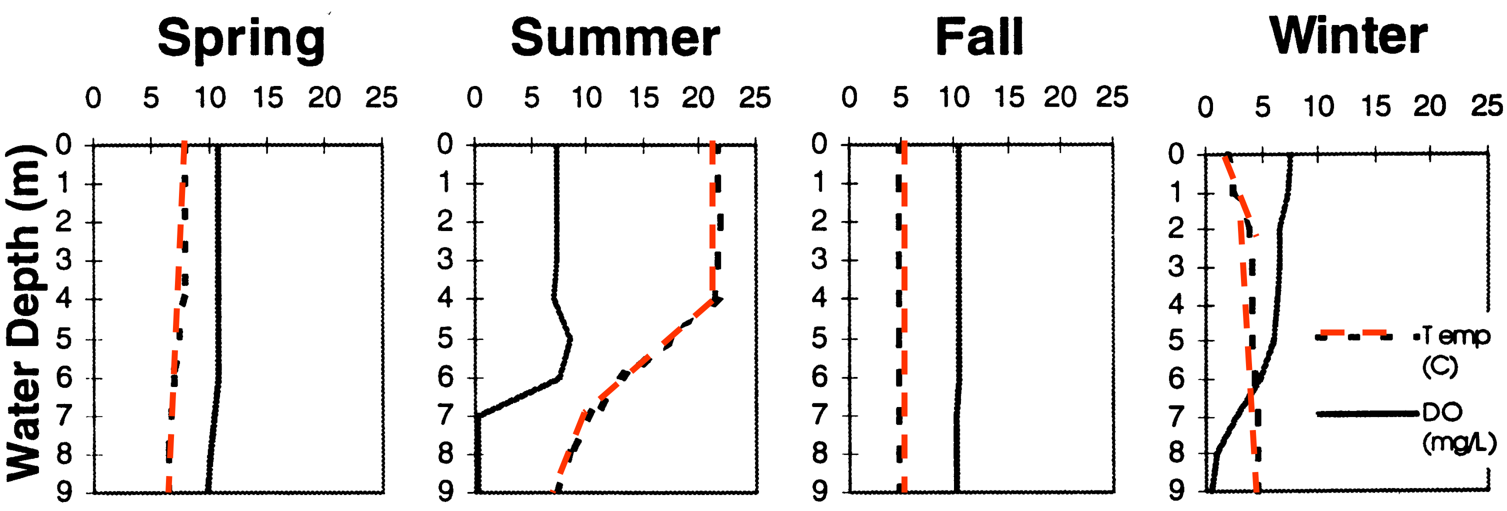


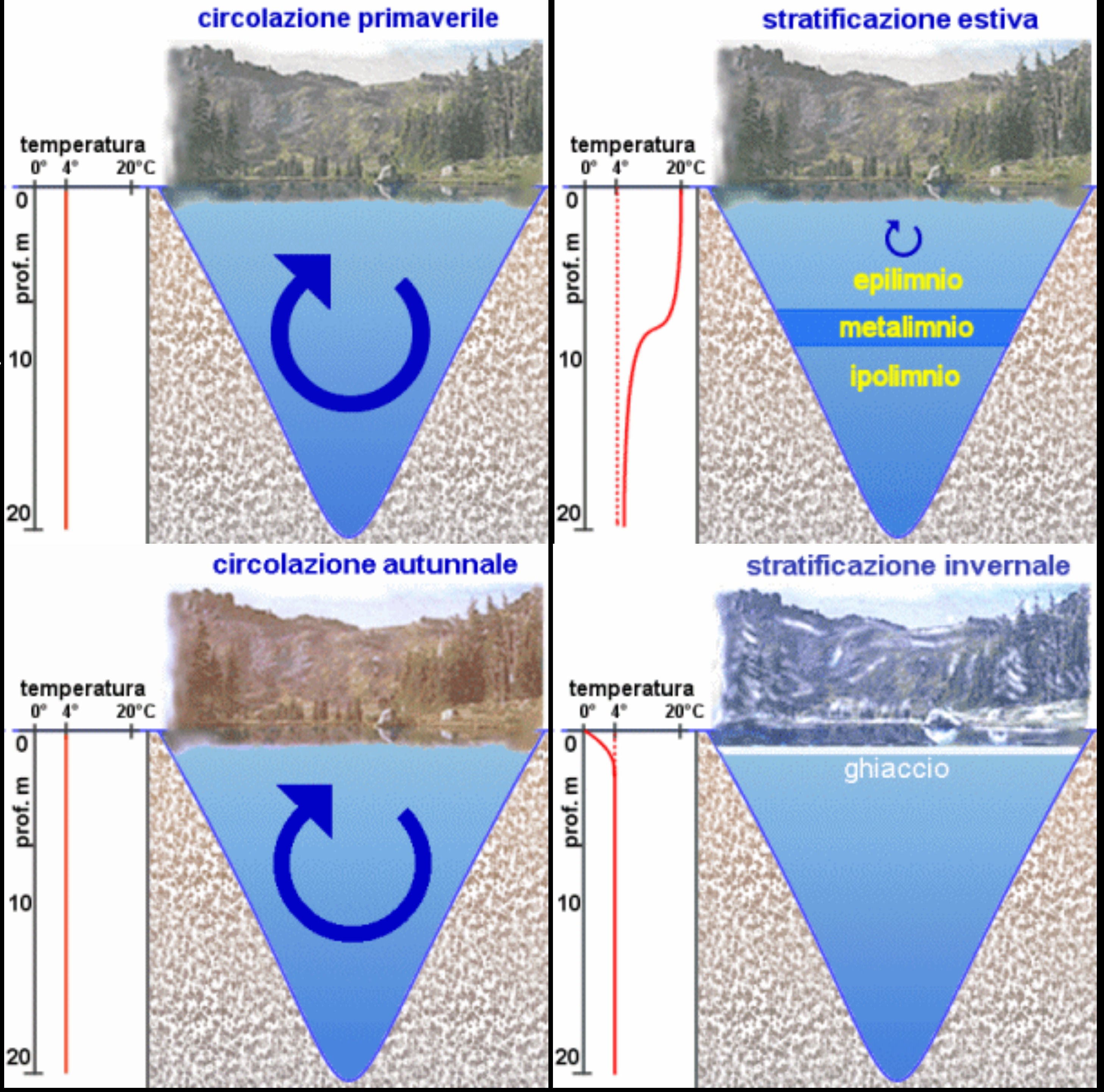
Figure 4.1. Seasonal water column dissolved oxygen and temperature for the Treatment Basin of Little Rock Lake. Samples were collected from the deepest, central location in the basin on the following dates: Spring – 4/27/88, Summer – 8/26/96, Fall – 11/8/96, Winter – 1/29/97. The Treatment Basin demonstrated mixing during Spring and Fall while during Summer and Winter there is stratification and oxygen depletion.

Lago 20 m di prof. Densità max H_2O: 4 ° C

Fine inverno: T= ca. 4° C.
Aumenta la radiazione con innalzamento della T della acque superficiali

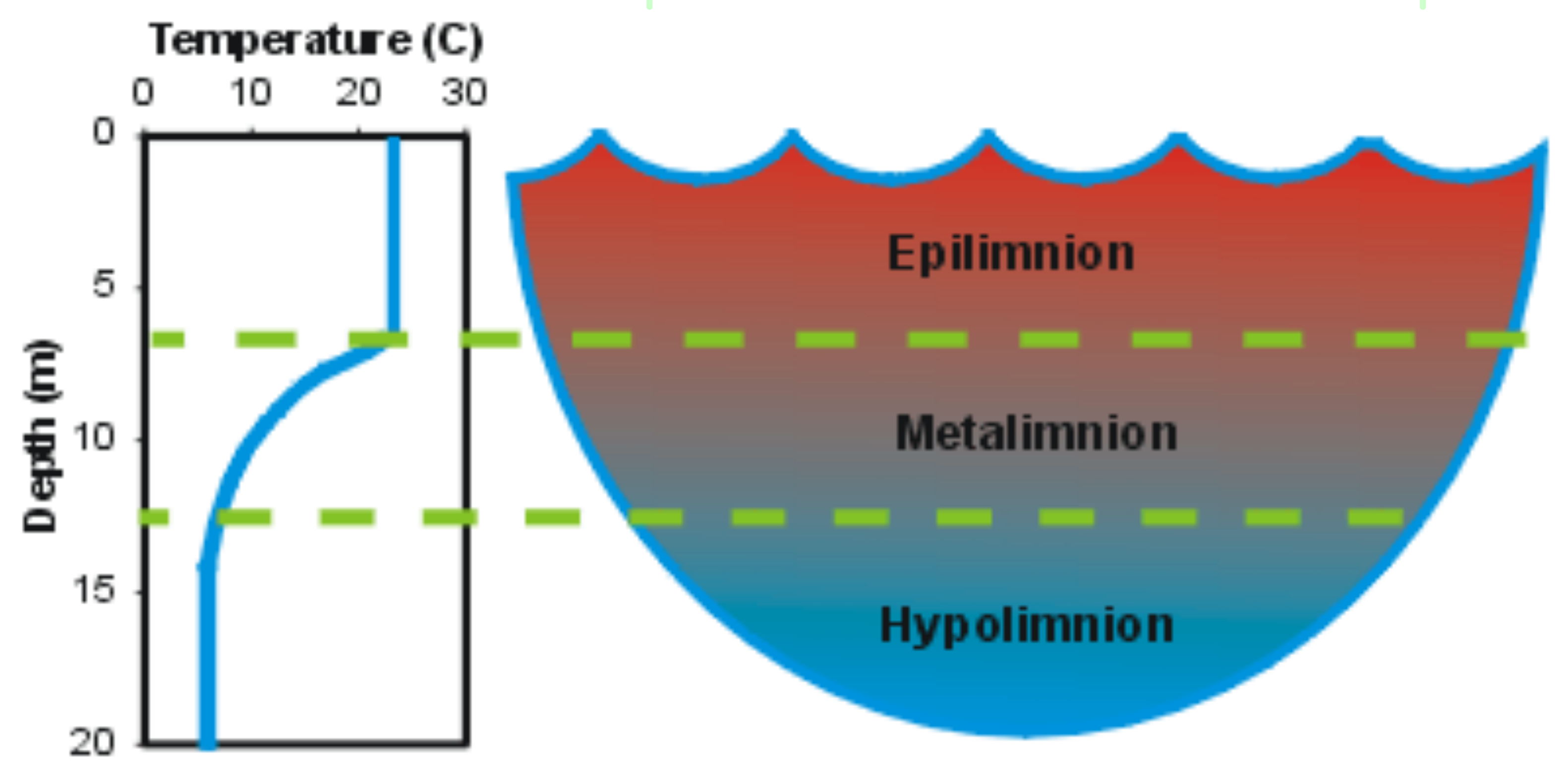
L'acqua superficiale si raffredda, diventa più densa e scende verso il fondo.

La densità dell'acqua diminuisce per un ulteriore raffreddamento: stratificazione termica inversa. Il ghiaccio può rendere stabile la stratificazione termica inversa.



Epilimnio: intende lo strato superficiale di un lago e risente della radiazione solare con temperature maggiori degli strati sottostanti.

Il **Metalimnio** è quella zona in cui si assiste alla rapida diminuzione della temperatura.



Se il lago è abbastanza profondo è presente uno strato in cui la temperatura si mantiene costante intorno ai 4 ° C: **ipolimnio.**

Two other definitions:

A chemical one:

Chemiocline – It is a cline (water layer where the physico-chemical properties rapidly change) caused by a rapid and sharp vertical chemical gradient. It is similar to thermocline (metalimnion) where warmer water meets cooler waters.

Volcanic lakes

…and a general one:

Crater lake is a volcanic lake within an active volcano (e.g. Poas, Copahue, El Chichon, Kawah Ijen).

Volcanic lake is not necessarily in a crater of an active volcano.
Other lakes: maar lake, caldera lake, etc.

According to climatic conditions and lake depths, we may have annual cycling of the lake waters. Accordingly, a sort of classification can be done:

Olomictic lakes, at least one full circulation phase;

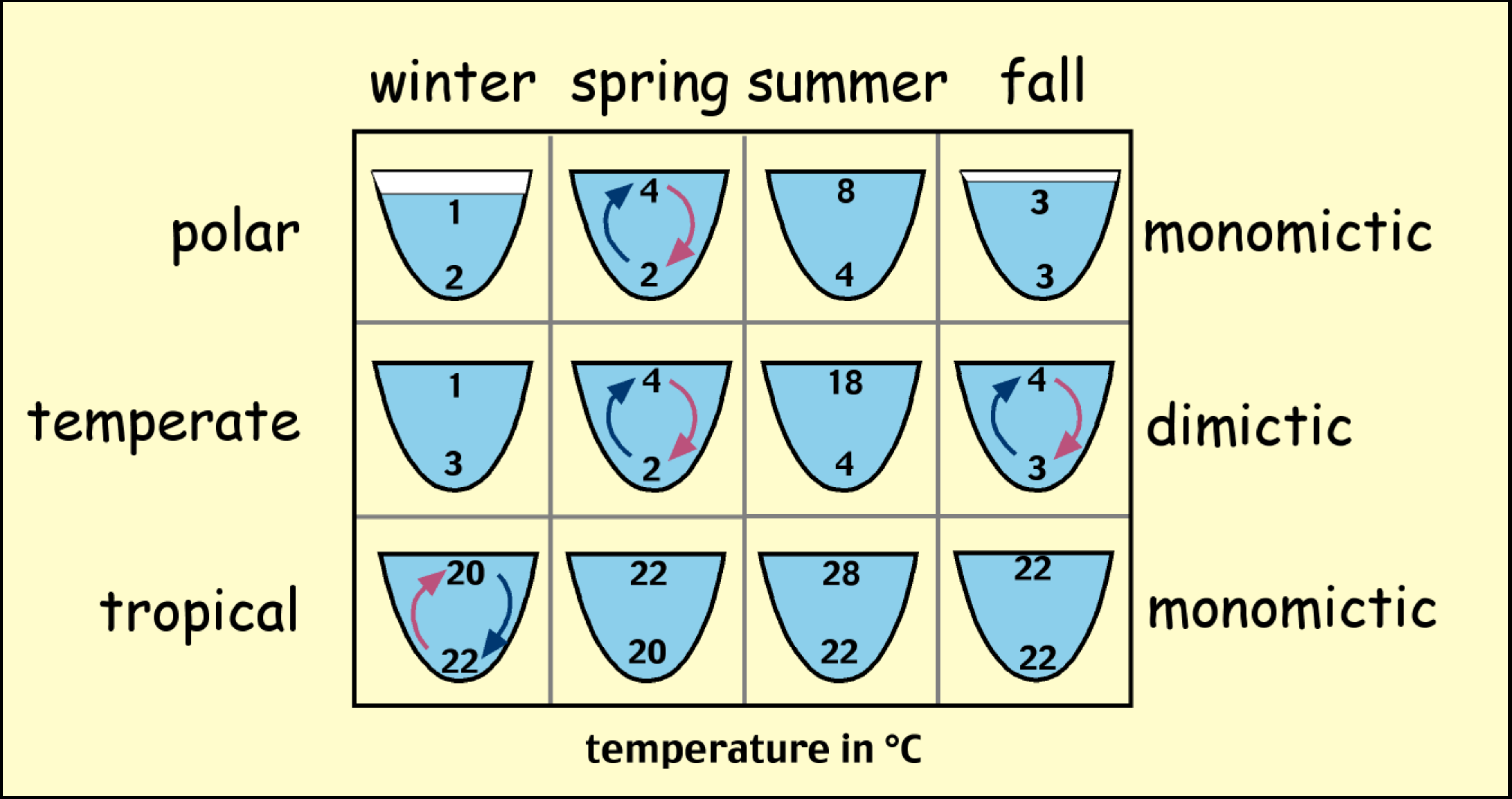
Dimictic lakes, two phases of full circulation;

Oligomictic lakes, phase of full circulation not each year;

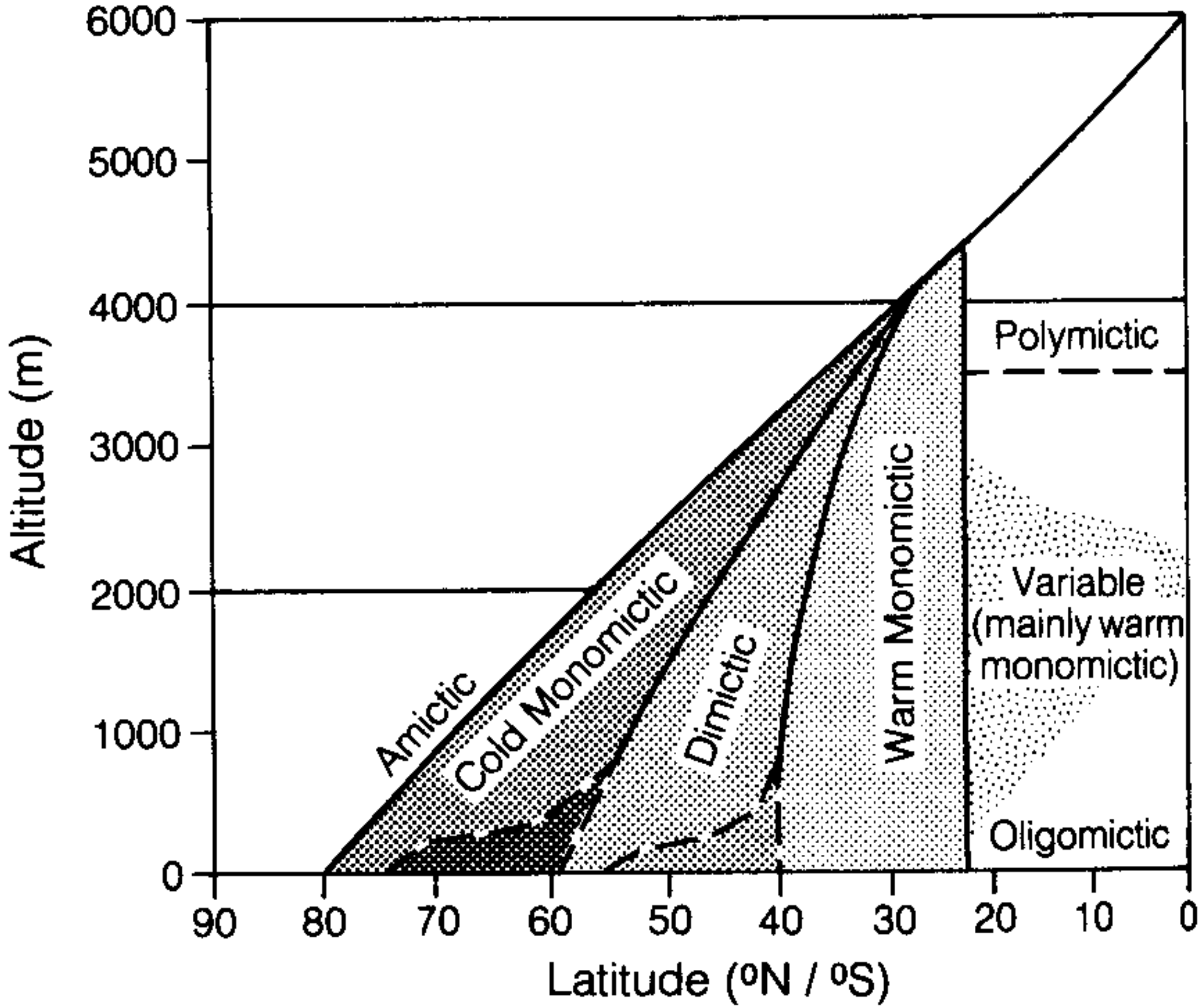
Monomictic lakes, and so forth;

Meromictic lakes, no full circulation phase (perennial stratification due to either thermal reasons or high saline contents or both).

Lake mixing types



Lake mixing types

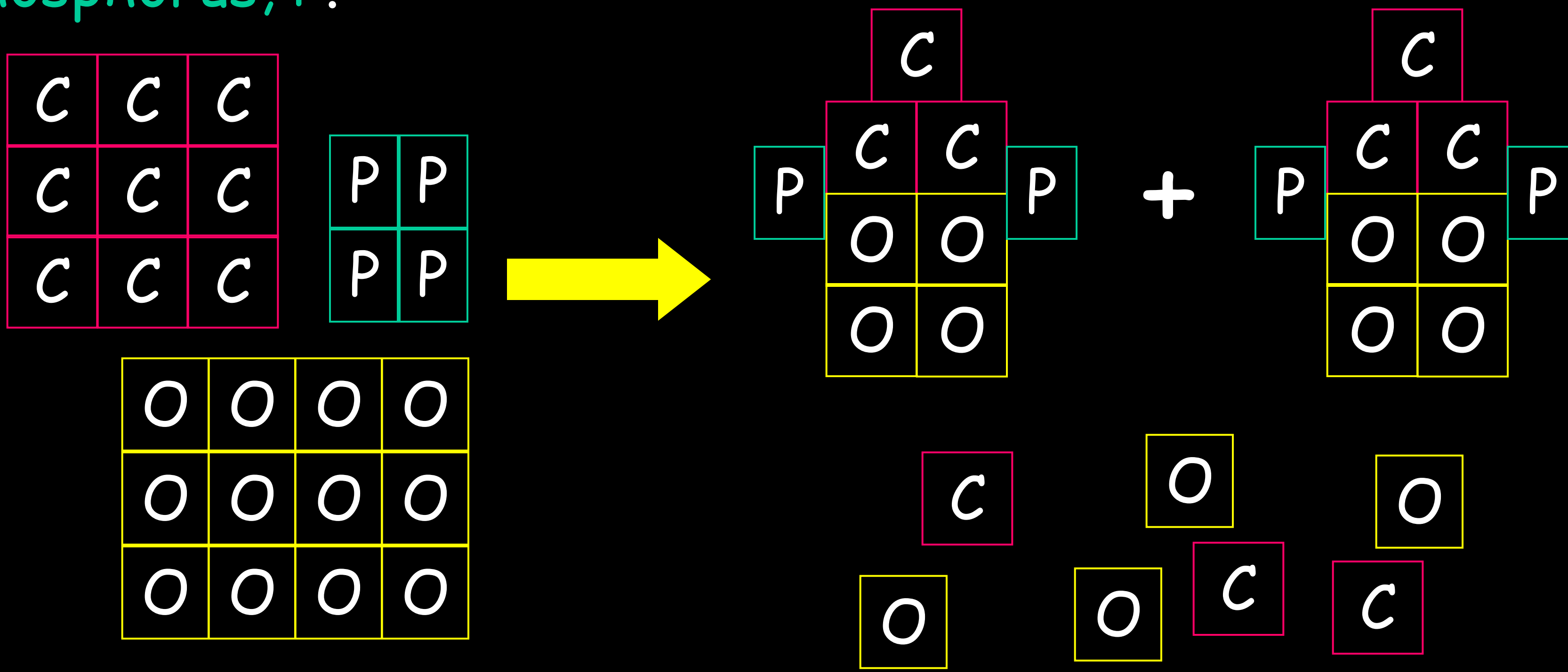


Perturbations of lake environments

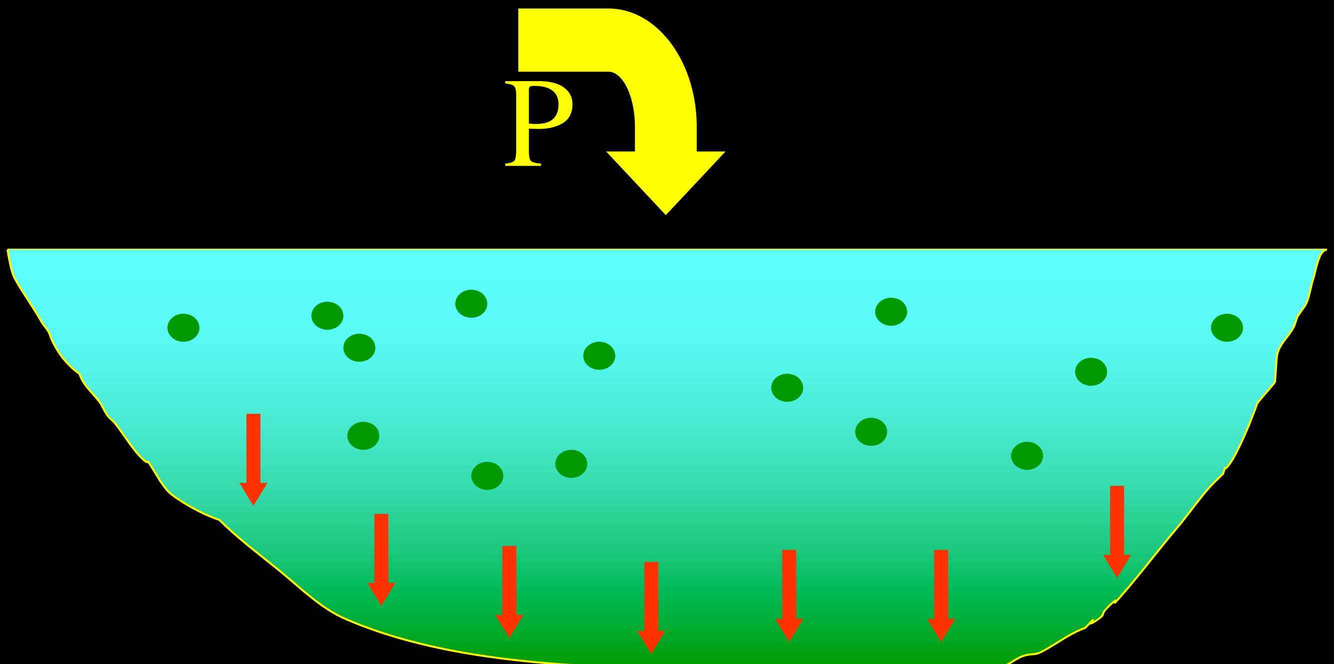
1. GEOLOGICAL
   local events such as landslides;
   regional events such as tephra deposition
2. CLIMATIC
   changes in regional climate (precip. or evap.)
3. ANTHROPOGENIC
   agricultural/industrial/urban pollution
4. BIOTIC
   invasion by exotic species (often anthropogenic)

Nutrient Limitation

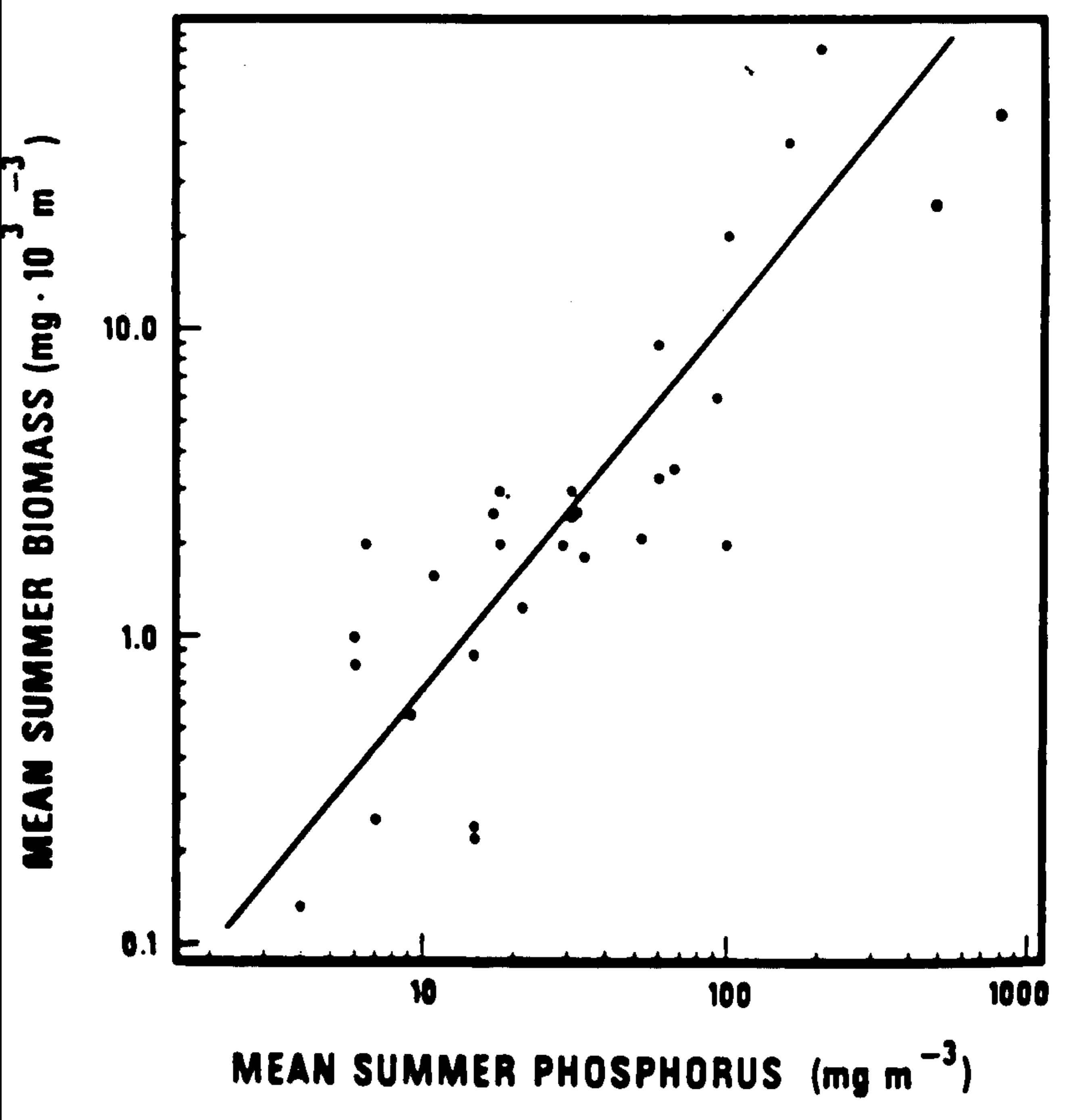
The growth of algae and higher aquatic plants in lakes is regulated by conditions of light and temperature and the availability of those inorganic nutrients required to support growth. The element most often in limiting supply is phosphorus, P.



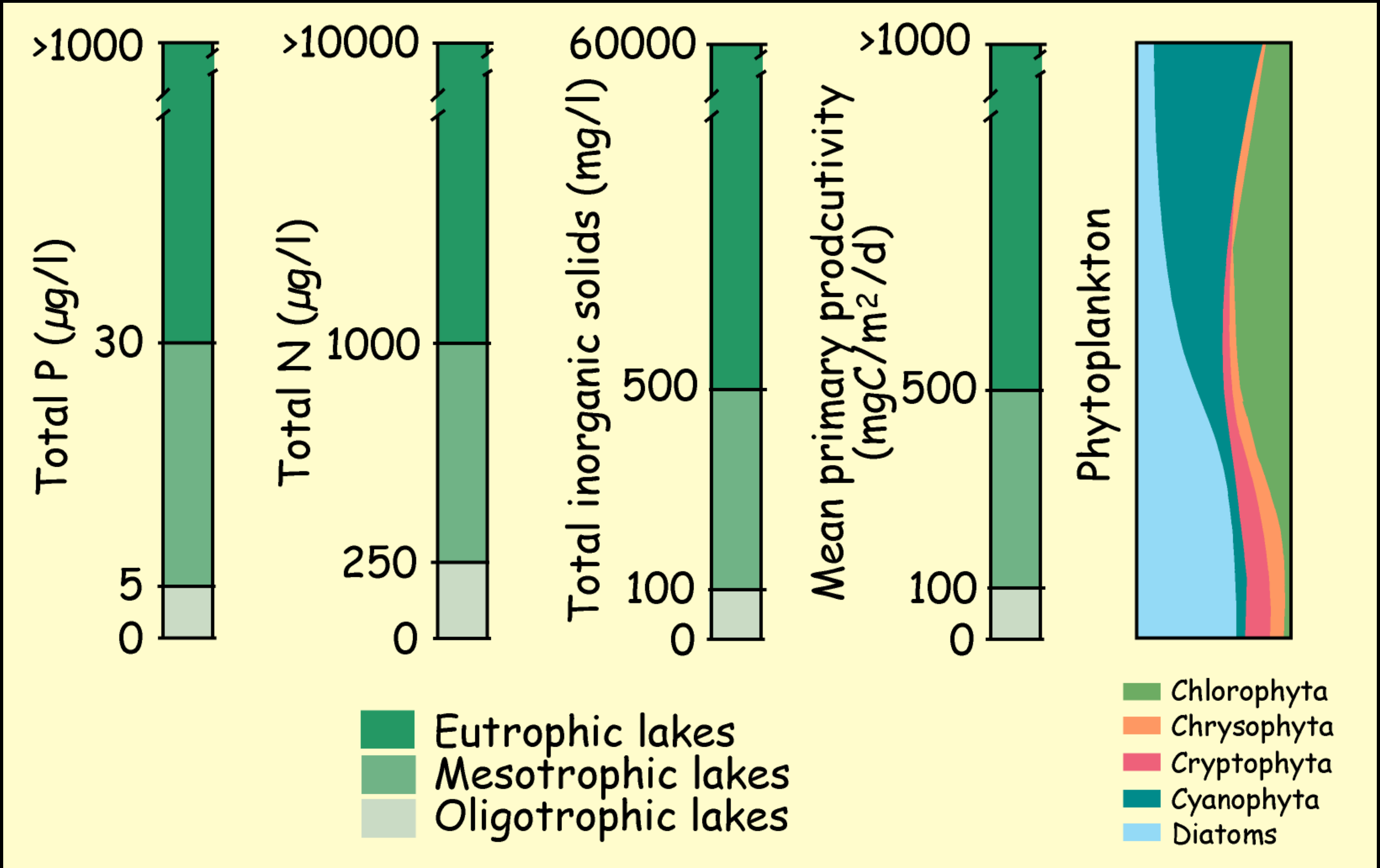
Eutrophication



Biomass (= lake primary productivity) in relation to P availability



Lake classification: trophic status



Effects of Eutrophication

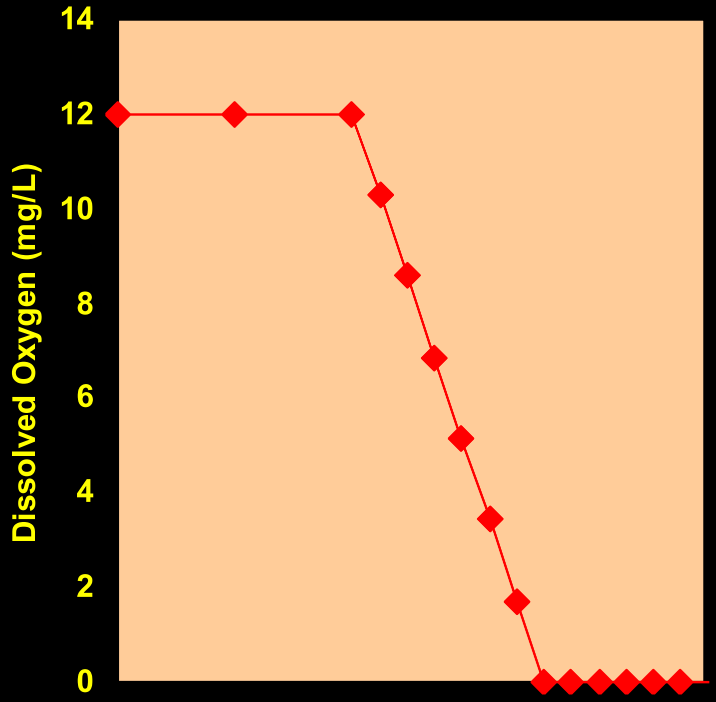
<u>Oligotrophic</u>

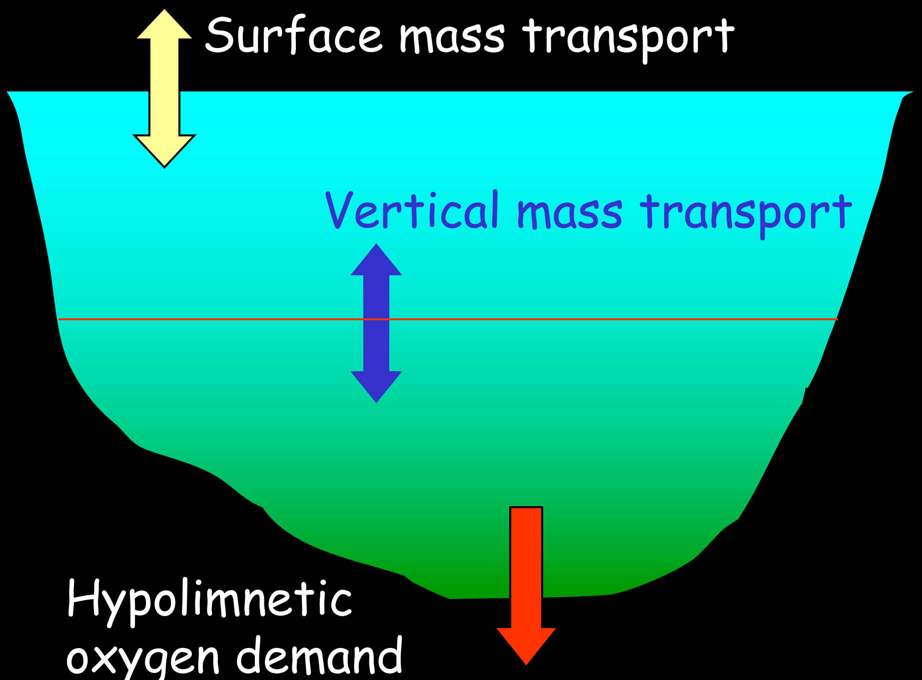
1. Low biomass
2. High diversity
3. Complex food web
4. Oxic waters
5. Cold-water fish present
6. High aesthetic quality
7. No taste or odor problems

<u>Eutrophic</u>

1. High biomass
2. Low diversity
3. Simple food chain
4. Anoxic bottom waters
5. Cold-water fish absent
6. Low aesthetic quality
7. Taste and odor problems
8. Rough fish abundant
9. Toxic algae present

Oxygen supply





Biogeochemical Cycles

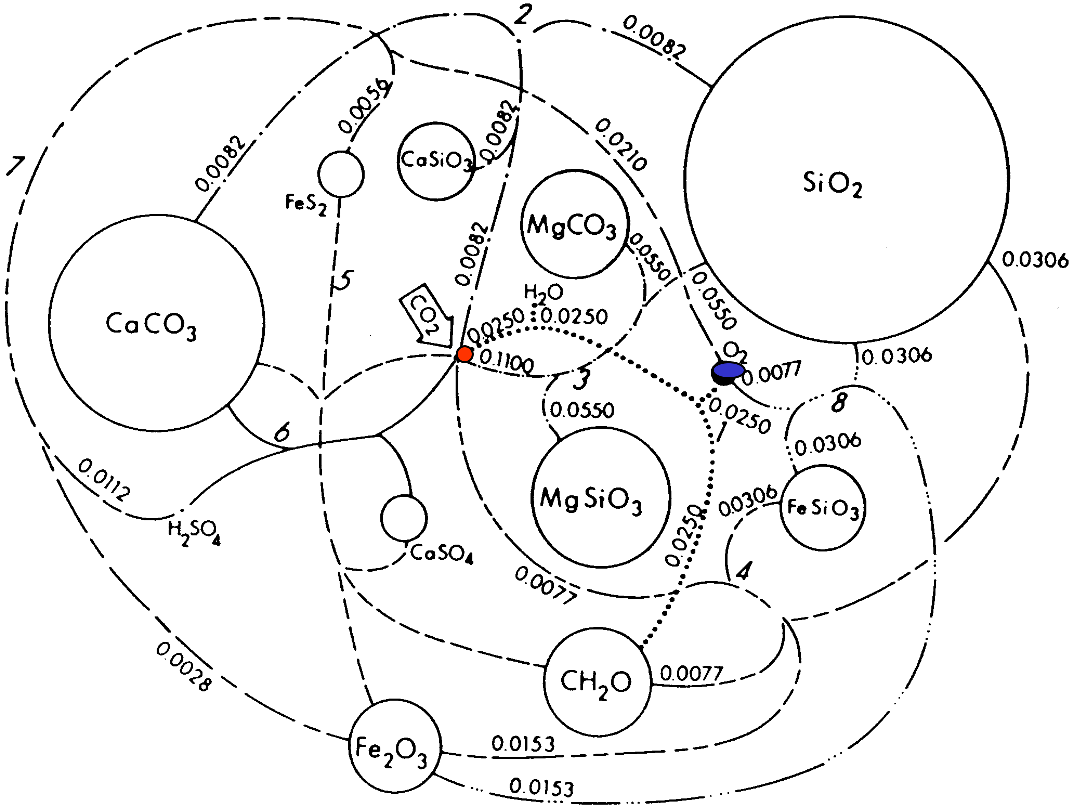
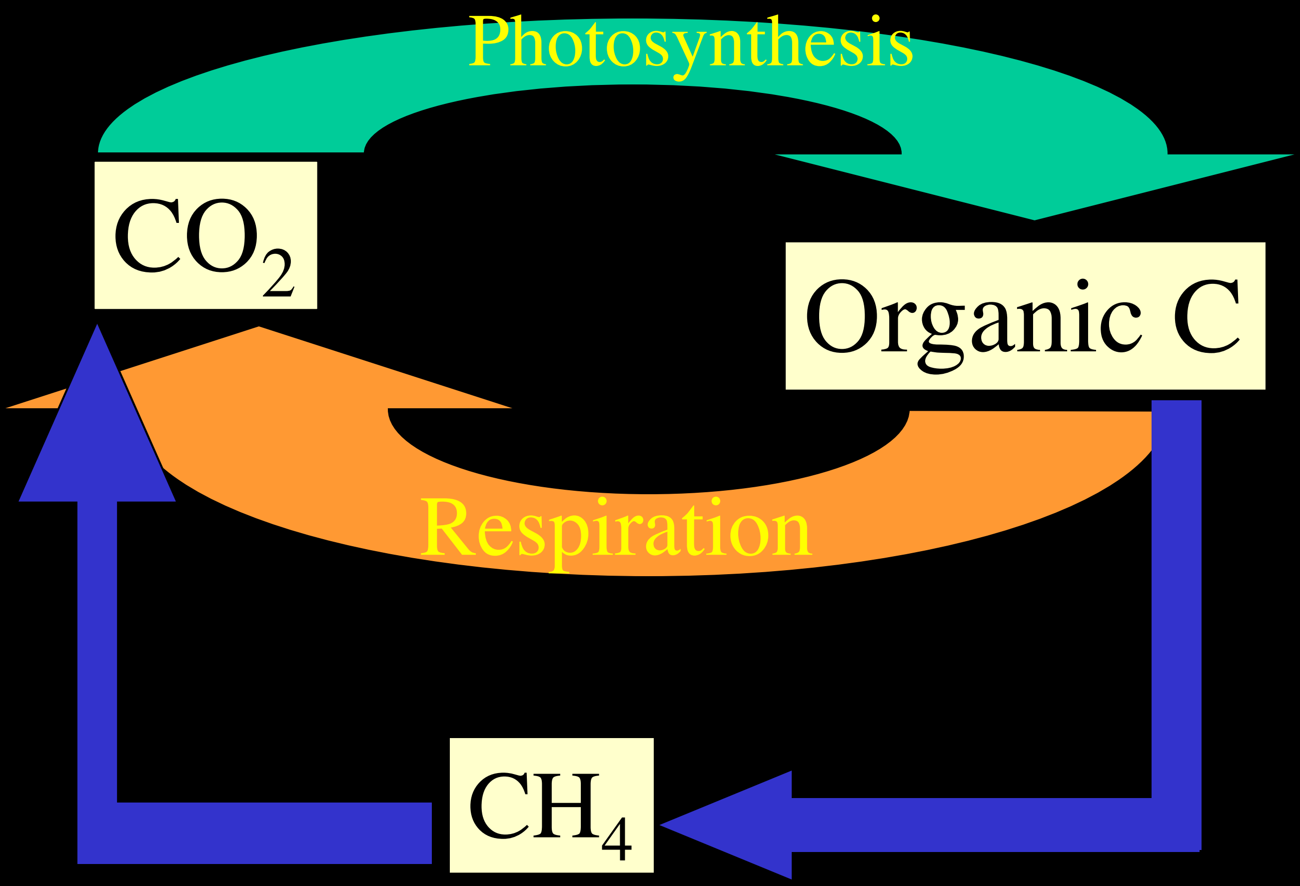
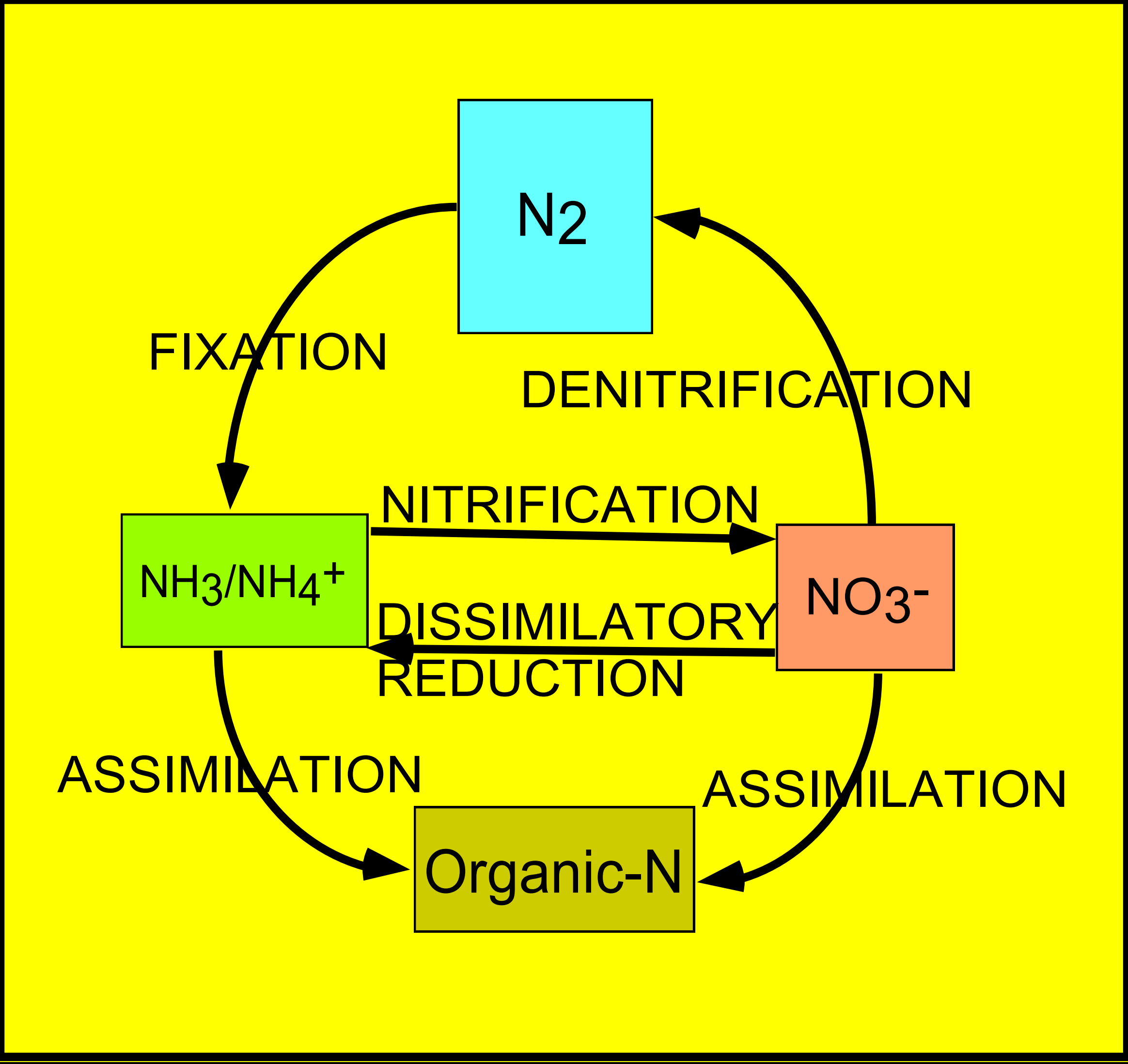


Fig. 6. Steady-state flow net. The circled numbers refer to reactions given in Table IV. Reactions 5 and 6 involve reservoir transfers so that steady-state fluxes are not given. Reservoir areas are proportional to the number of moles contained.

Another view of the carbon cycle



Nitrogen Cycle



Human perturbations to N Cycle

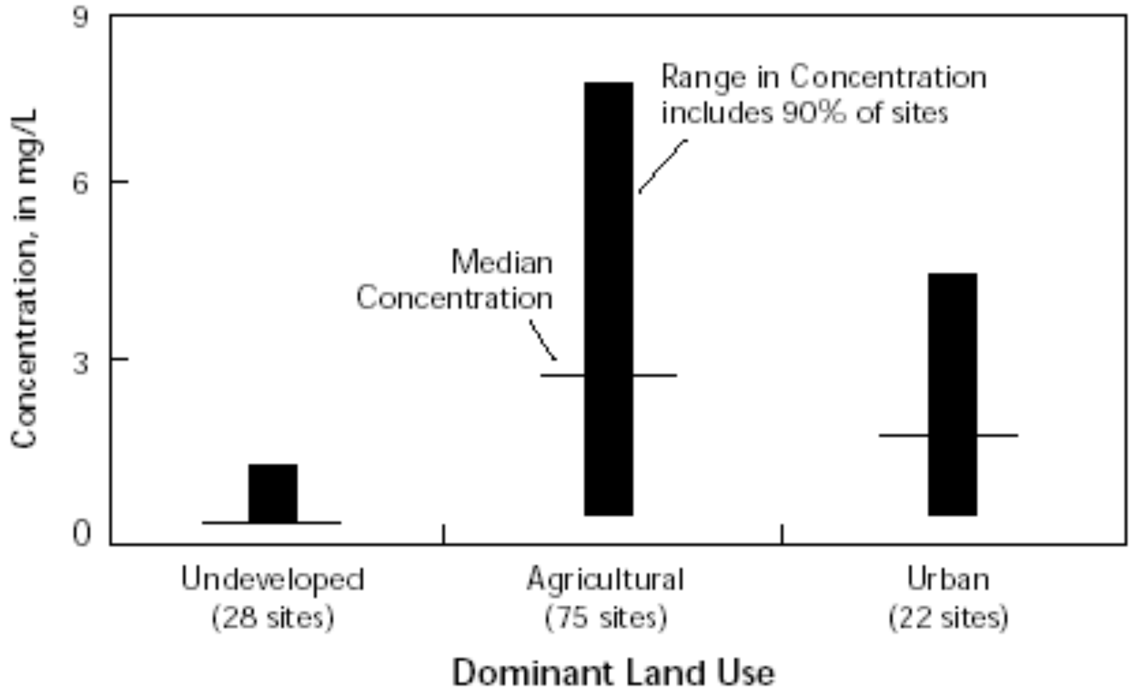


Figure 1. Total Nitrogen in Streams

Eutrophication

Eutrophication: the process of becoming or being made eutrophic

Eutrophic: the state of being enriched in nutrients or food sources

In aquatic ecosystems, eutrophication is caused by excessive inputs of nutrients, both N & P. Generally, freshwaters are P-limited and coastal estuarine waters are N-limited. The nutrients **enhance algal growth**, and this, in turn, may have a cascade of effects on the ecosystem. These effects may include: **algal blooms**, growth of **undesirable algal species**, **oxygen depletion** or **anoxia** in bottom waters, loss of cold-water fish species, abundance of "**rough fish**", **fish kills**, unpleasant **tastes and odors**.

Sources of nutrients

- Point sources
  - Sewage treatment plant discharges
  - Storm sewer discharges
  - Industrial discharges
- Non-point sources
  - Atmospheric deposition
  - Agricultural runoff (fertilizer, soil erosion)
  - Septic systems

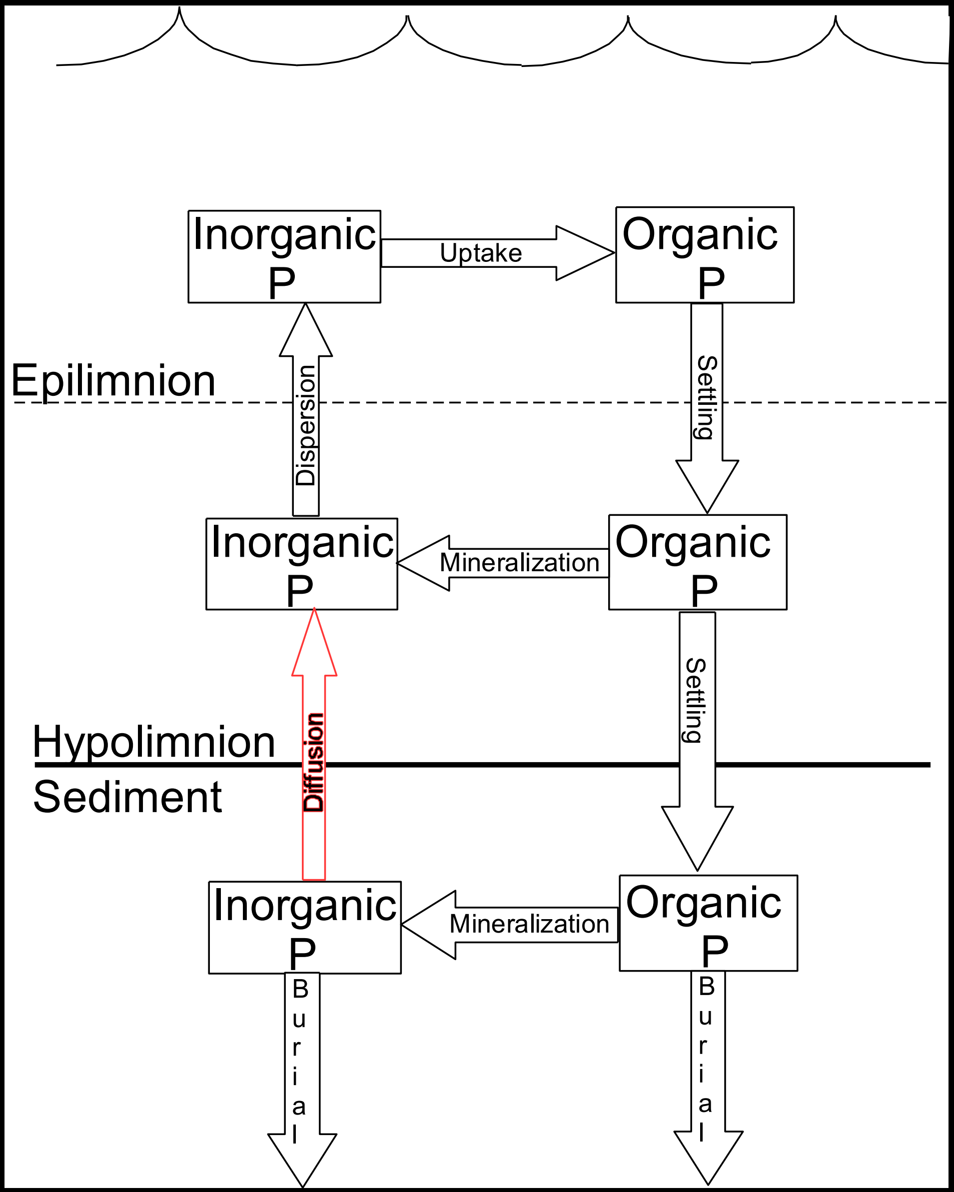
Solution: Reduce nutrient inputs

- Agriculture
  - Reduce animal density, restrict timing of manure spreading, buffer strips by streams, reduced tillage, underground fertilizer application, wetland preservation and construction
- Watershed management
  - Buffer zones, wetland filters
- Storm runoff
  - Eliminate combined sewer systems (CSO's)
  - Stormwater treatment required (holding ponds, alum)
  - Education on yard fertilization
- Erosion from construction, forestry
  - Erosion barriers, soil cover, road and bridge stabilization
- Septic systems
  - Distance from lake, adequate drainfields

Mitigation strategies

Often there is pressure for quick actions that will reduce the severity of the symptoms. Numerous options exist. To understand these options and choose among them, one should understand the nutrient cycle within the aquatic system (lake).

P Cycle



The P cycle may be manipulated in several ways to reduce the regeneration of inorganic P and its transport to the epilimnion or to reduce the algal uptake of P.

Volcanic lakes in the world

- 16% of the 714 volcanoes which are youger than 10,000 years contain a lake
- higher percentage for arc volcanoes
- they can store large amounts of lethal gases (CO_2)

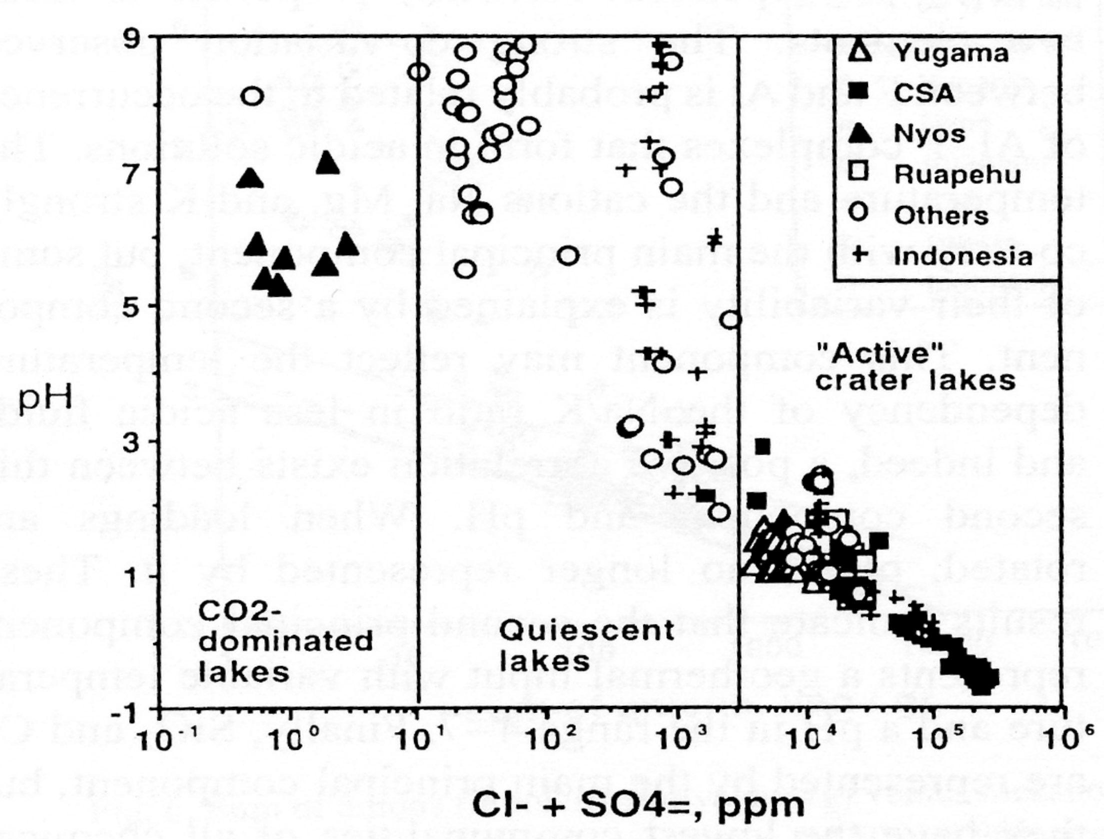
some are mixtures of HCl and H_2SO_4 → they are the most acidic natural waters on Earth (down to pH < 0)

Crater lakes : a first classification

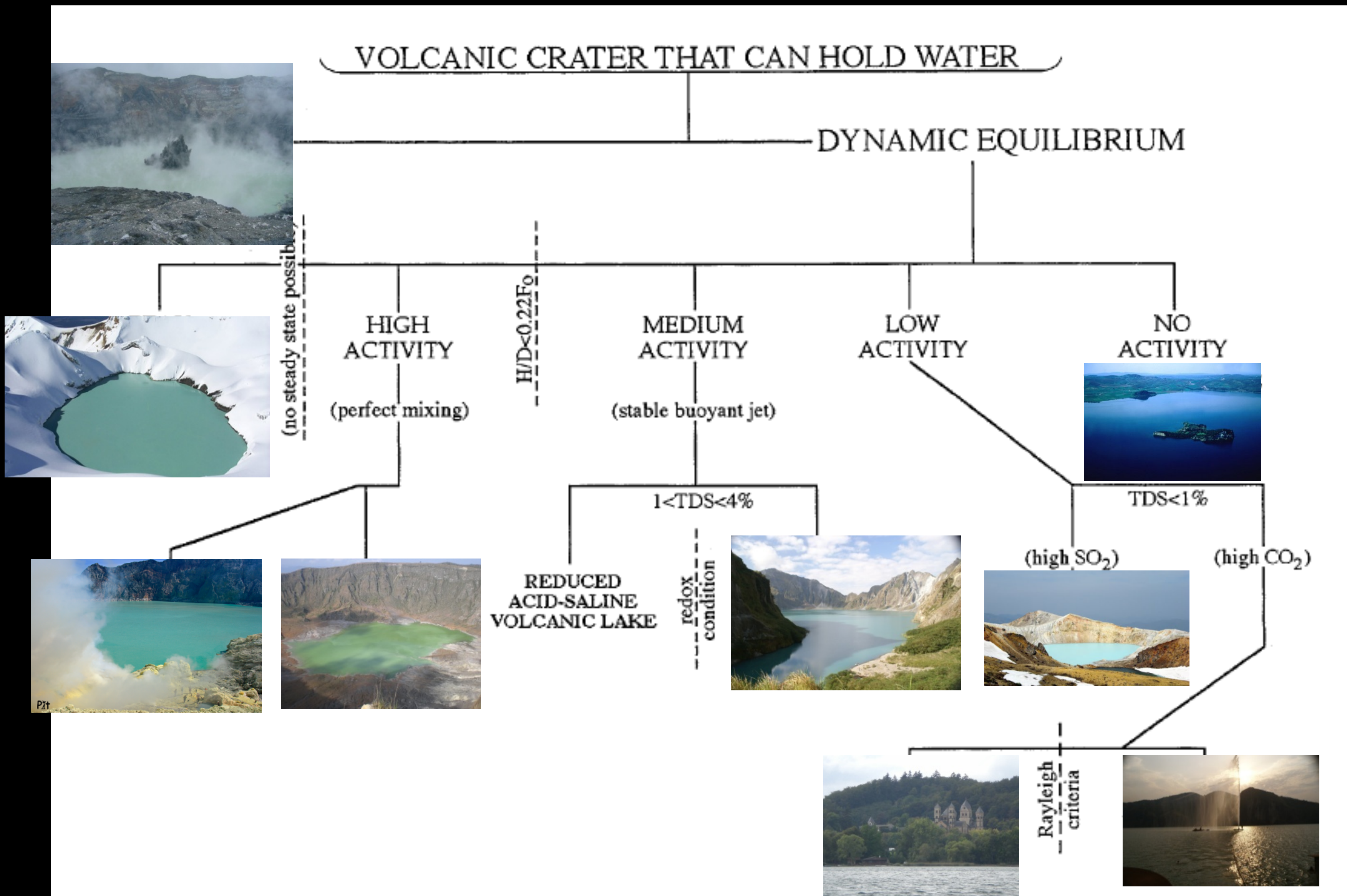
pH-Cl+SO_4 classification:

CO_2-lakes (Nyos type) : neutral pH (~5-7) + low Cl+SO_4 (< 5 ppm): ALBANO

- geothermal quiescent lakes: large-range pH (2-9), moderate Cl+SO_4 (< 2000 ppm): IRAZU (Costa Rica)
- active crater lakes: acidic pH (2 - -1), high Cl+SO_4 (> 2000 ppm): POAS (Costa Rica)

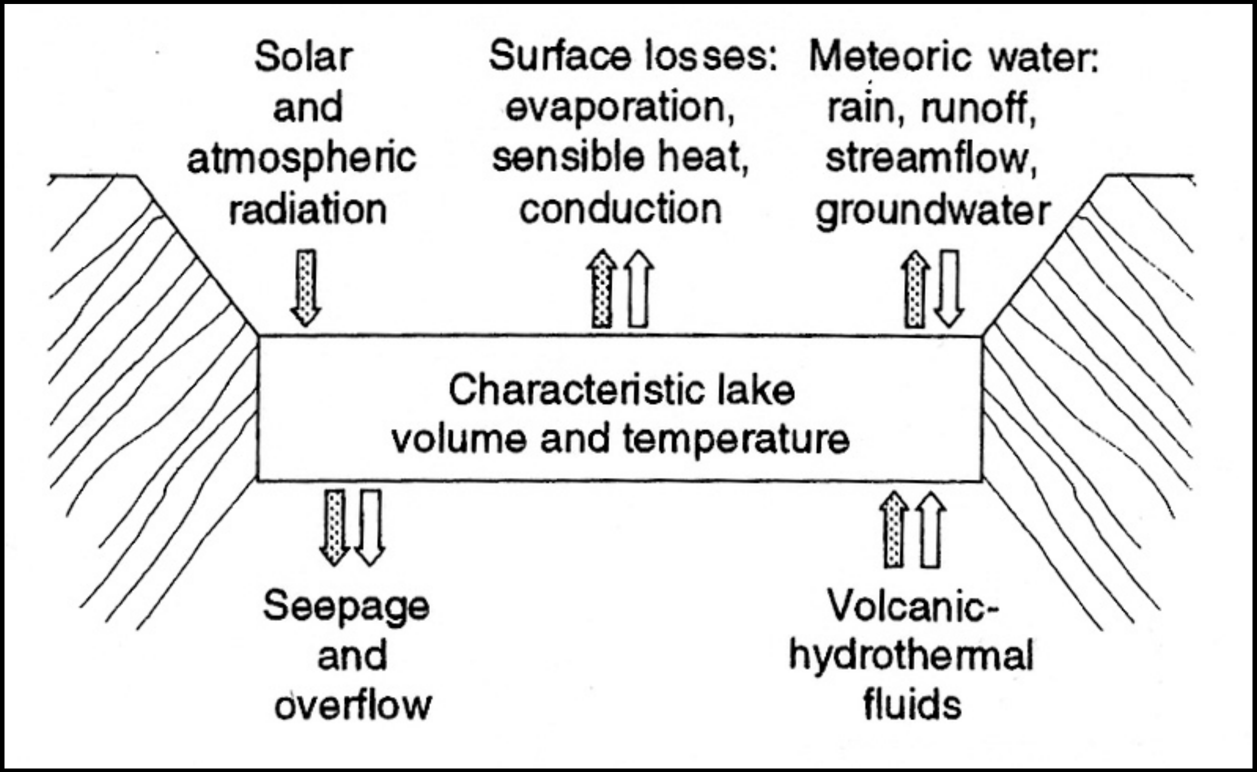


Pasternack & Varekamp (1997)




Active Crater lakes

Active Crater lakes: condensers & calorimeters



Persistent volcanic lakes result from hydrothermal systems which transport heat, water & chemicals from a cooling & degassing magma body

dynamic processes in lakes

ratio heat input/heat dissipation determines the persistence and the temperature of the water

most heat dissipation occurs at lake surface ➔ small lakes have small capacity for heat dissipation and their T rises quickly with small inputs

great lakes are better buffered against variations in heat inputs

Fluid balance

Inputs: volcanic & hydrothermal fluids (gas, steam, brines) + meteoric water (precipitation, runoff, streamflow)

outputs: evaporation, lake water seepage, overflow, ground infiltration

Heat balance

Input: enthalpy of the entering fluid + solar & atmospheric radiation

Outputs: evaporative & radiative fluxes from lake surface, seepage and overflow and cooling effect of precipitation and runoff in lake

Active Crater lakes and volcanic hazard

Heat-water interaction…phreatic and phreato-magmatic eruptions

Ash (volcanics)-water interaction…lahars

How to study (and monitor) active crater lakes ?

- The box model approach

Mass balance: sum of the in- and output fluxes of water mass

water mass budget of the lake can be expressed in a differential form:

$$V_L - V_{L0} = Q_f\,Dt + Q_m\,Dt + Q_{sp}\,Dt - Q_e\,Dt - Q_s\,Dt - Q_o\,Dt$$

$V_L - V_{L0}$ is the change in volume of crater lake water during the period of observation

Q_f is the input flux of "volcanic" fluid from beneath the lake (kg/s)

Q_m is the input flux of meteoric water (kg/s)

Q_{sp} is the input flux of water from springs located outside the lake (kg/s)

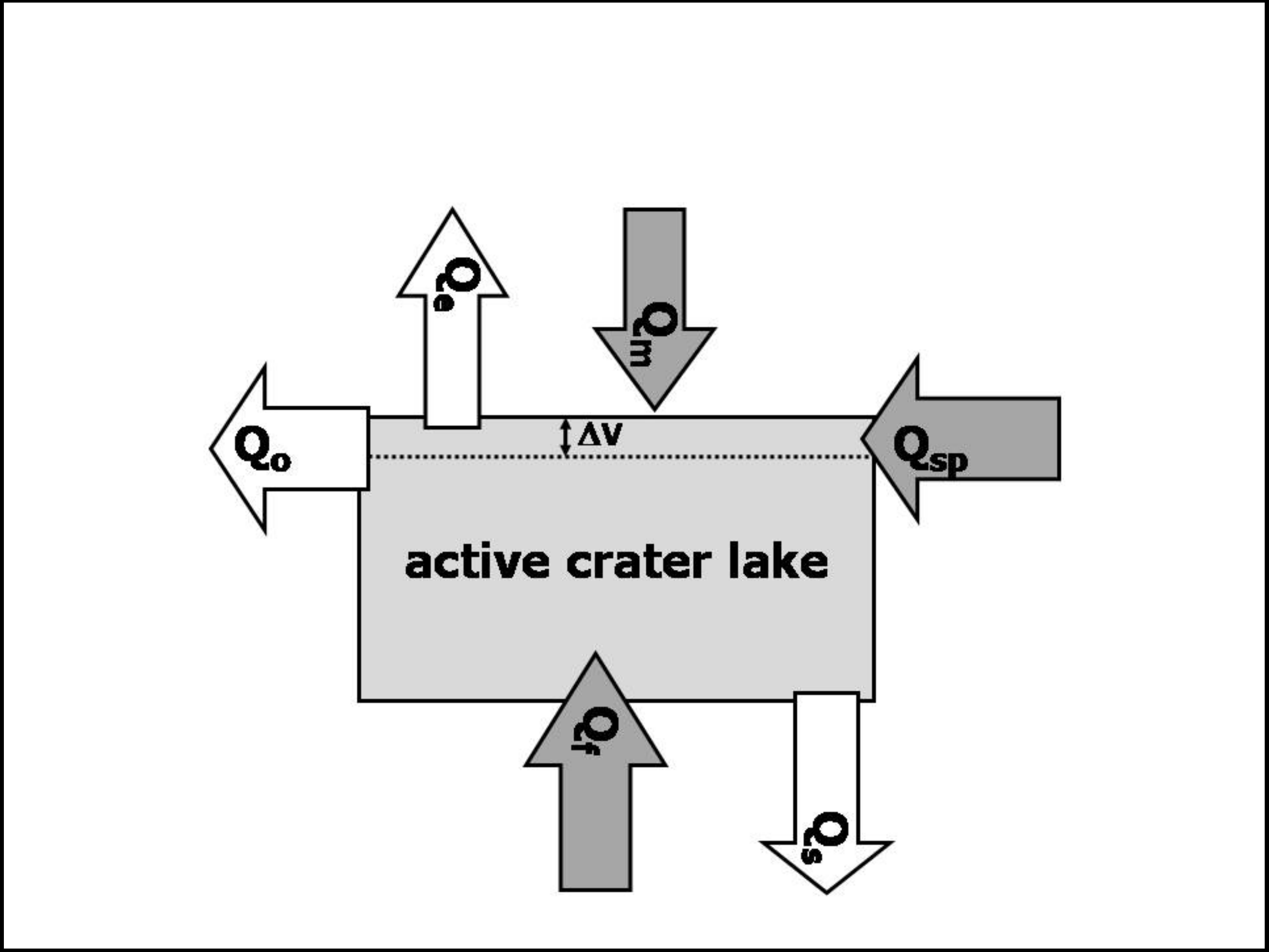
Q_e is the evaporative flux of water from the lake surface (kg/s)

Q_s is the seepage flux of water at the lake bottom (kg/s)

Q_o is the overflow flux of water out of the lake basin (kg/s)

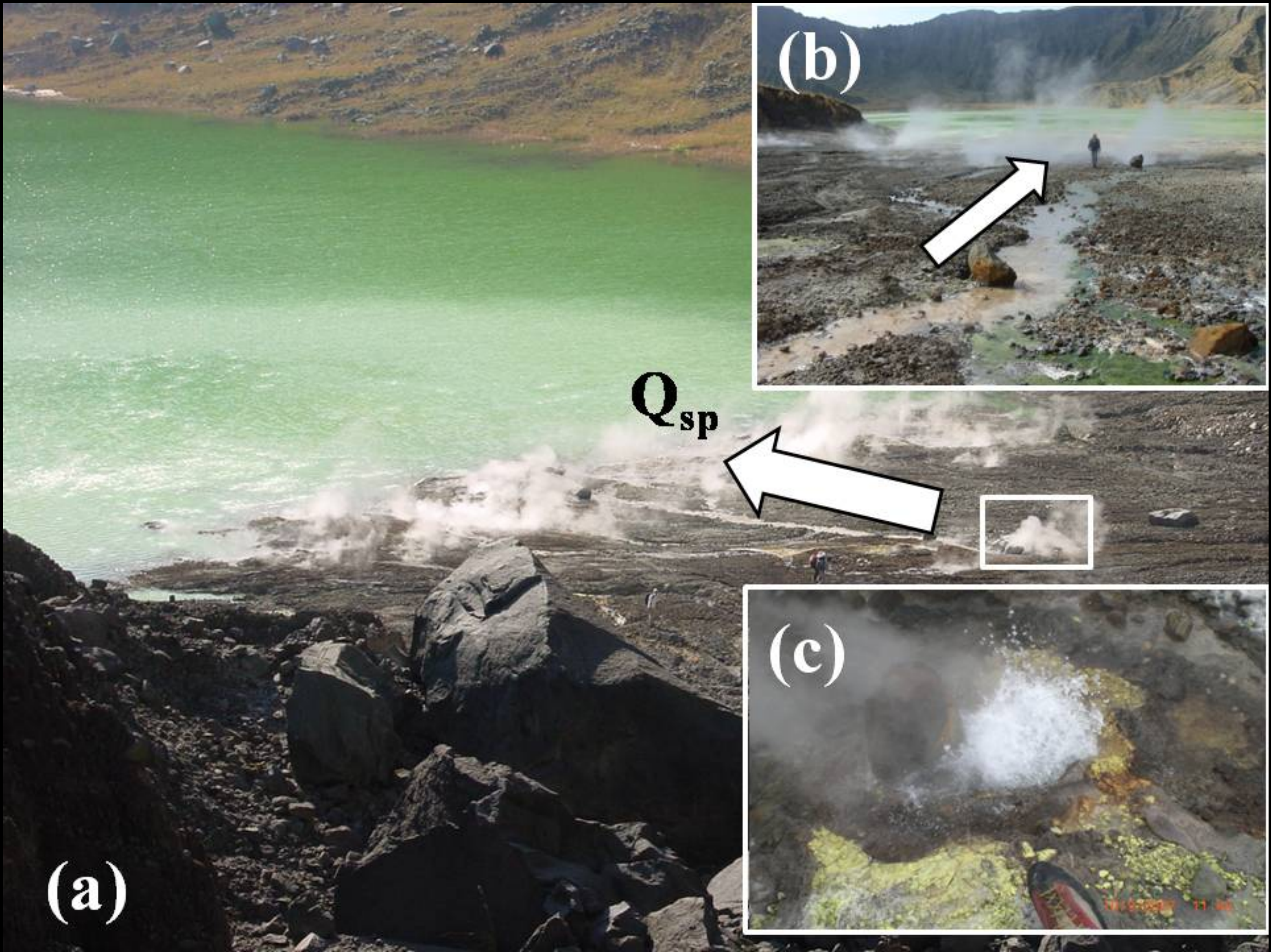
Dt is the period (s) between two times of observation of the crater lake (≈ sampling frequency).

Mass input and output



some example...

Input from springs (out of the lake)



Evaporative flux

What can be measured ?

- the variation in lake volume (V_L - V_{L0}). In general, the lake volume is deduced empirically and independently for each crater lake
- The input flux of meteoric water (Q_m) depends on the precipitation rate that can be measured installing a rain gauge as near as possible to the lake.
- The input flux of springs (Q_{sp}) and the overflow output flux (Q_o) located outside the lake in the catchment area can be directly measured in the field, by means of a flow meter device.
- The evaporative output (Q_e) can be calculated from latent heat of vaporization of water on the basis of wind speed, air humidity and temperature, atmospheric pressure and water lake temperature.

What cannot be measured ?

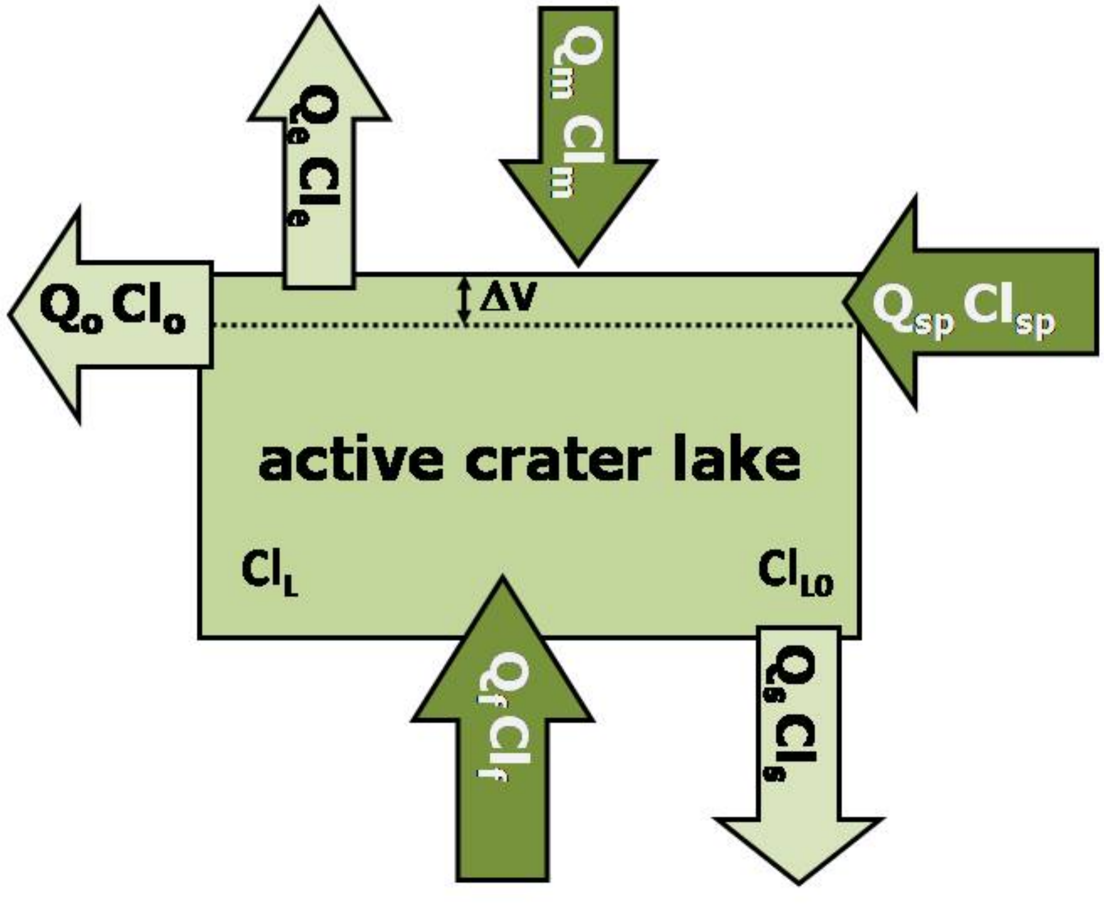
- The seepage loss (Q_s) through the crater lake floor may (to solve the equation, must) be only estimated semi-quantitatively on the basis of hydrogeochemical models

Chemical badget

- Multiplying each term in the mass budget with the corresponding concentrations of a conservative chemical species (Cl), we obtain the chemical budget equation:

$$V_L\ Cl_L - V_{L0}\ Cl_{L0} = Q_f\ Cl_f\ Dt + Q_m\ Cl_m\ Dt + Q_{sp}\ Cl_{sp}\ Dt - Q_e\ Cl_e\ Dt - Q_s\ Cl_s\ Dt - Q_o\ Cl_o\ Dt$$

Chemical budget

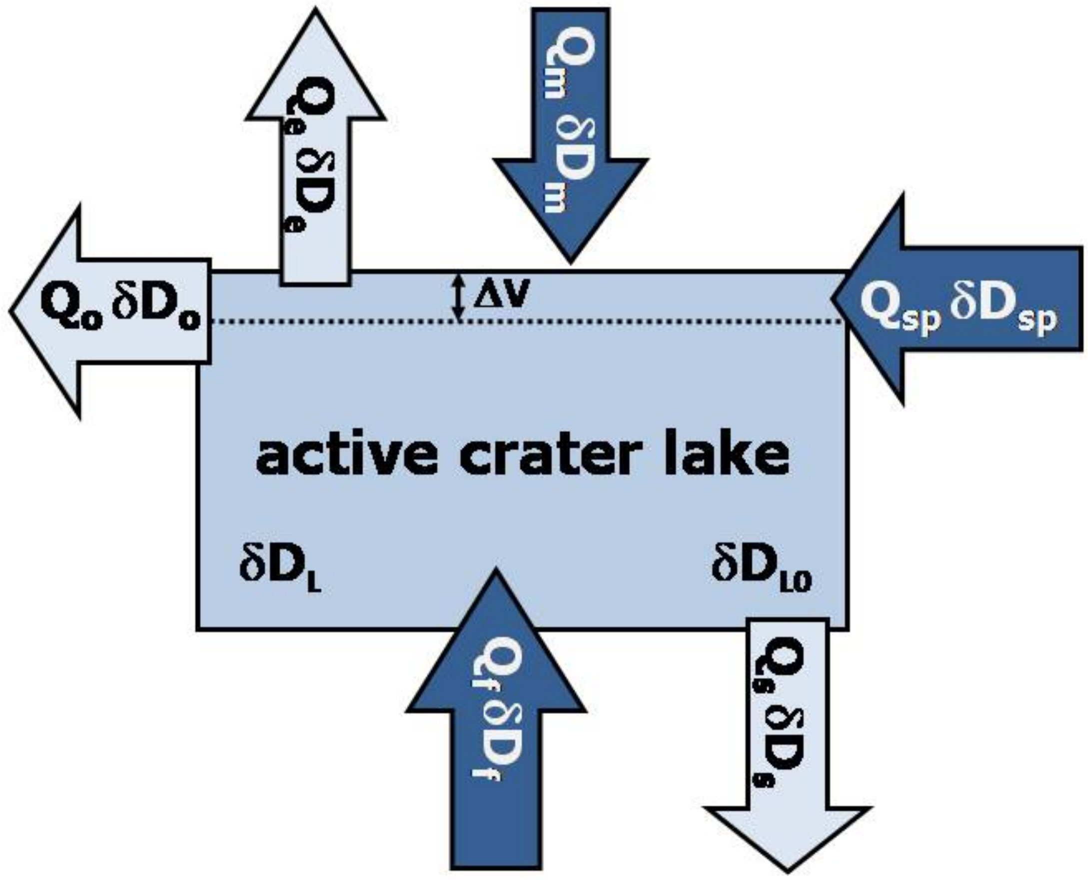


Isotope badget

- Multiplying each term in the mass budget with the corresponding values of the water isotopic composition (δD or $\delta^{18}O$), we obtain the isotope budget equation:

$$V_L\ \delta D_L - V_{L0}\ \delta D_{L0} = Q_f\ \delta D_f\ Dt + Q_m\ \delta D_m\ Dt + Q_{sp}\ \delta D_{sp}\ Dt - Q_e\ \delta D_e\ Dt - Q_s\ \delta D_s\ Dt - Q_o\ \delta D_o\ Dt$$

Isotope budget



Aims ?

By quantification of the non-volcanic factors affecting the physical-chemical state of the active crater lake, the box model allows to calculate the volcanic input flux (Q_f), which cannot be directly measured.

Variation in volcanic fluid inputs may be related to changes of….volcanic activity.

Nyos type lakes

"Gas burst"

A phenomenon regulated by the balance between gas input and gas loss. A gas bursts may occur when recharge surpasses loss. Alternatively, the gas excess may be released through a controlled degassing, where the cycle of recharge-release is short-circuited.

Lethal CO_2-rich gas mass released from crater lake in volcanoes at hydrothermal stage

"CO_2 clouds" can run along several km without significantly mixing with air

The Nyos lethal wave

How to study (and monitor) Nyos-type lakes ?

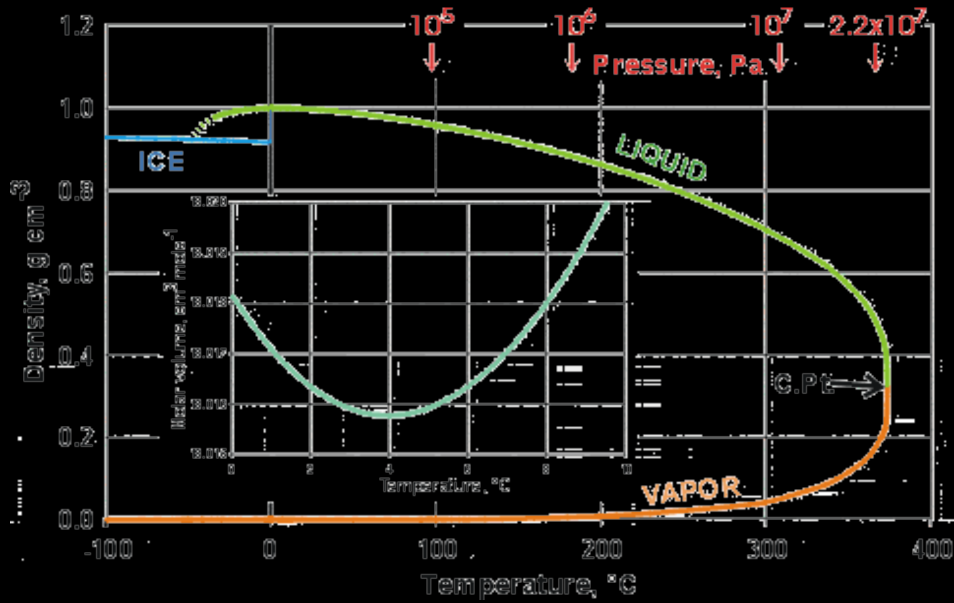
- Assessment of thermal and chemical stratification: the density gradient

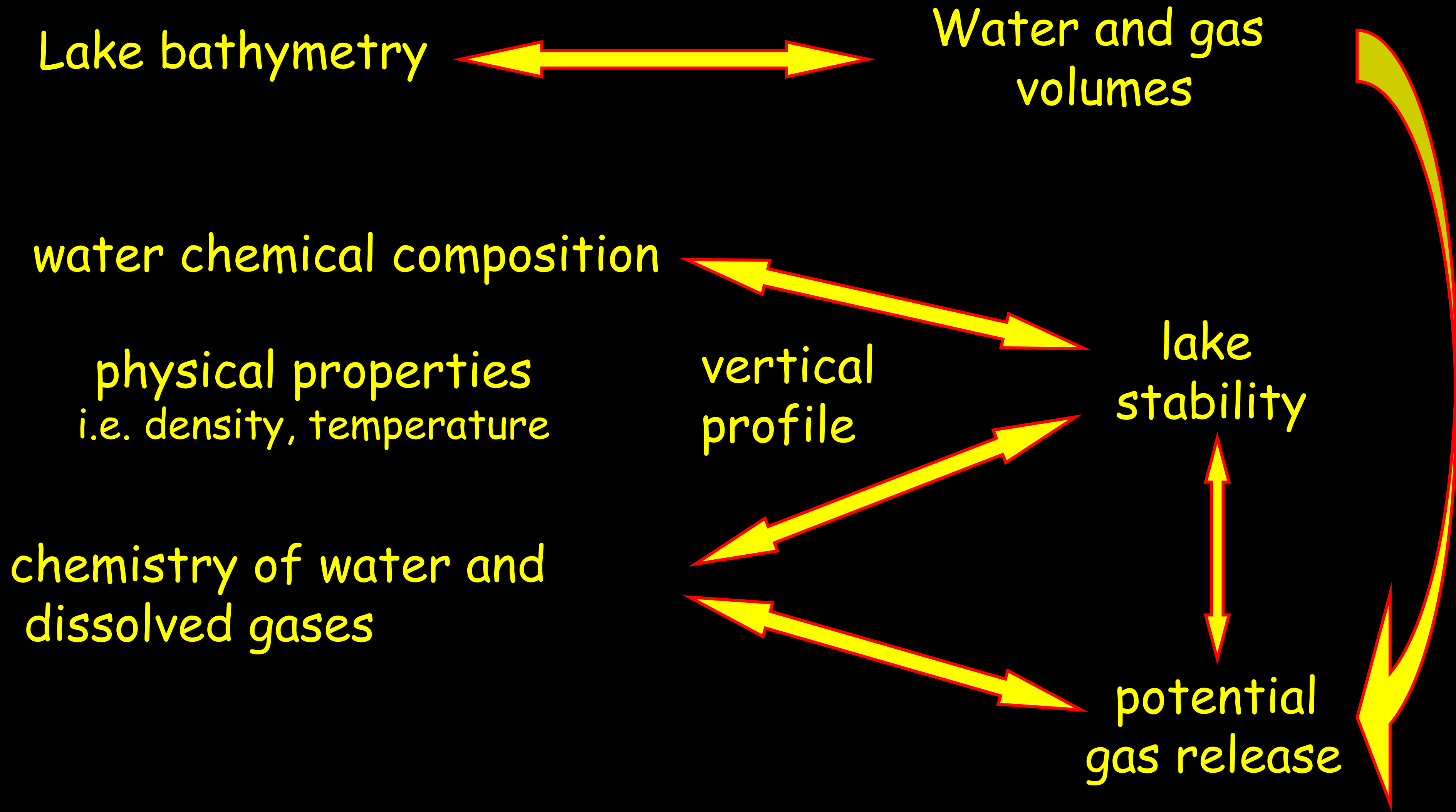
The density gradient is the main parameter controllin lake stability.

It depends on temperature and composition vertical profiles, as well as the distribution of dissolved gases

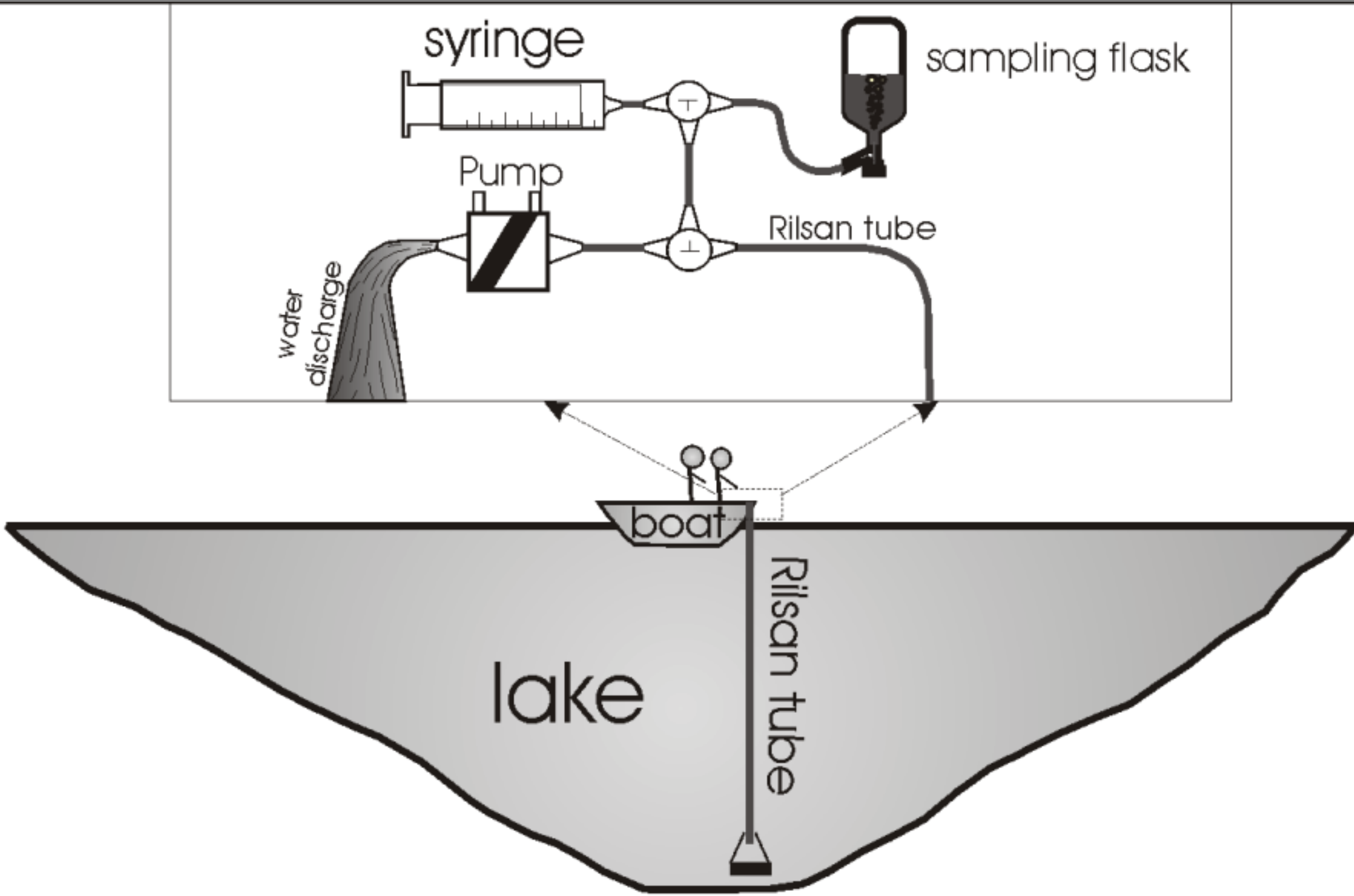
Temperature-Density

- Non-linear
- Maximum density at 4° C
- Lower density at higher and lower temperatures
- Hydrogen bonding and molecular movement




Lake bathymetry
Water and gas volumes
water chemical composition
physical properties
i.e. density, temperature
vertical profile
lake stability
chemistry of water and dissolved gases
potential gas release

sampling equipment




equipment ready
fighting against
a stupid engine
show must go on !
Eco-sonar
measurements
pumping started
In situ measurements
sampling
...and sampling
end of the game

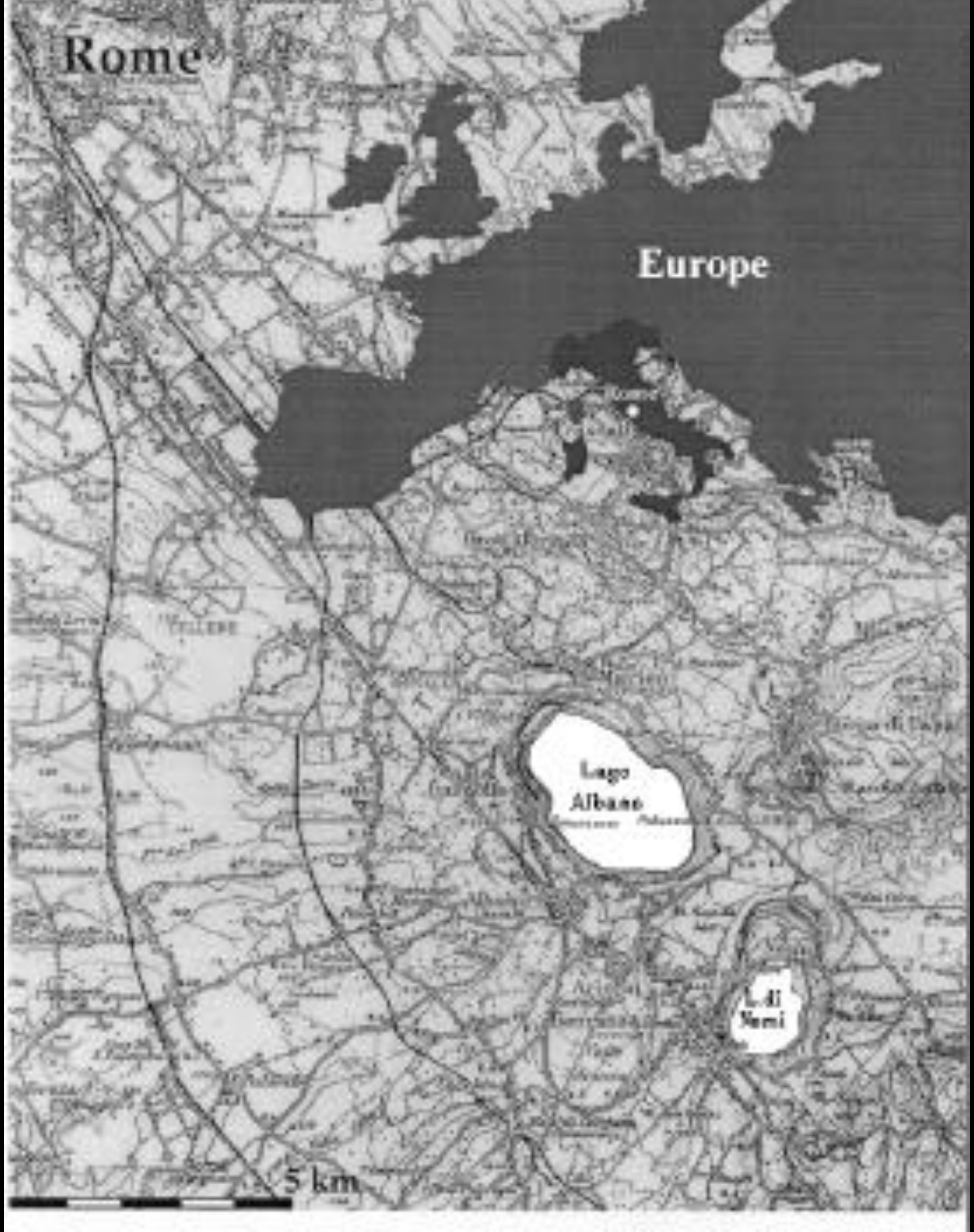
Three examples of Nyos-type lakes

The italian example:

Volcanic lakes: Albano, Averno, Monticchio's

Sink hole: Accesa

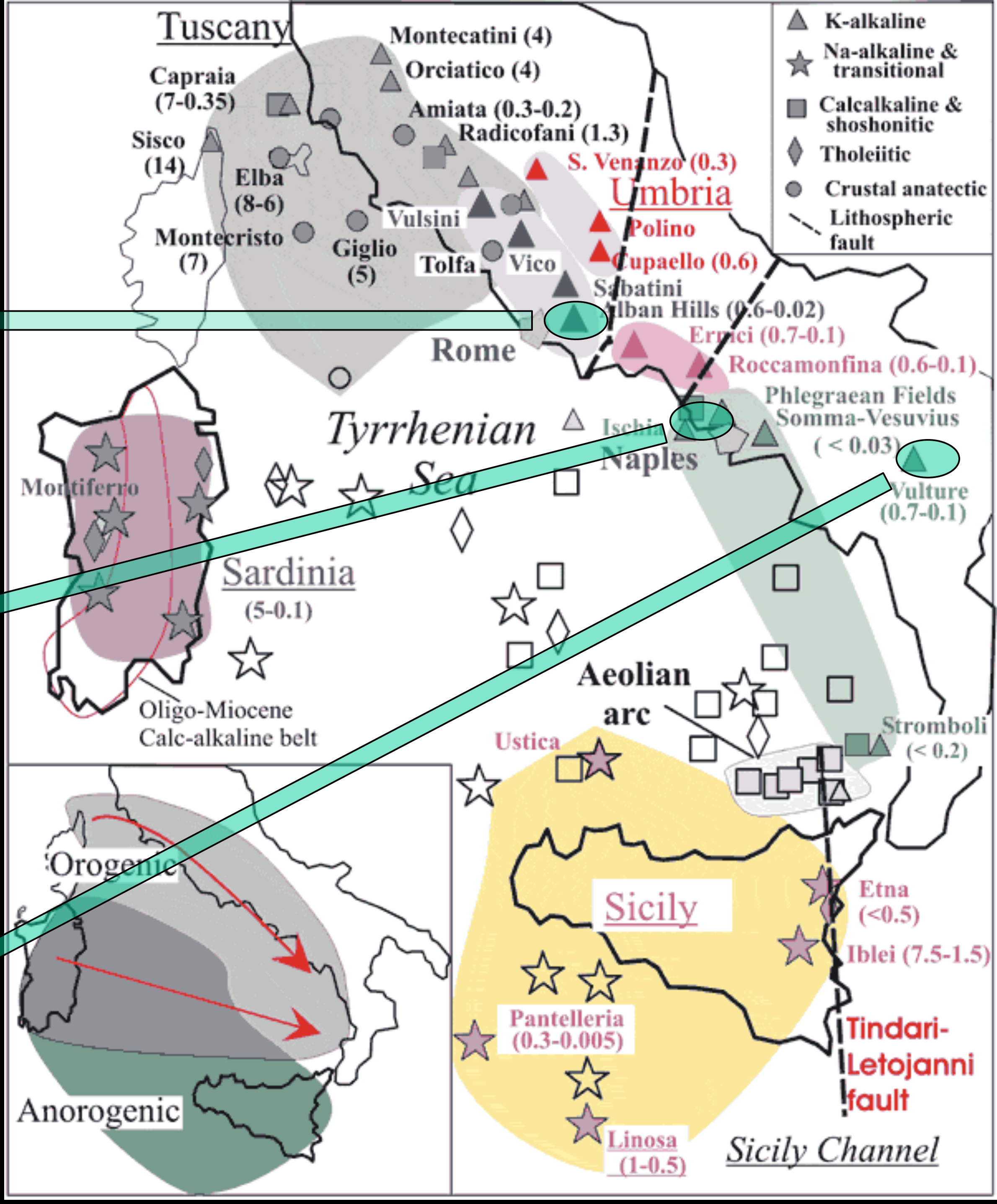
Albano lake



Albano Lake
Alban Hills

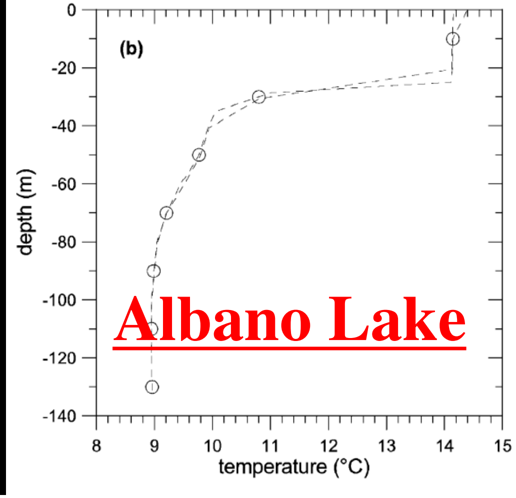
Averno Lake
Phlegrean Fields

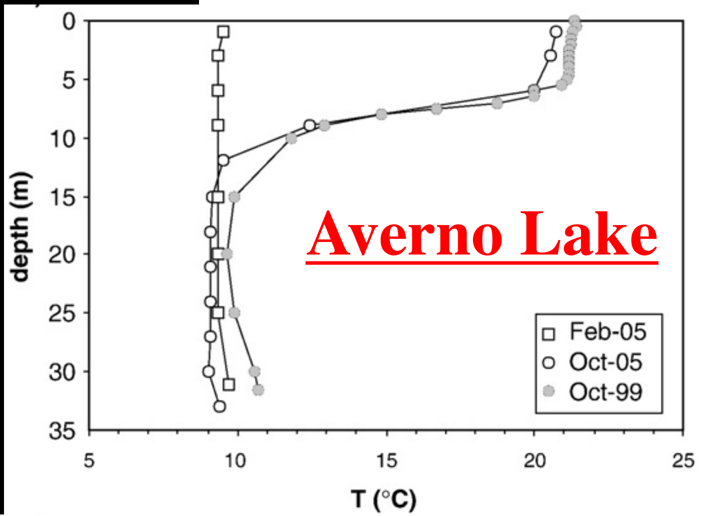
Monticchio Lakes
Vulture volcano

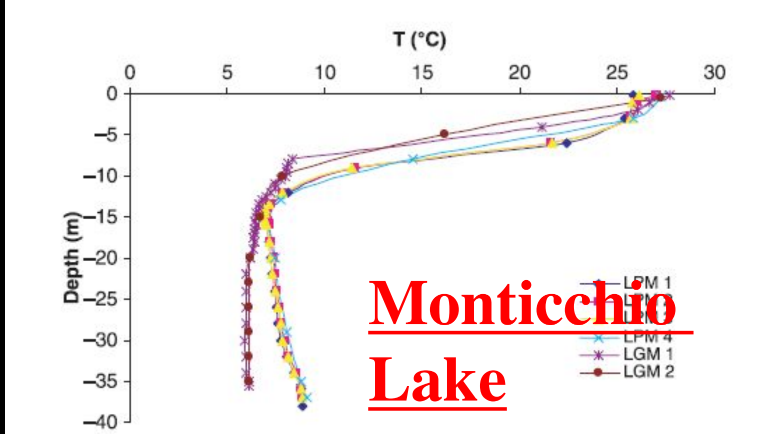


Among the Italian crater lakes these are the only meromictic and characterized by presence of CO_2-CH_4 gas reservoirs.

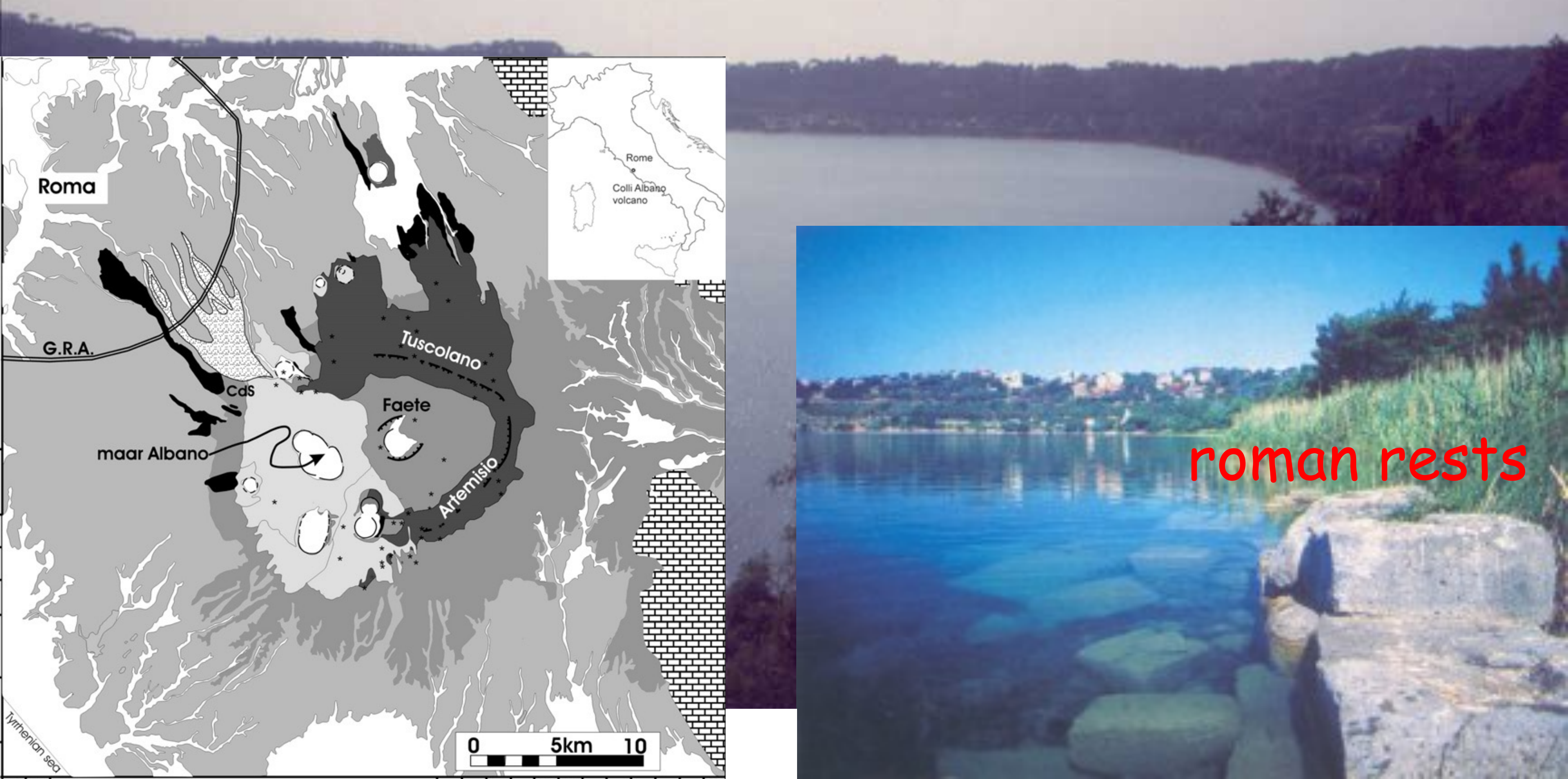
Repeated events of water rollover have eccurred in historical and recent times.

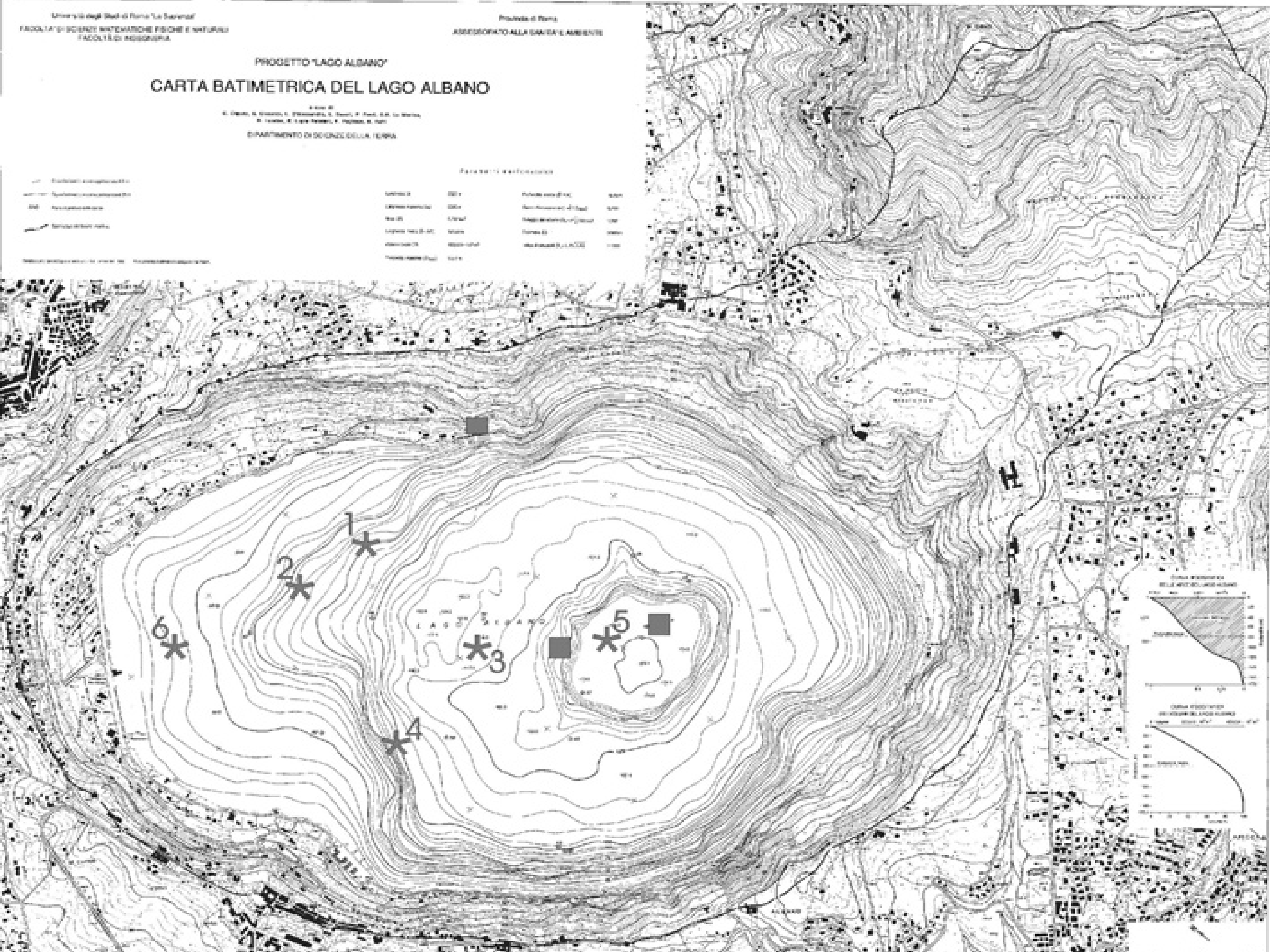




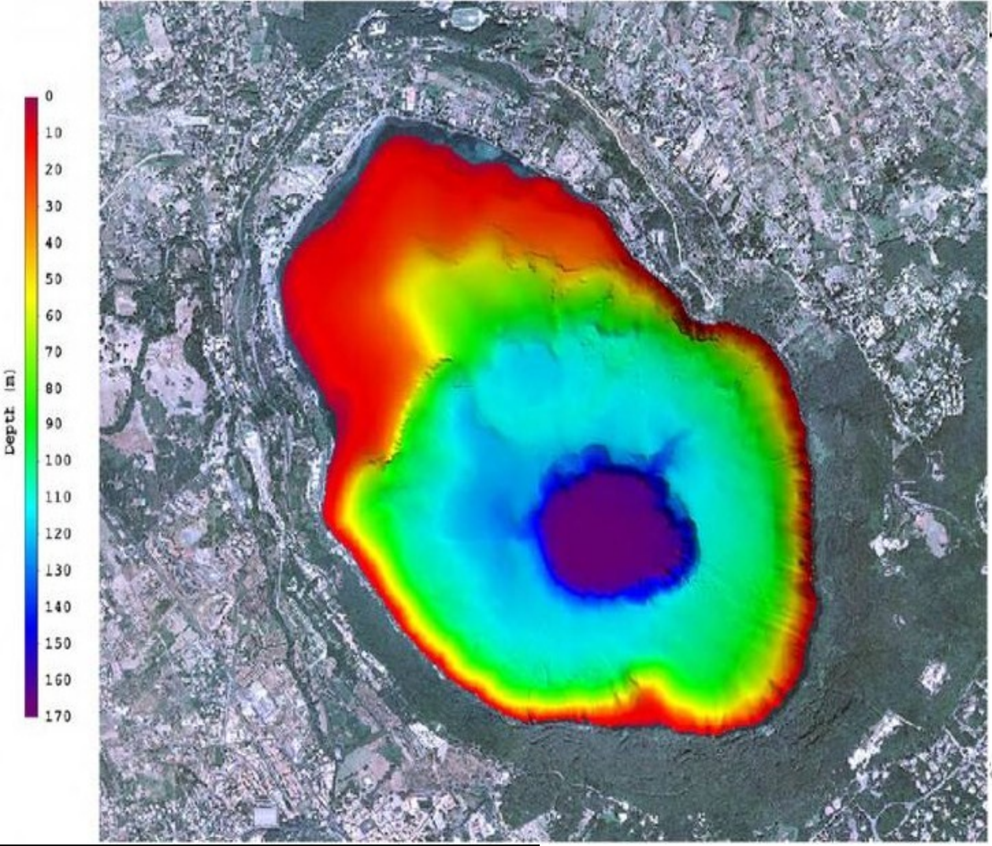


Albano lake is located in the Alban Hills volcanic complex (Central Italy), a region characterized by the presence of several CO_2-rich emissions, fed by an over-pressured hydrothermal aquifer, and that is frequently affected by seismic activity. Until the 4th century B.C. catastrophic exondations have occurred from the lowest rim of the lake, with lahar emplacement on the northern slope. The repetition of these phenomena was prevented by a drain-tunnel, dug by the Romans, that controls water level fluctuations.

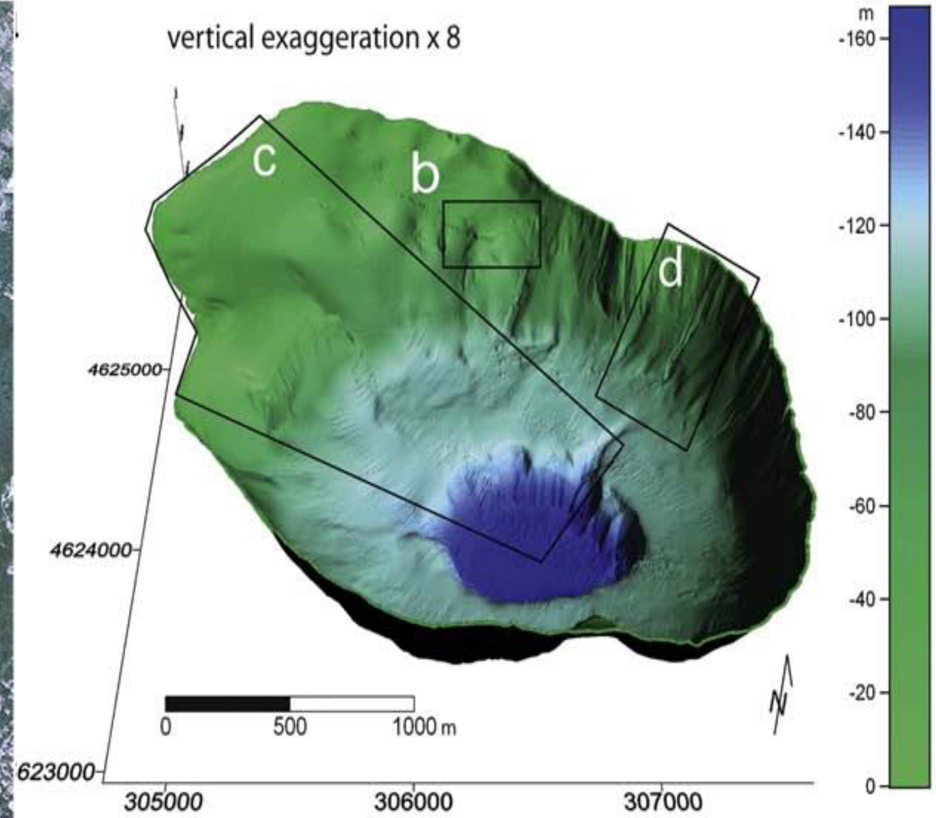



Università degli Studi di Roma "La Sapienza"
FACOLTA' DI SCIENZE MATEMATICHE FISICHE E NATURALI
FACOLTÀ DI INGEGNERIA
Provincia di Roma
ASSESSORATO ALLA SANITA' E AMBIENTE
PROGETTO "LAGO ALBANO"
CARTA BATIMETRICA DEL LAGO ALBANO
DIPARTIMENTO DI SCIENZE DELLA TERRA
LAGO ALBANO
1
2
3
4
5
6

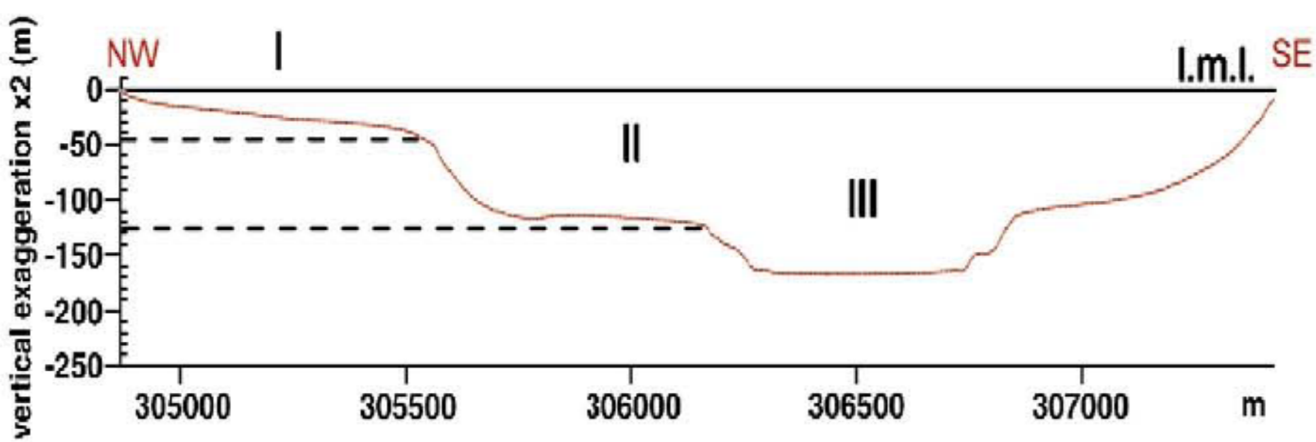
Albano



Depth (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170



vertical exaggeration x 8
c
b
d
4625000
4624000
623000
305000
306000
307000
0
500
1000 m
m
-160
-140
-120
-100
-80
-60
-40
-20
0
N

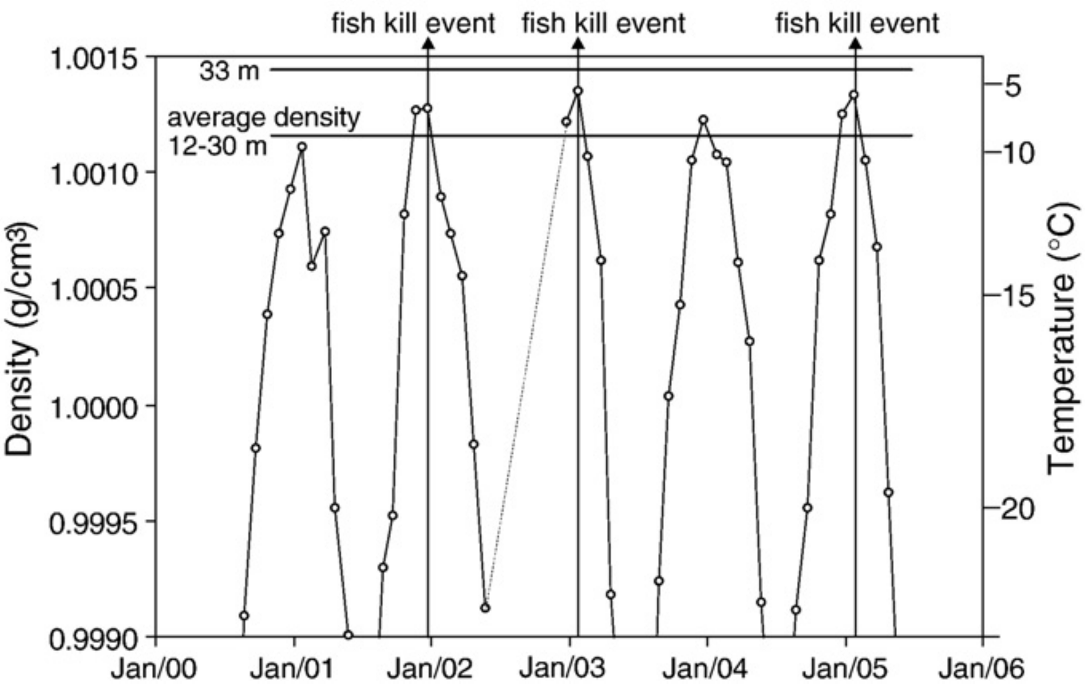


vertical exaggeration x2 (m)
NW
SE
I
II
III
l.m.l.
0
-50
-100
-150
-200
-250
305000
305500
306000
306500
307000
m

Averno Lake

The lake was generated during two eruptions, 3.7-4.5 ky BP. In Greek and Roman times was considered to be the entrance of the underworld.

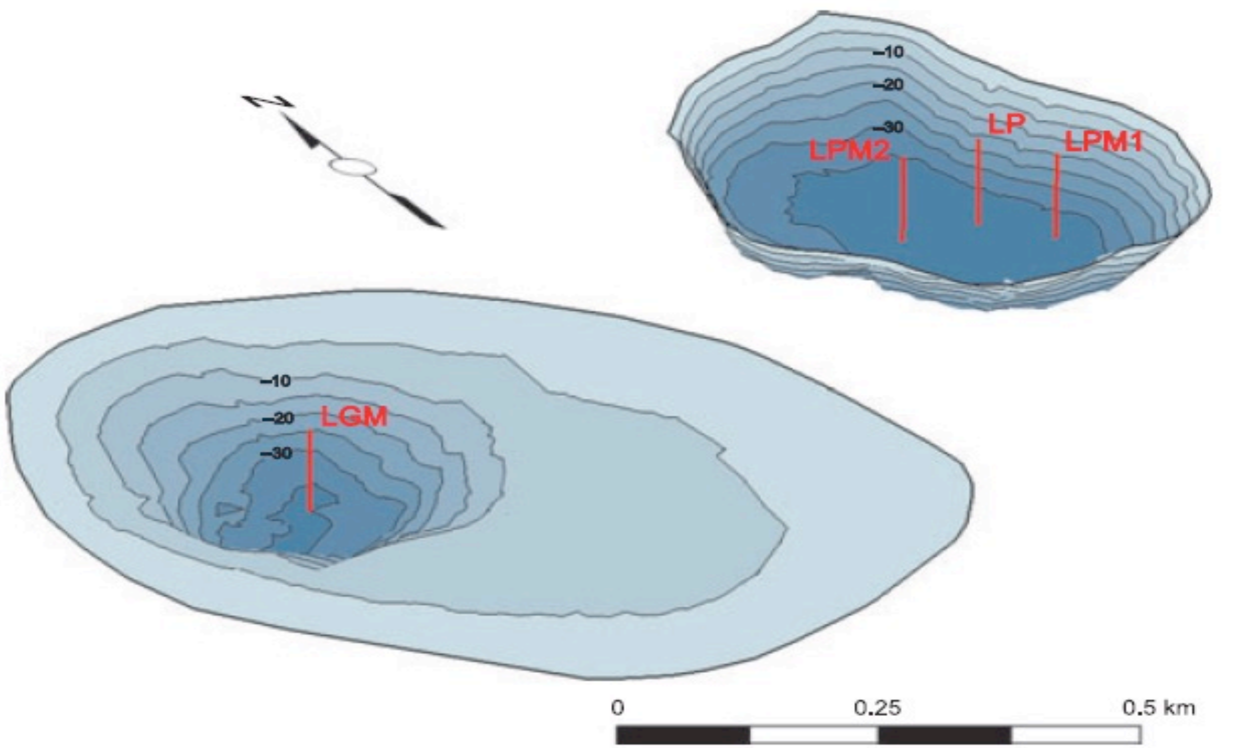
Density variations of the epilimnion (computed by Caliro et al. 2008) likely triggered repeated fish kill events, such as in February 2005.



Monticchio Lakes (Piccolo and Grande)

The two Monticchio maars formed 140 ky ago during the last eruptive activity of Mt. Vulture. The area is characterized by intense CO_2 degassing. Bubbling gases are present along the lake shore. Lake rollover events were witnessed on June and August 1810 and in 1820 (fishes were killed and columns of water up to 6 m high formed).

Monticchio Grande & Piccolo

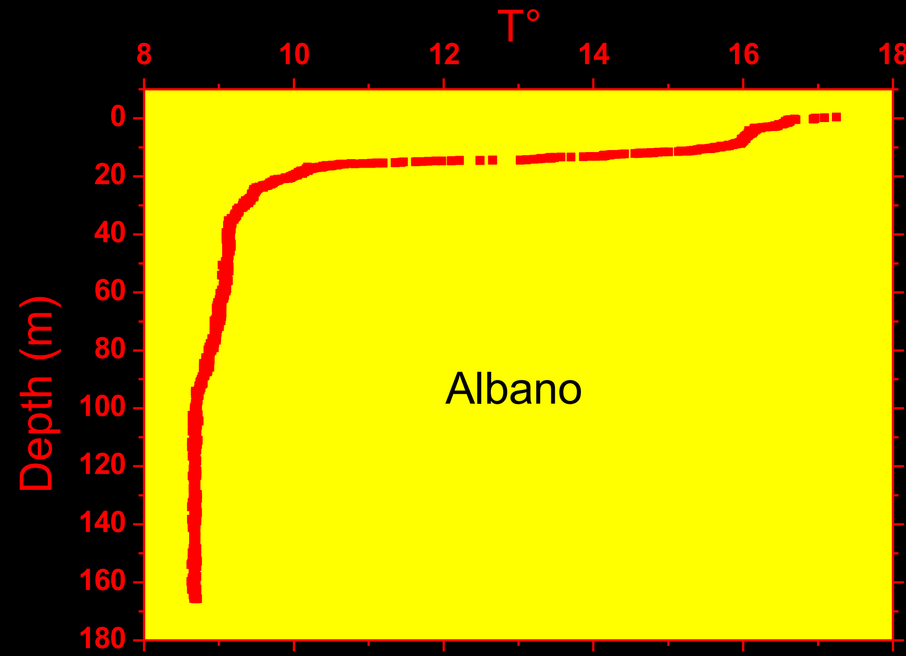


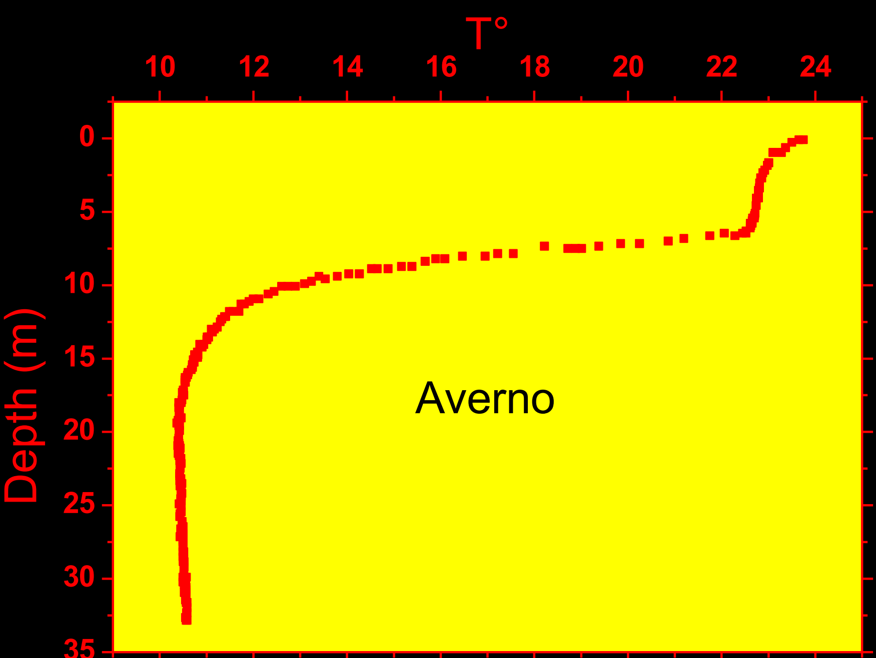
Among the Italian crater lakes these are the only meromictic and characterized by presence of CO_2-CH_4 gas reservoirs.

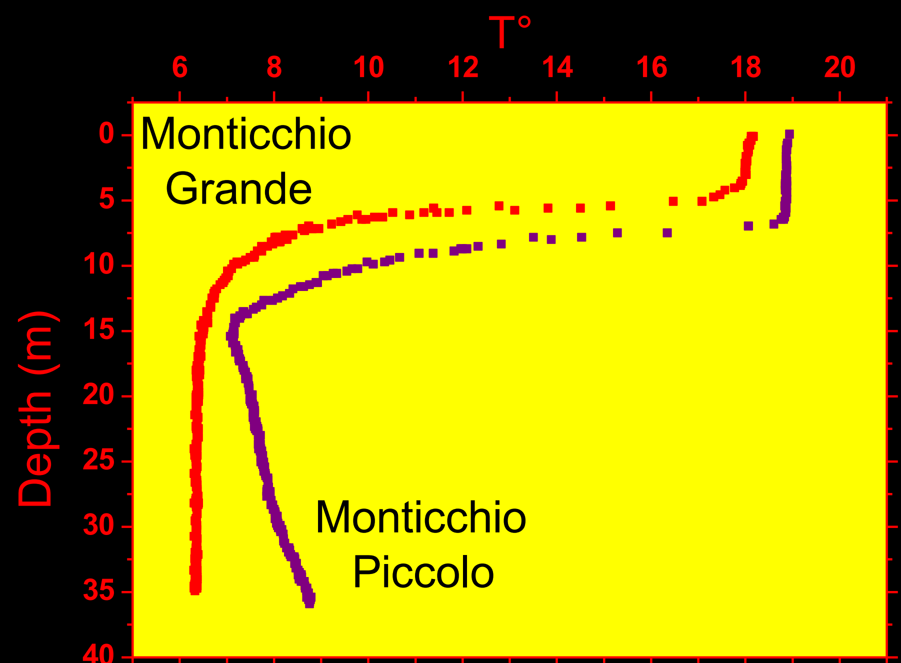
Such gas accumulation at depth may be favouring a pronounced vertical thermal, chemical and isotopic stratification.

Repeated events of water rollover have occurred in historical and recent times.

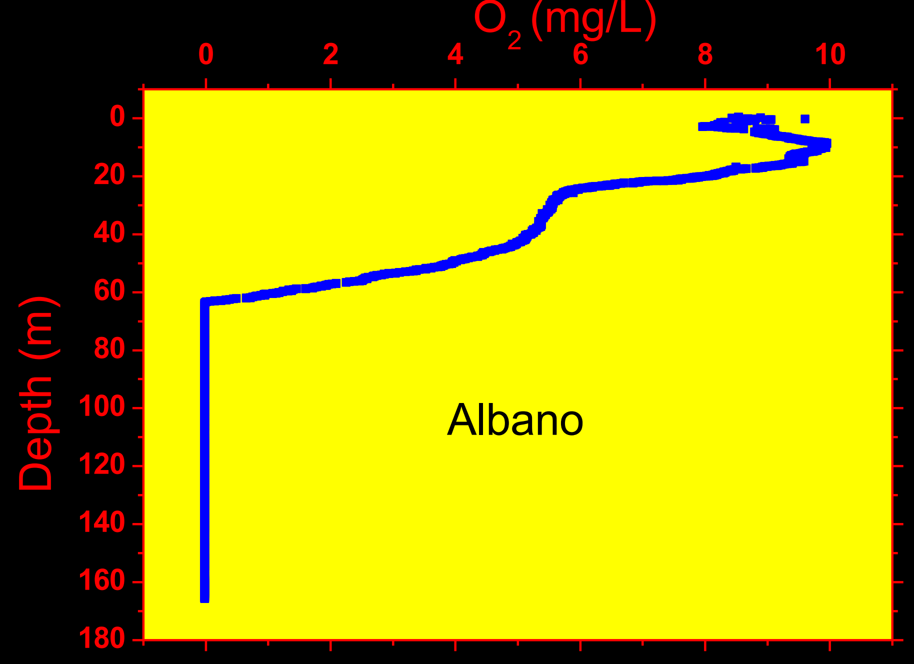
Depth vs. Temperature

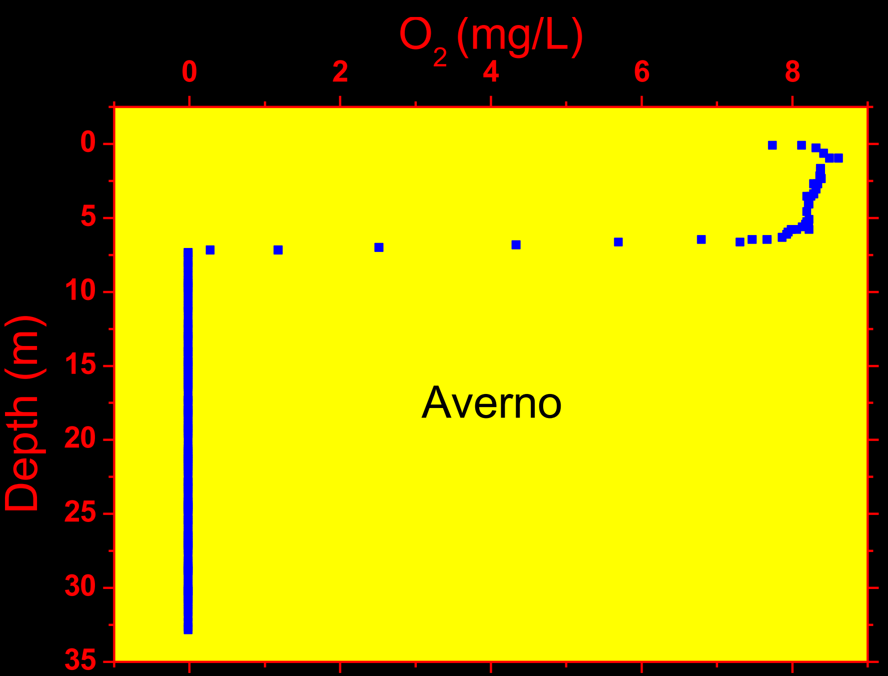


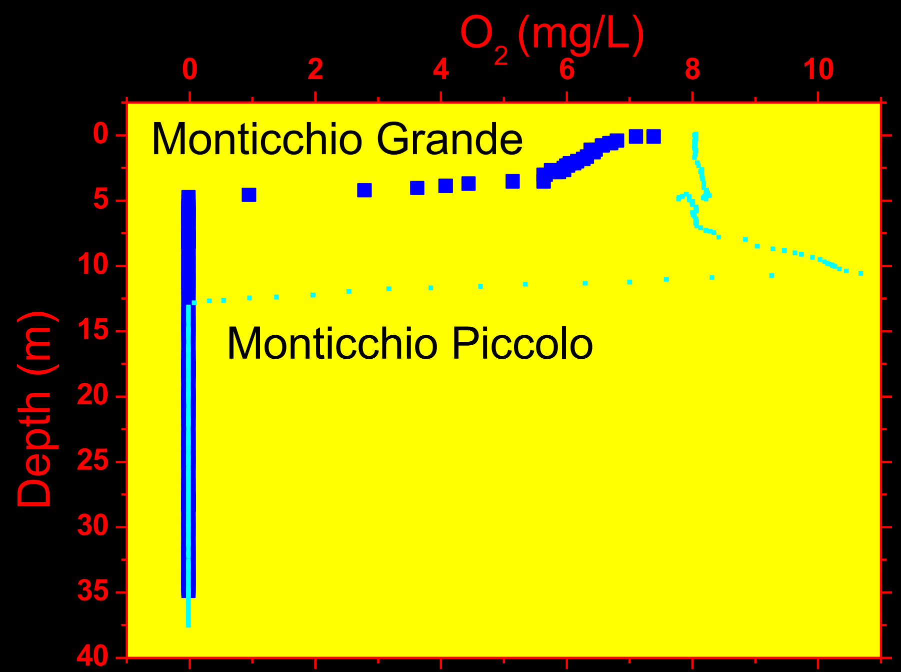




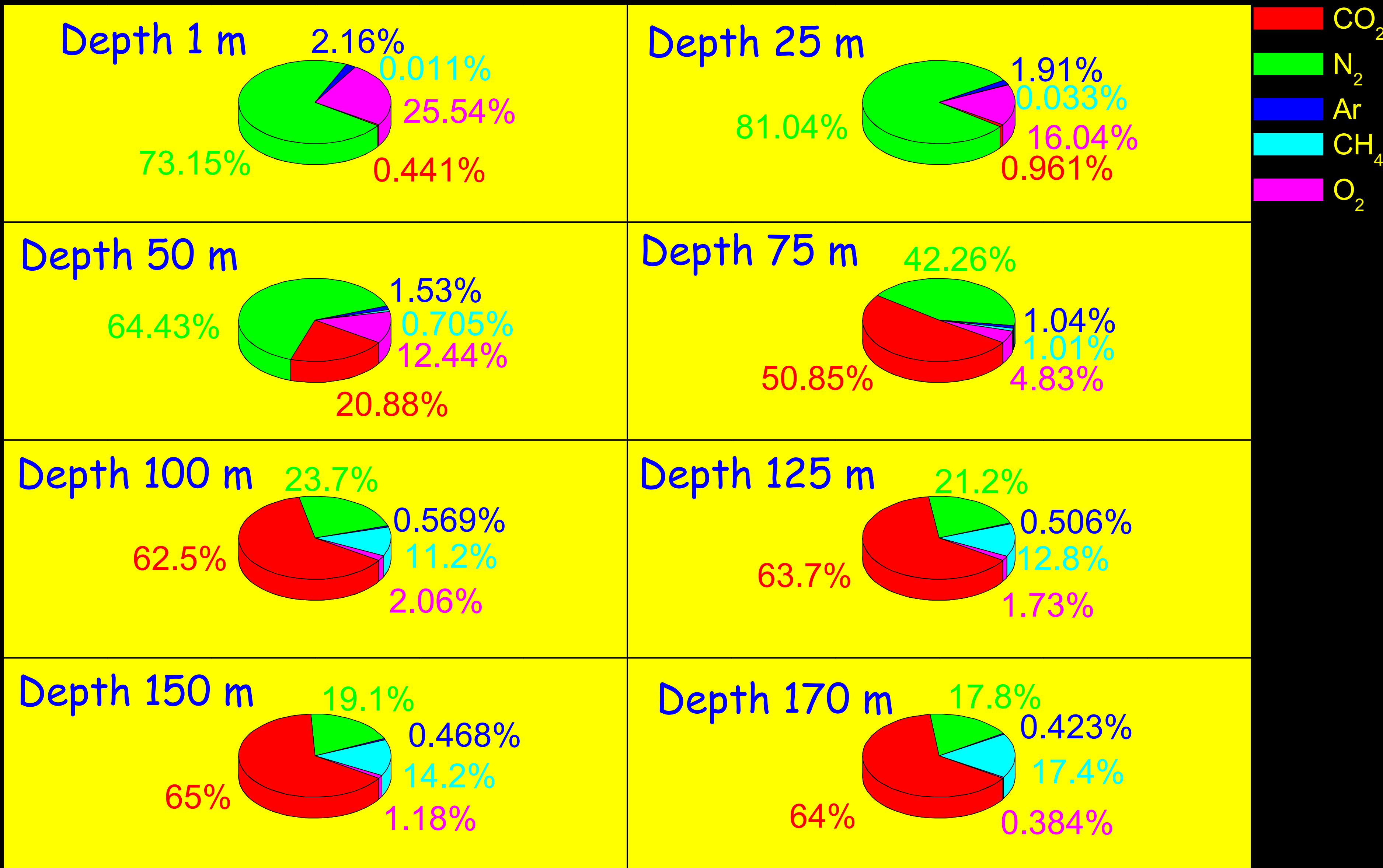
Depth vs. Oxygen





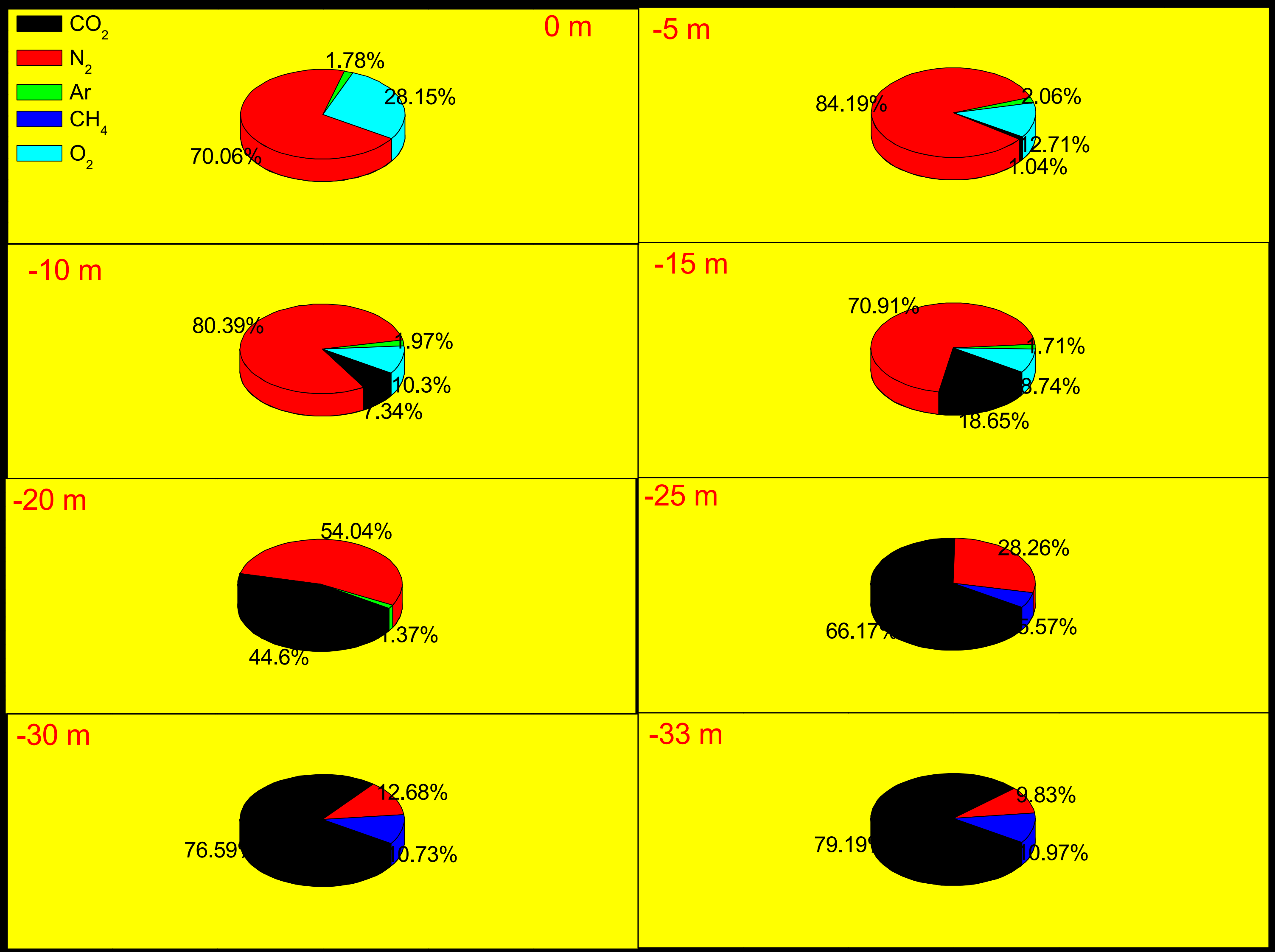


Composition of the dissolved gases

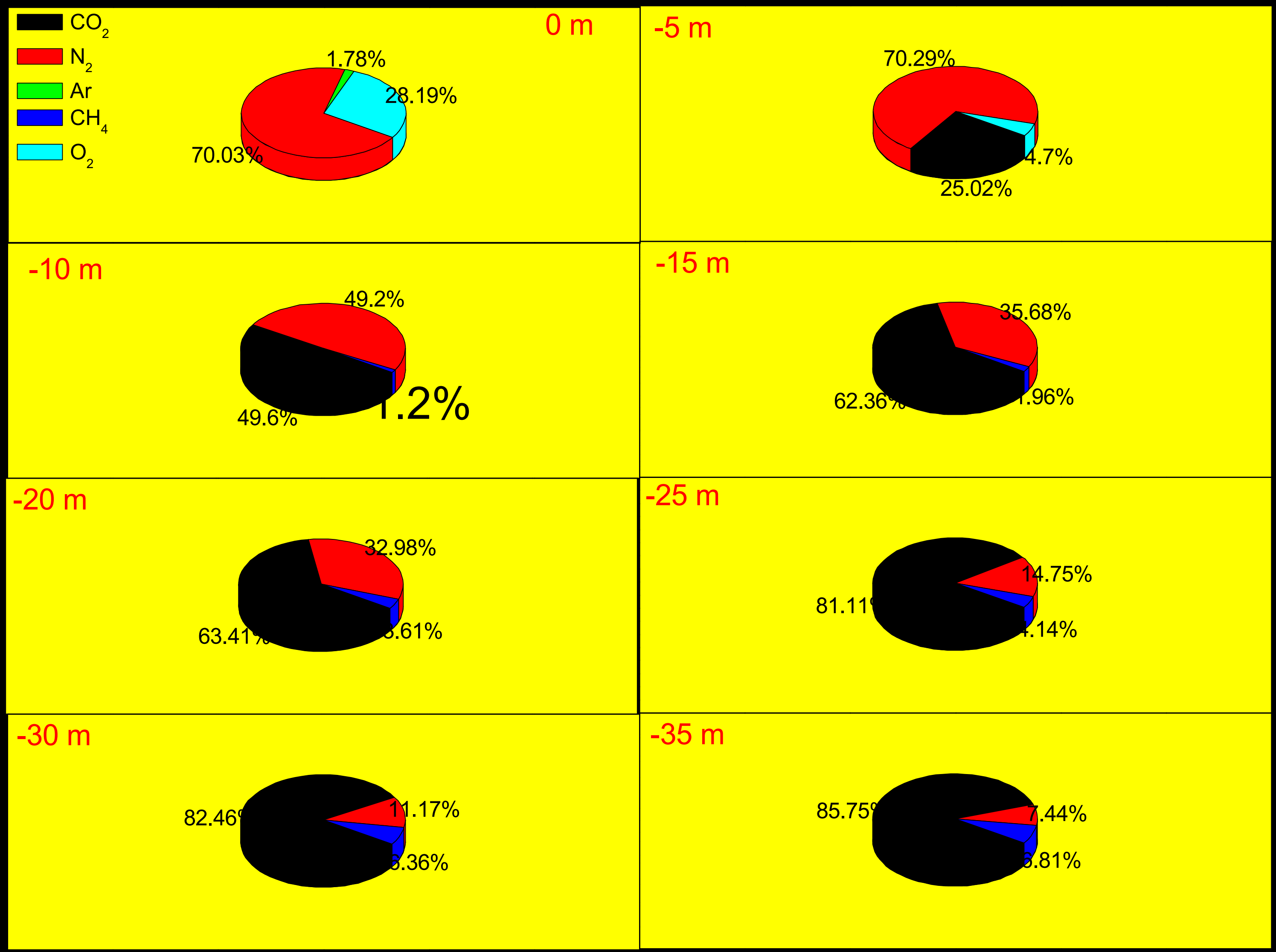


Composition of the dissolved gases

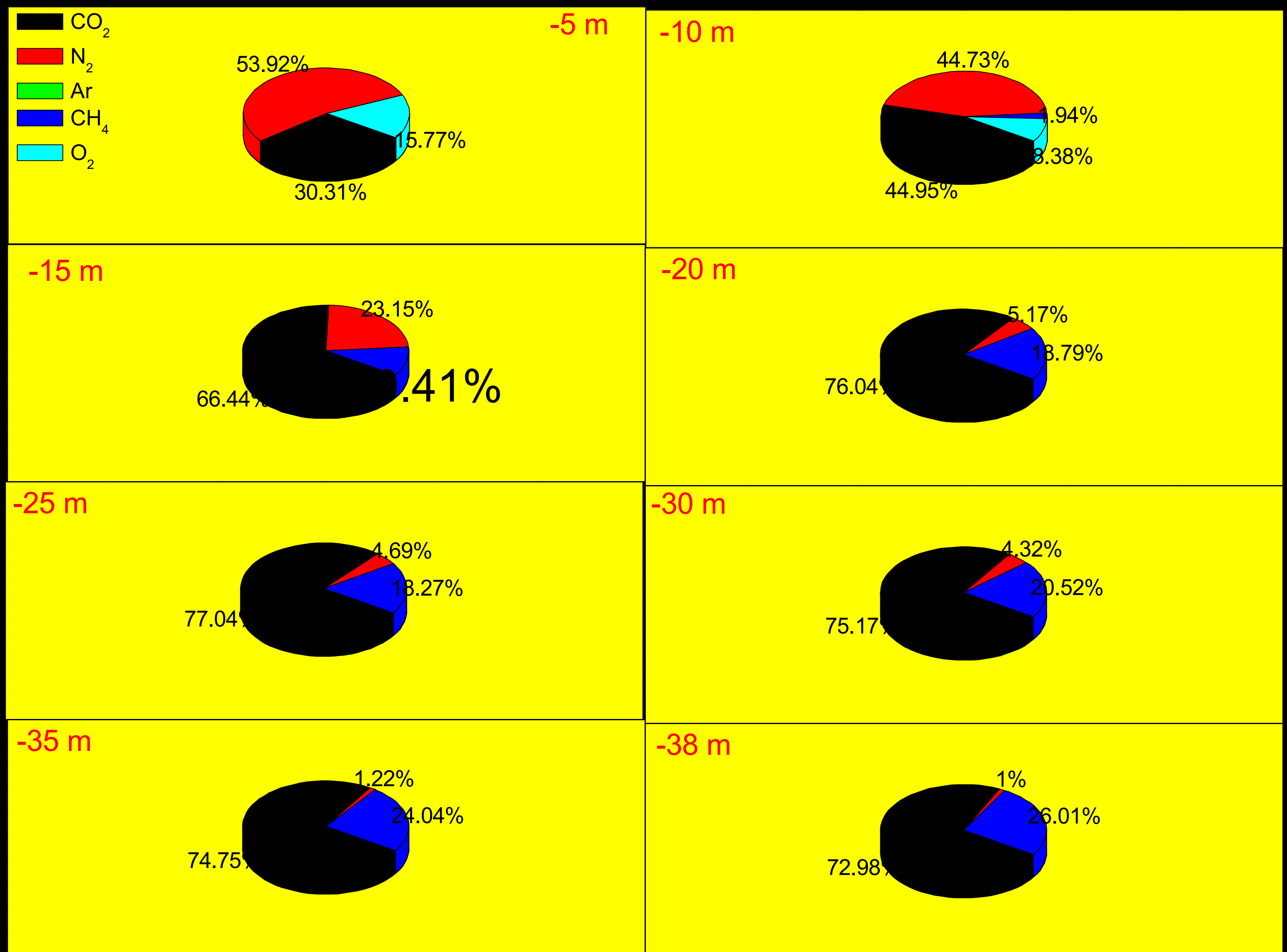
Averno

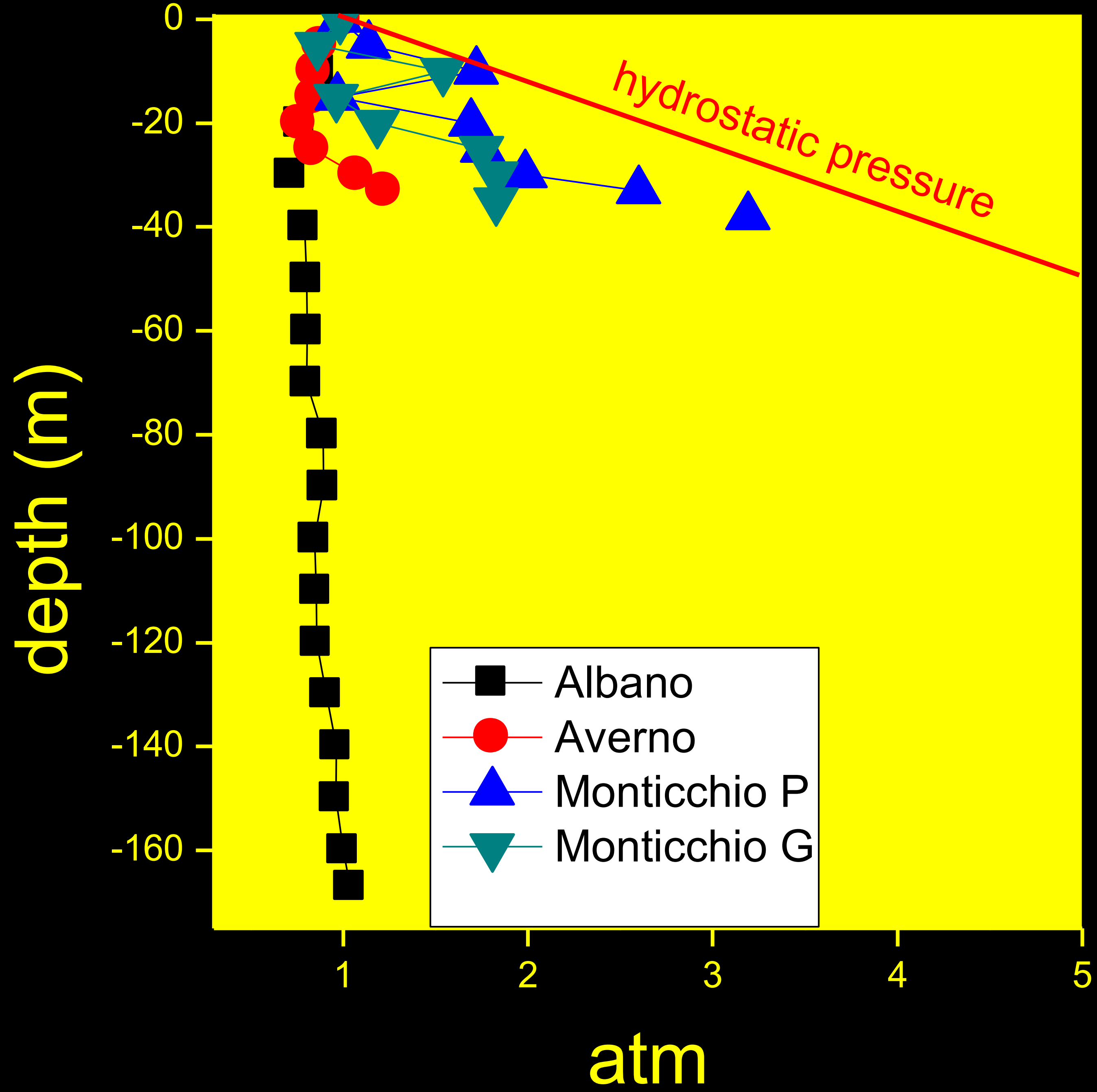


Composition of the dissolved gases Monticchio Grande



Composition of the dissolved gases Monticchio Piccolo



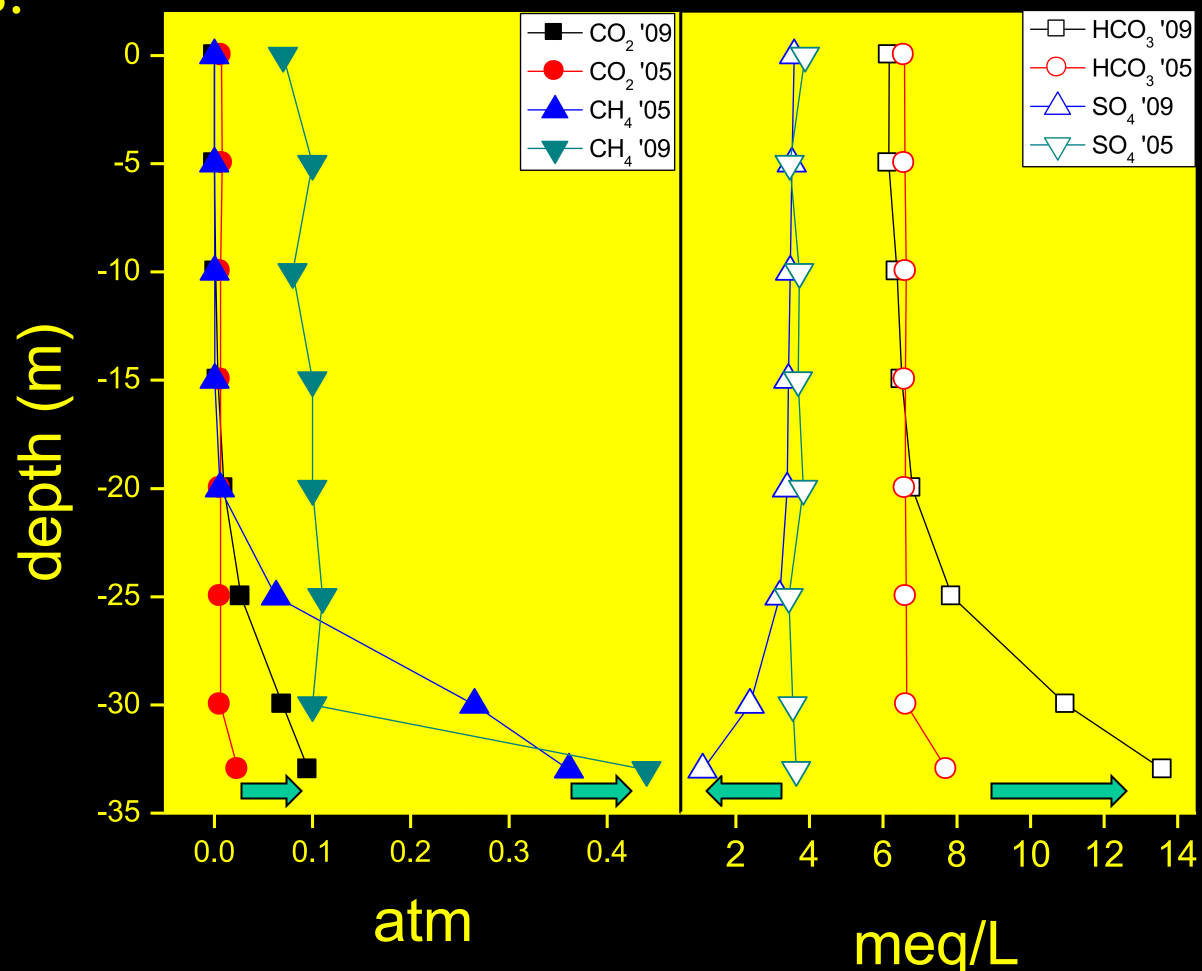


0
-20
-40
-60
-80
-100
-120
-140
-160
depth (m)
1
2
3
4
5
atm
hydrostatic pressure
Albano
Averno
Monticchio P
Monticchio G

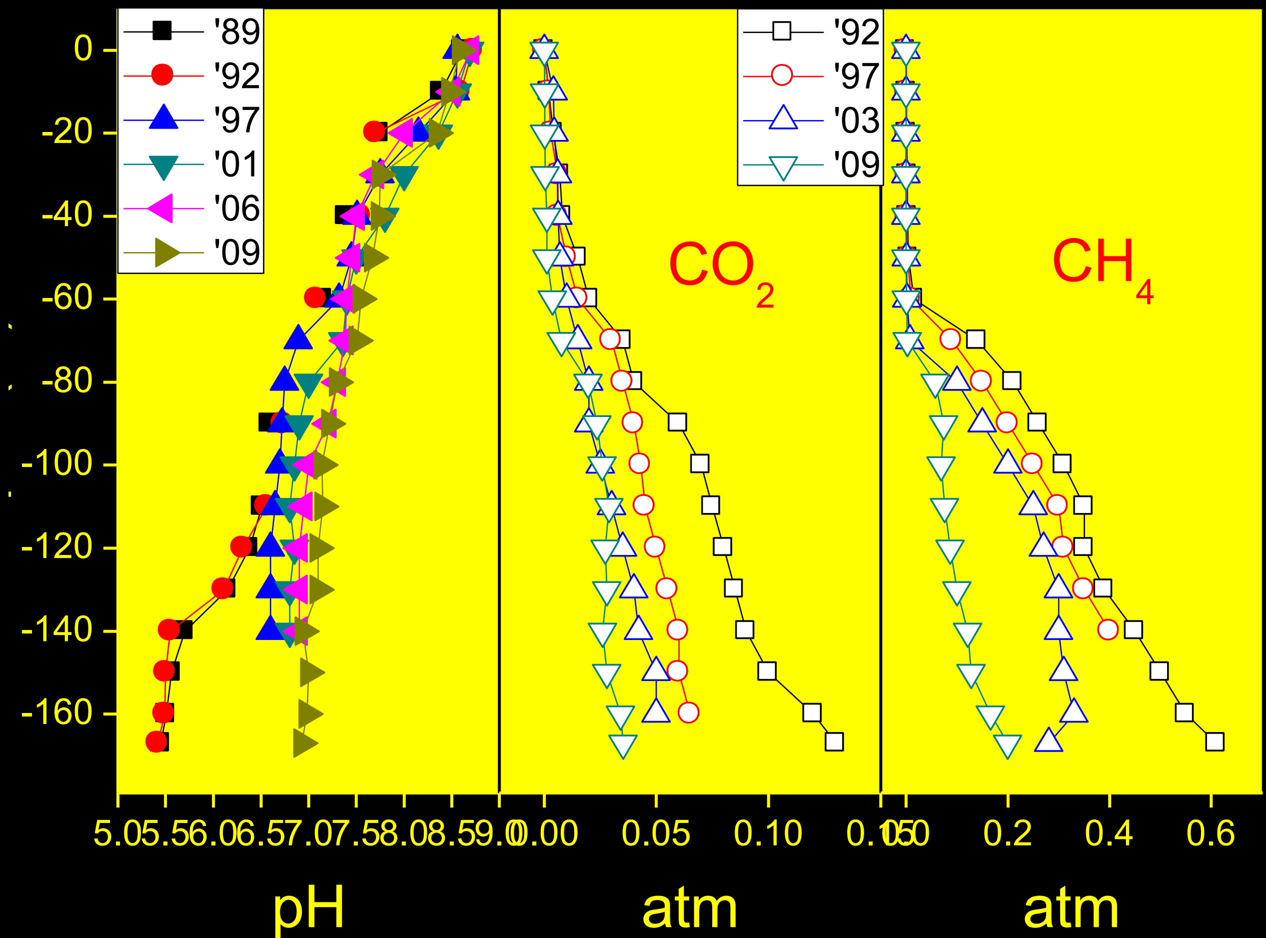
Temporal evolution

Gas concentrations and water chemistry of ***Monticchio Piccolo*** and ***Monticchio Grande*** lakes in 2009 are consistent with previous data of sampling campaigns carried out in 1996 (Chiodini et al. 2000), and 2007 (Caracausi et al. 2008). However, several water rollover events were observed in Lago Piccolo (fishes are currently living there only at very shallow depth)

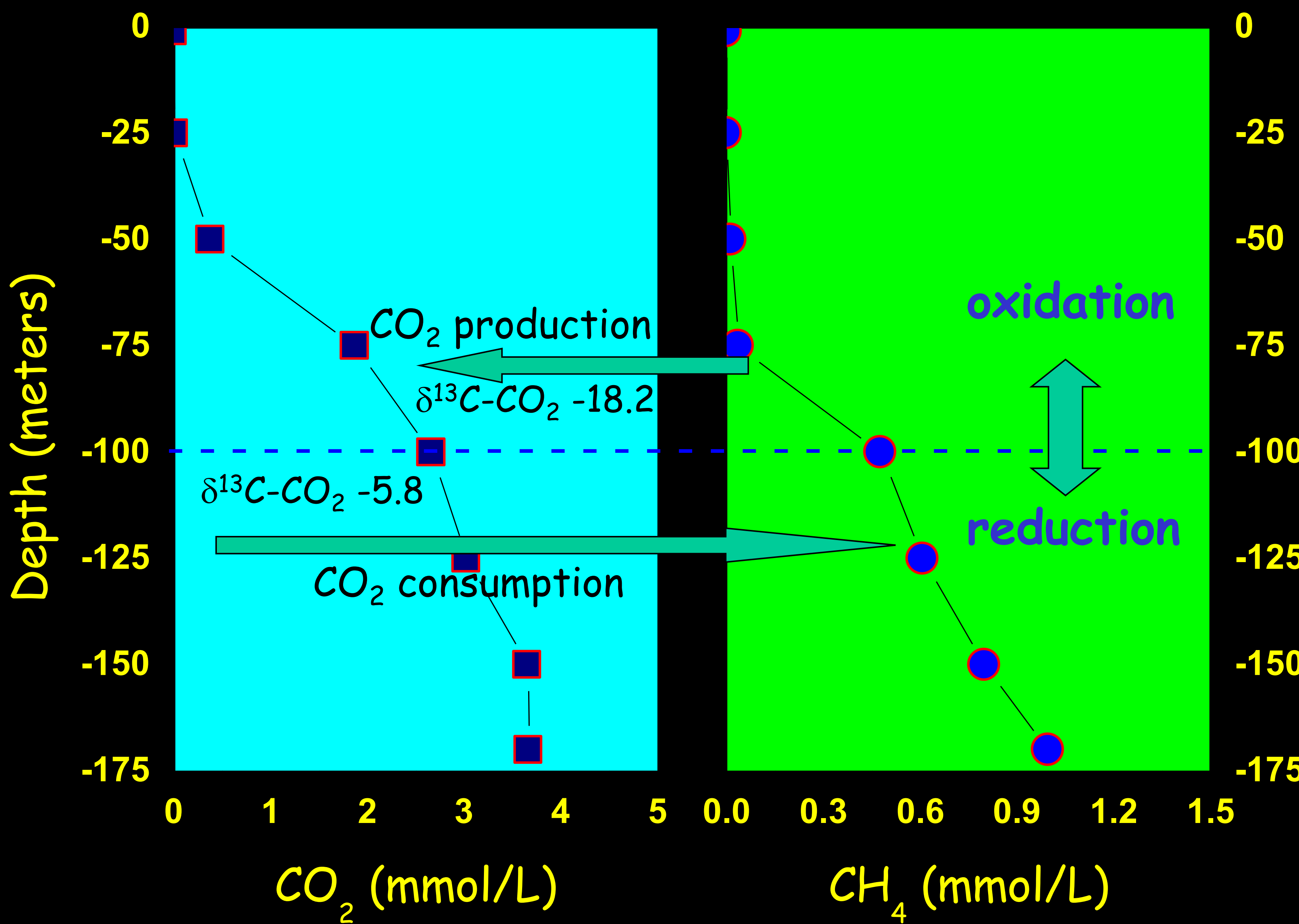
Gas concentrations and water chemistry of *Averno* in 2009 are similar to those measured in November 2004 (unpubl. Data) and October 2005 (Caliro et al. 2008). In February 2005, just after a fish kill event, the gas reservoir was significantly lower: few month for restoration of pre-event conditions.



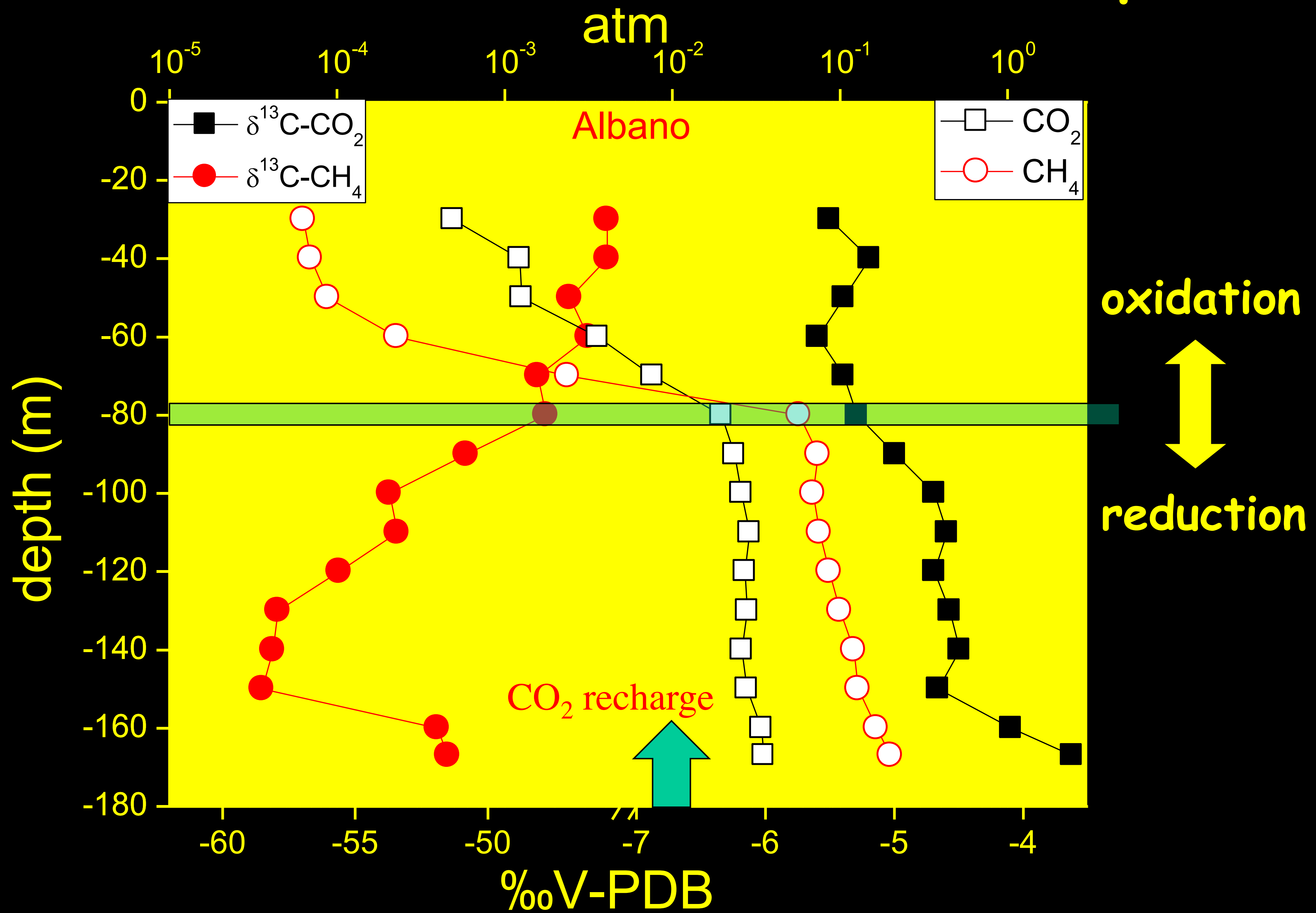
Water chemistry of *Albano* in 2009 is similar to that measured in 1989, 1992 (unpubl. data), 1997 (Cioni et al., 2003), 2001, 2003 (Carapezza et al. 2008). Dissolved gases have decreased, whereas pH has increased. Lake water was supposed to overturn in 2003-2004.



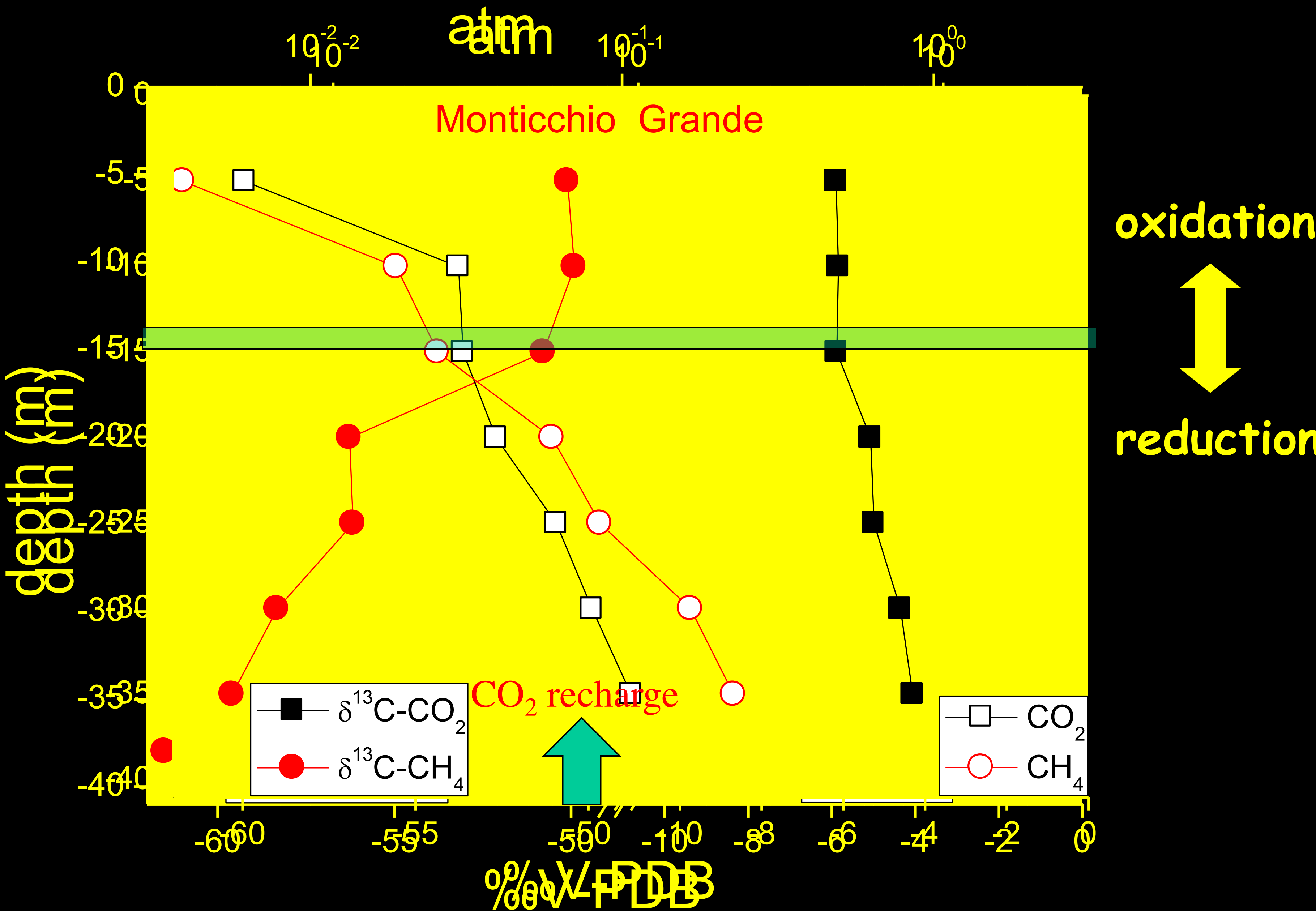
Bacterial activity and redox conditions



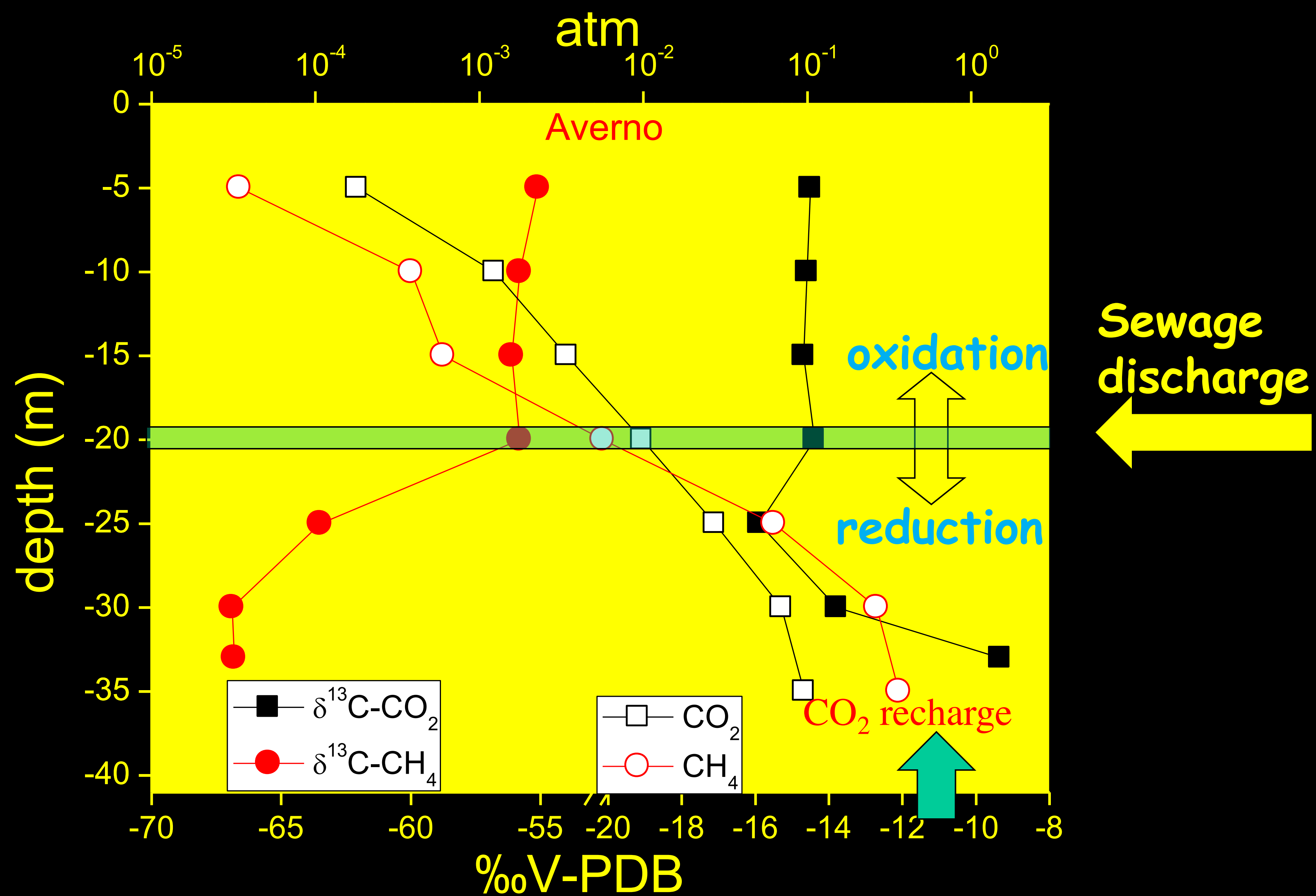
Vertical distribution of carbon isotopes



Vertical distribution of carbon isotopes



Vertical distribution of carbon isotopes



- The flat vertical profiles of Cl, Na, K, Mg, N_2, and Ar suggest that physical, chemical, and biological processes have not had enough time to change the vertical distribution of these chemical species;

- Intense microbial activity slightly regulated the SO_4 profile, while strongly affects the vertical distribution of CO_2 Ca and HCO_3;

- The behaviour of CO_2, CH_4 and O_2 is related to the balance between 1) the photosynthetic production, in the trophogenic epilimnion, of organic matter, which settles into the anoxic hypolimnion upon death of the organisms, and 2) the decomposition of organic matter and the consequent gas generation occurring, under the anoxic conditions, mainly in the lake sediments,

Conclusions 1/3

Albano

The CO_2-,CH_4-rich reservoir of this lake seems related to CO_2-rich gas inputs through the main tectonic structures underlying the lake area (R/Ra = 1.4). The behaviour of CO_2 and CH_4 within the lake is then controlled by 1) CH_4 oxidation (in the epilimnion), 2) CO_2 reduction and decomposition of organic matter (in the hypolimnion and within the lake sediment. The barrier between oxic and anoxic waters is at a depth of 80 m.

Gas pressure is strongly lower than the hydrostatic pressure. The continuous decrease of the gas reservoir seems to be related to a decrease of input from the CO_2-rich fluid source. Lake overturn events have unlikely occurred in the recent past.

The CO_2 and CH_4 contents of Lake Albano could also be related to gas inputs from below, essentially along the main tectonic structures underlying the lake area.
The CO_2-rich deep gases, whose addition rate is higher than the amount of CO_2 consumed by CH_4-producing bacteria in lake sediments, may explain the measured CO_2 excess in deep lake waters.

Gas pressure, ranging between 0.9 and 1.5 bars, is strongly lower than hydrostatic pressures. This suggests that at Albano lake the overturn of deep waters, able to trigger exsolution of accumulated gases, is to be considered, at least presently, unlike.

Conclusions 2/3

Monticchio Piccolo

Relatively strong CO_2-rich fluid inputs from the lake bottom are able to maintain a pronounced chemical stratification and a gas reservoir approaching saturation conditions, although rollover events are frequent and gas is continuosly discharged from tha lake surface. Accordingly, the lake water is charactereized by high R/Ra values (up to 6.1).

Monticchio Grande

The lake receives part of its waters from Monticchio Piccolo. However, CO_2-rich fluid inputs from the lake bottom are likely present, although their flux rate is significantly lower than that of Piccolo lake. This may explain the morphology of the lake bottom, characterized by funnel-shape depression distant from the lake center.

Conclusions 3/3

Averno

The origin of Averno waters is related to mixing of shallow waters and a Cl-, CO_2-rich component.

Rollover events, which may be triggered by cooling of the shallow water strata, are frequent. However, the relatively high input rate of deep fluids allows a rapid restoration of meromictic conditions. The carbon isotopic signature of CO_2 along the vertical profile can only be explained admitting significant contribution from sewage discharges

summarizing

In Albano-type lakes, biogeochemical processes are the main responsible for gas accumulation at depth. These processes especially when an external process (earthquake?) occur, may lead to massive gas exolution since CH_4, the main microbial product at reducing conditions, decrease the water density (whereas CO_2 increase water density)

GEOCHEMISTRY OF ACCESA SINKHOLE (SOUTHERN TUSCANY, CENTRAL ITALY): AN ANALOGUE OF A VOLCANIC LAKE

Lake Accesa

Location

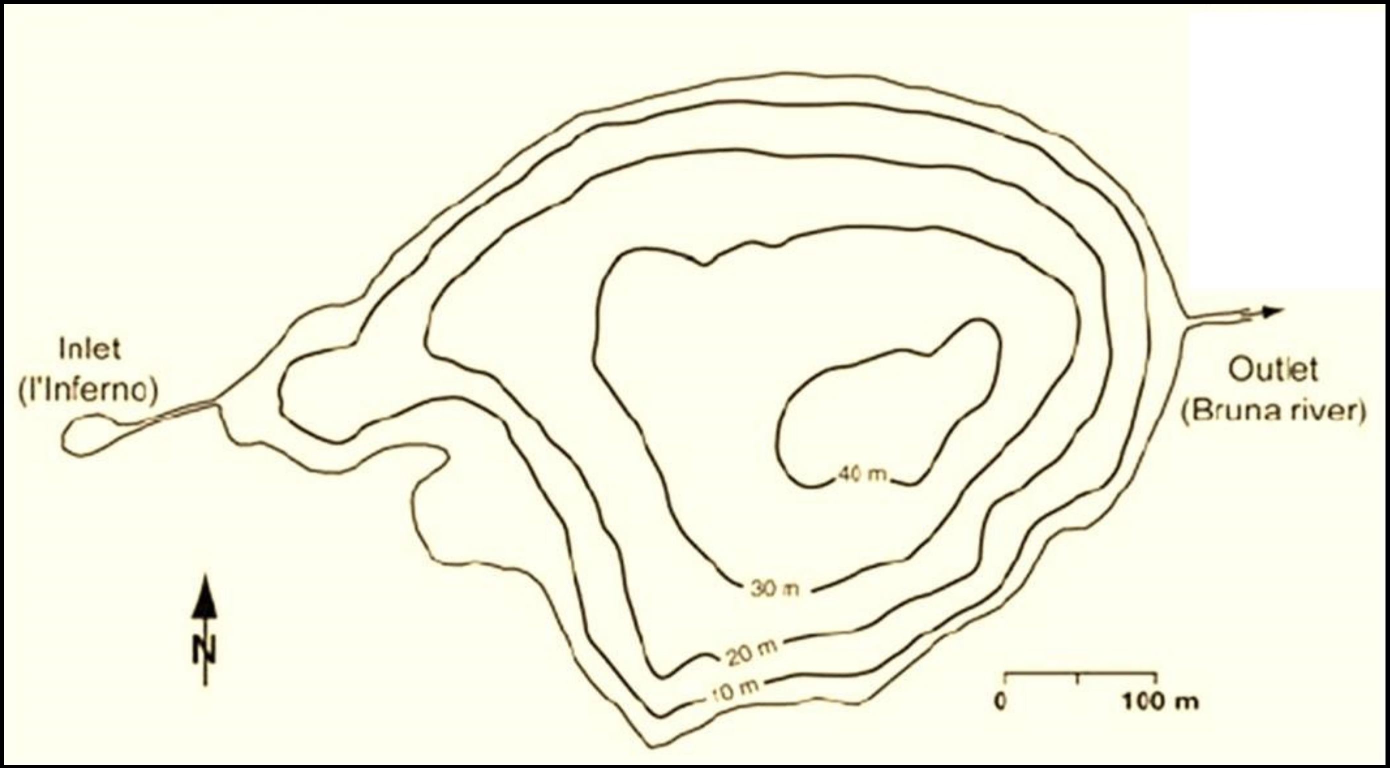
South. Tuscany (42° 59’ N and 10° 53’ E)
10 km W of the Tyrrhenian Sea

located at the southern border of the “Colline Metallifere”

↓

presence of S-bearing mineralization associated to magmatic ore bodies and gypsum-anydritic evaporites

Morphological features



funnel-shaped cavity originated by karst phenomena (<u>sinkhole</u>)

- sub-circolar shape (~ 400 m diameter)
- maximum depth ~ 40 m
- surface area = 16×10^4 m^2
- estimated volume = 2.5×10^6 m^3

Morphological features

- no litoral platform, except for the S-W zone (carbonate bench between 0 and -5 m)

- steep walls followed by a gentle slope reaching the sub-horizontal bottom

- depth-ratio = 0.5
ellipsoid shape (Carpenter, 1983)

Input & Output

<u>Lake water main sources</u>:

- **sub-aquatic epithermal springs and groundwater**
- **subordinate meteoric water**

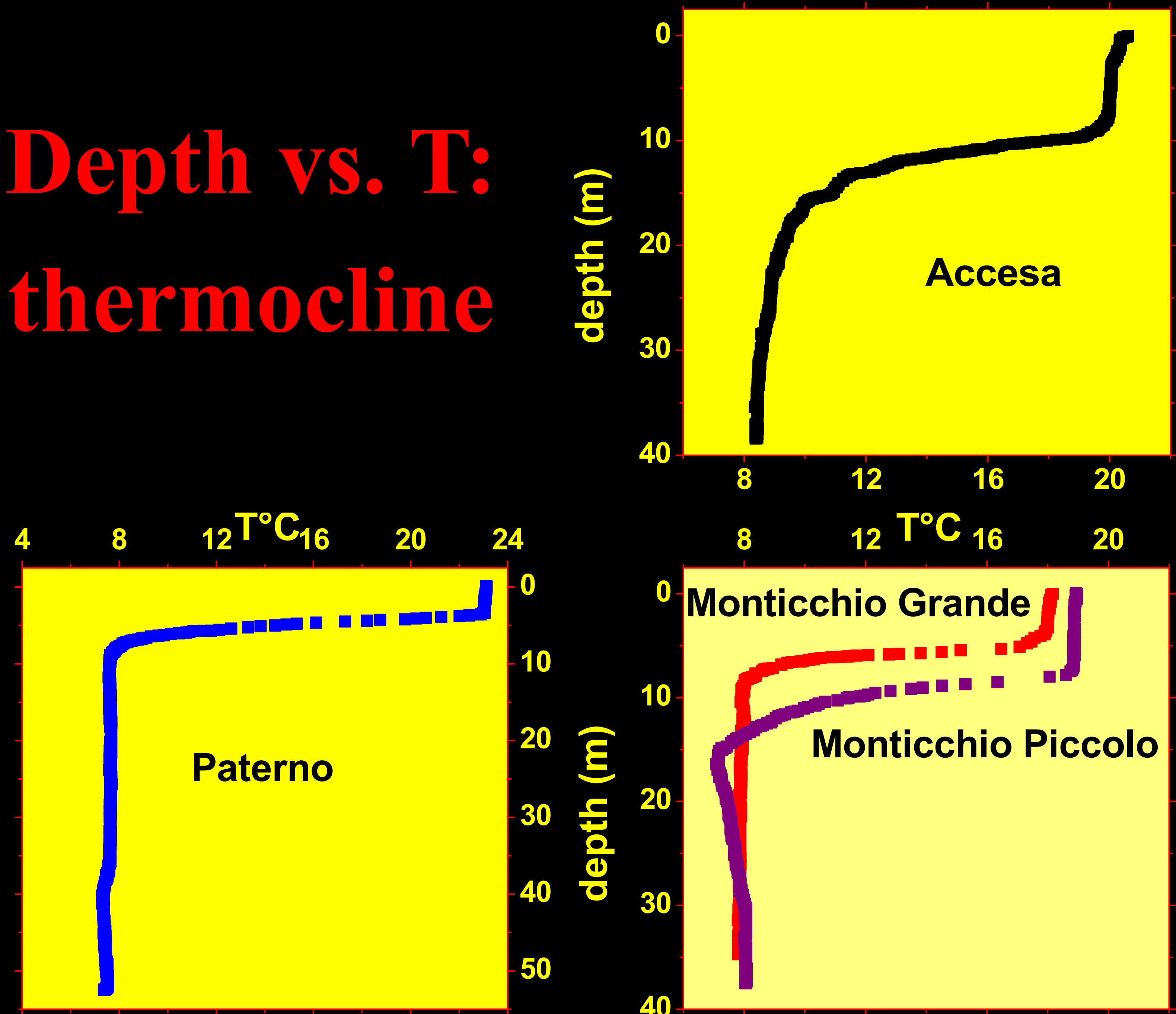
<u>Main effluent</u>:

Bruna River (315 L/sec)

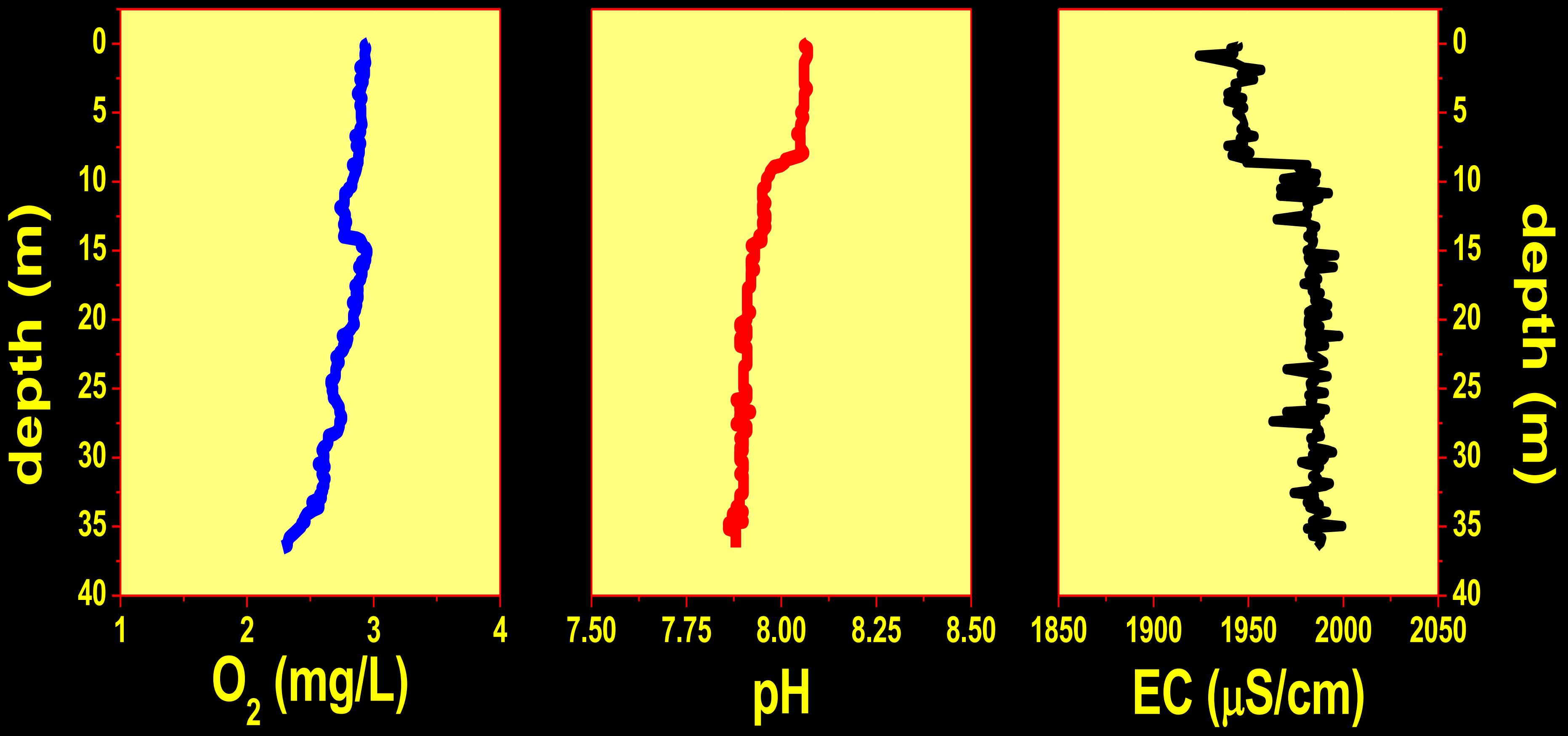
<u>TOTAL INPUT ≈ TOTAL OUTPUT</u>

These peculiar morphological and hydrological features resemble those typically shown by lakes hosted in active and quiescent volcanic systems

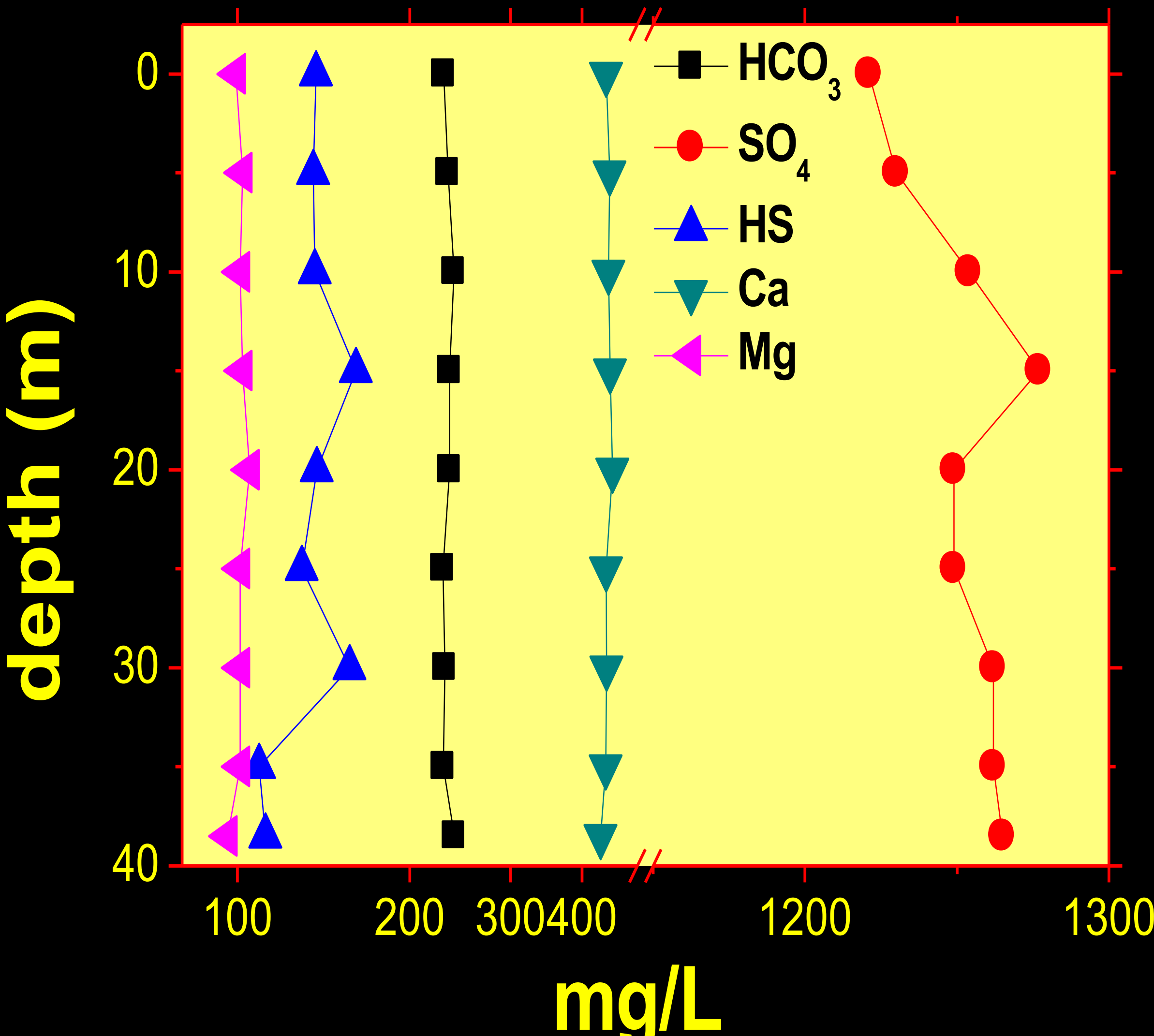
Depth vs. T: thermocline



Probe vertical profiles

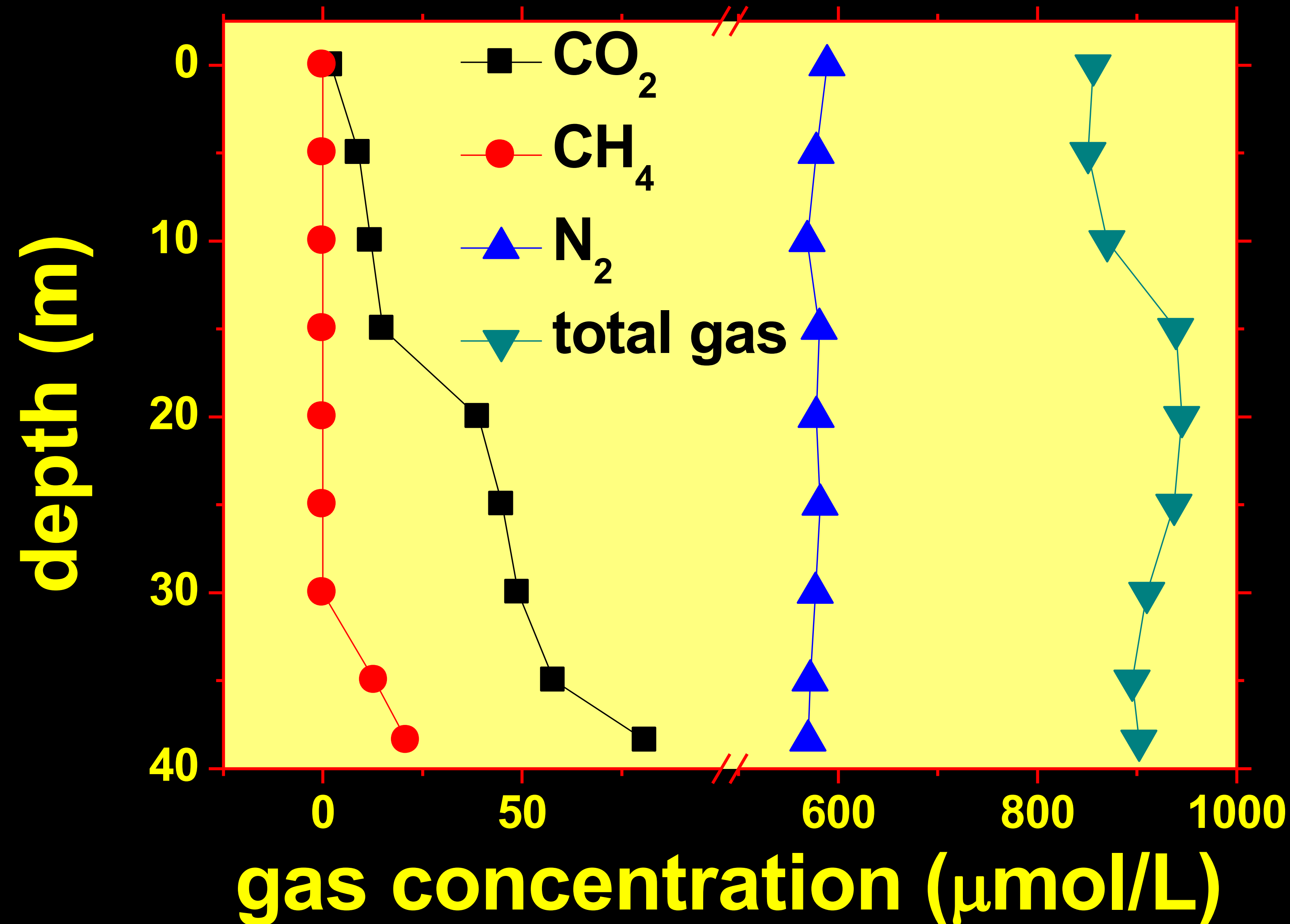


Dissolved chemical species



- ❖ relatively high TDS ~ 2 g/L
- ❖ Ca(Mg)-SO_4 composition
- ❖ high contents of:
  - $\Sigma S^{2-} \leq 160$ mg/L
  - B ≤ 1.6 mg/L
  - Sr ≤ 7.2 mg/L

Dissolved gases



$\delta^{13}C$-CO_2 values

<u>Volcanic lakes</u>
e.g. Monticchio Lakes, Lake Albano

<u>$-5.8 < \delta^{13}C\text{-}CO_2 < -0.4$</u>

<u>Sinkholes</u>
e.g. Lake Paterno, Lake Accesa

<u>$-11.8 < \delta^{13}C\text{-}CO_2 < -9.2$</u>

↓

EXTERNAL CO_2 SOURCE

↓ consistent with mantle-derived CO_2

↓ contribution of deep inorganic CO_2

$\delta^{34}S$ values

Freshwater lakes with relatively high sulphate contents (karst lakes) have $\delta^{34}S$ values reflecting those of the source enriched in ^{34}S

water samples: $+13.7 < \delta^{34}S < +14.1$

anhydrite from local geological formations: average $\delta^{34}S = +15\text{-}16$ ‰
(Cortecci et al., 1983)

Aronna spring

- located N of Lake Accesa on the same NNW-SSE tectonic element of the sub-lacustrine springs

- temperature = 23 ° C

- similar $\delta^{13}C$-CO_2 (~ -12 ‰) and $^{34}S/^{32}S$ (+14.1 ‰) isotopic signatures and water chemistry

Final Considerations

- Water and gas chemical features found in Lake Accesa are uncommon for non-volcanic lakes, which are normally almost exclusively fed by meteoric water

- Morphology and temperature profile resemble those found in lakes hosted in active and quiescent volcanic systems

Final Considerations

- Simplified hydrological budget: water input are almost equal to the output!

- The $\delta^{13}C$-CO_2 and $\delta^{34}S$ values of both Lake Accesa and Aronna spring testify, respectively, a contribution of deep-originated inorganic CO_2 and of S-rich fluids interacting with anhydritic rocks

Final Considerations

The results suggest that Lake Accesa is part of a regional hydrologic deep circuit, having a predominant or even complete hydrothermal feeding - likely from sub-aqueous thermal springs - so far constituting a unique case of sedimentary lake that simulates the characteristics of a volcanic lake