ICF14 – 14th International Conference on Fracture

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Special Symposium in Honor of David Taplin

Nano-scale Fracture Phenomena and TeraHertz Pressure Waves as the Fundamental Reasons for Geochemical Evolution

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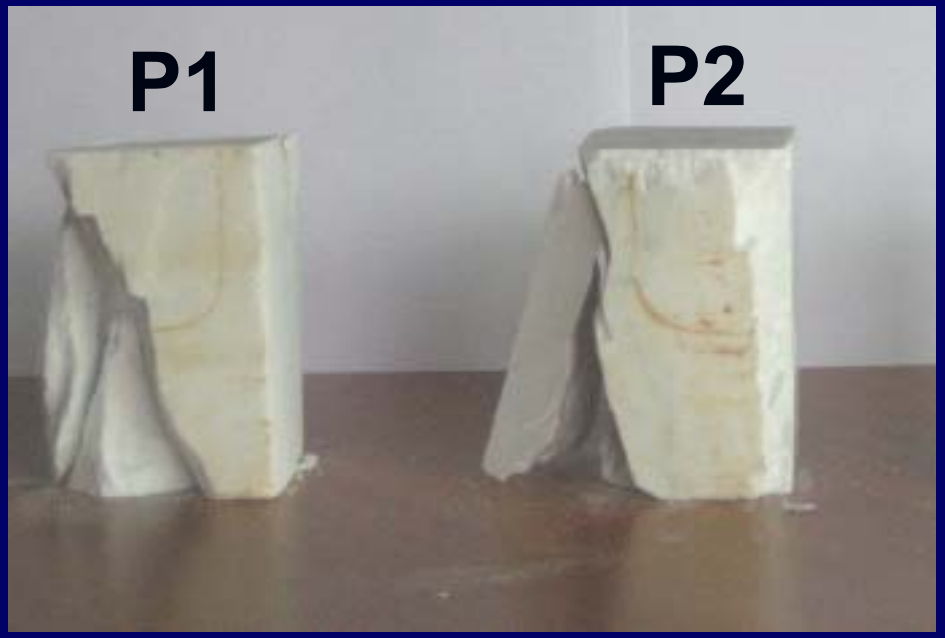
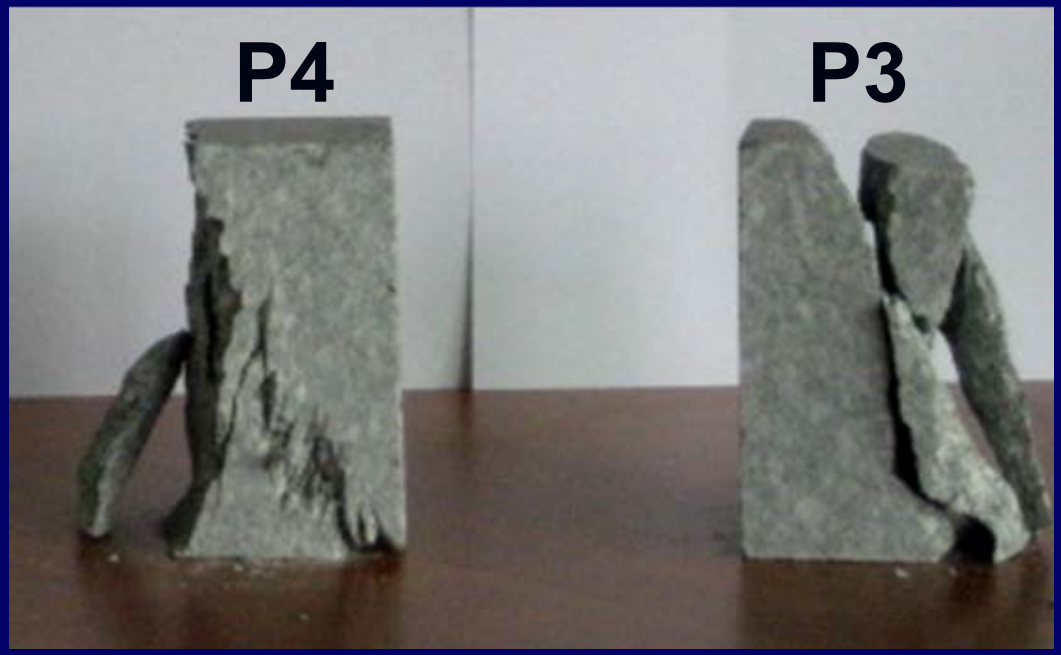
NEUTRON EMISSION FROM ROCK SPECIMENS

During a preliminary experimental analysis <u>four rock specimens</u> were used:

- two made of <u>Carrara marble</u>, specimens P1 and P2;
- two made of <u>Luserna granite</u>, specimens P3 and P4;
- all of them measuring <u>6x6x10 cm^3</u>.

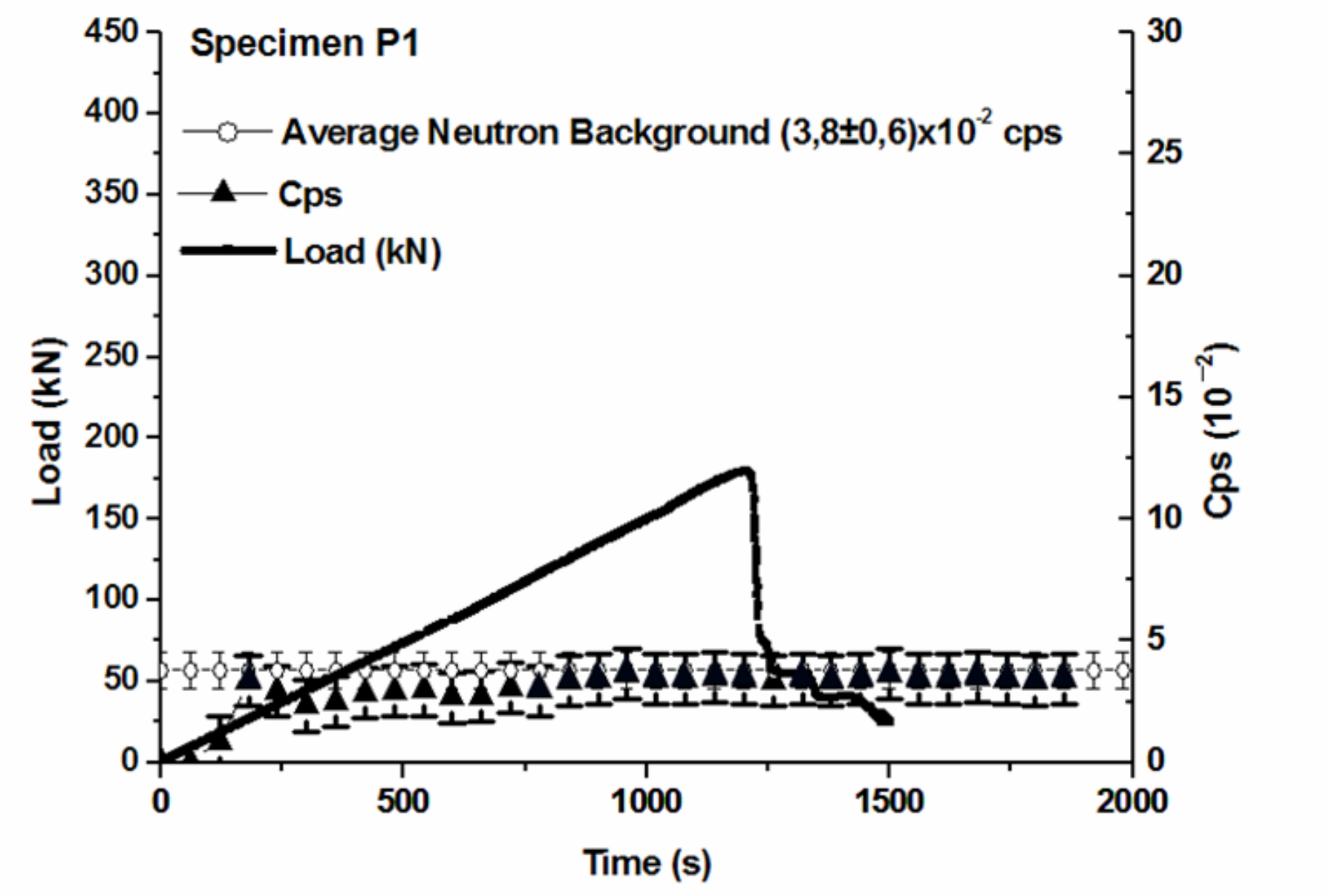


Specimens P1 and P2 in <u>Carrara marble</u> following compression failure.



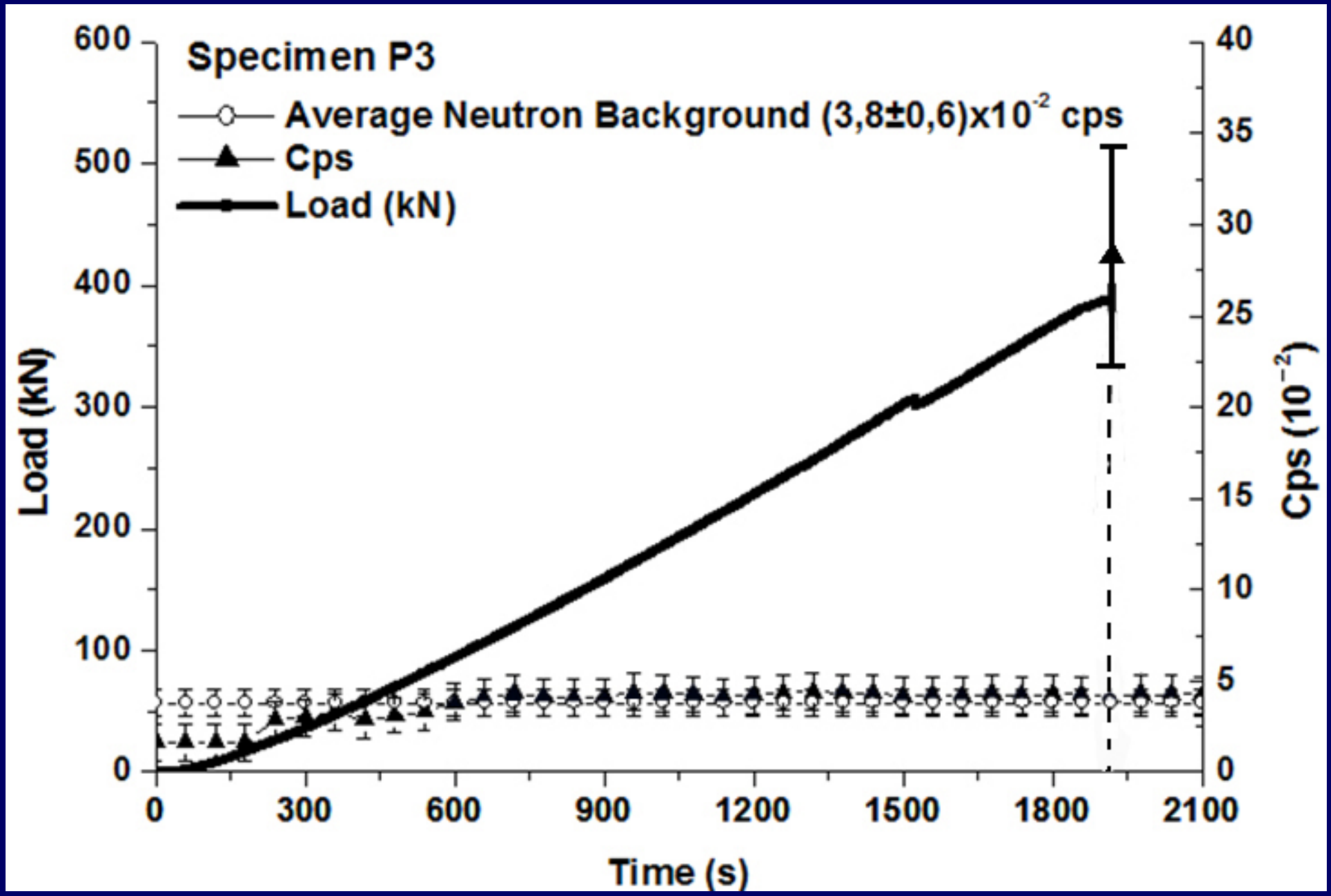
Specimens P3 and P4 in <u>Luserna granite</u> following compression failure.

Brittle Fracture Experiment on Carrara Marble specimen



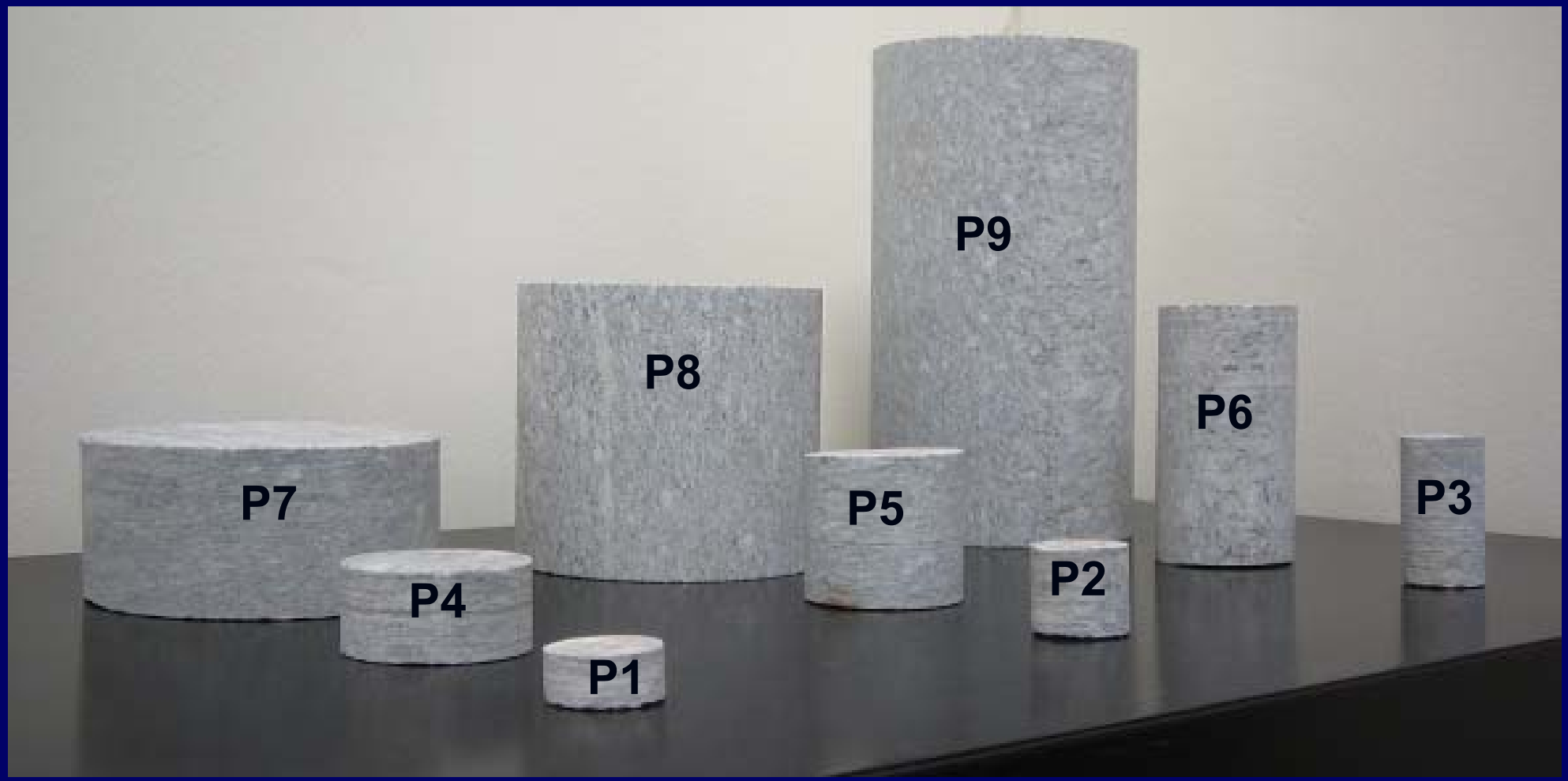
Load vs. time and cps curve for P1 test specimen of Carrara marble.

Brittle Fracture Experiment on granite specimen

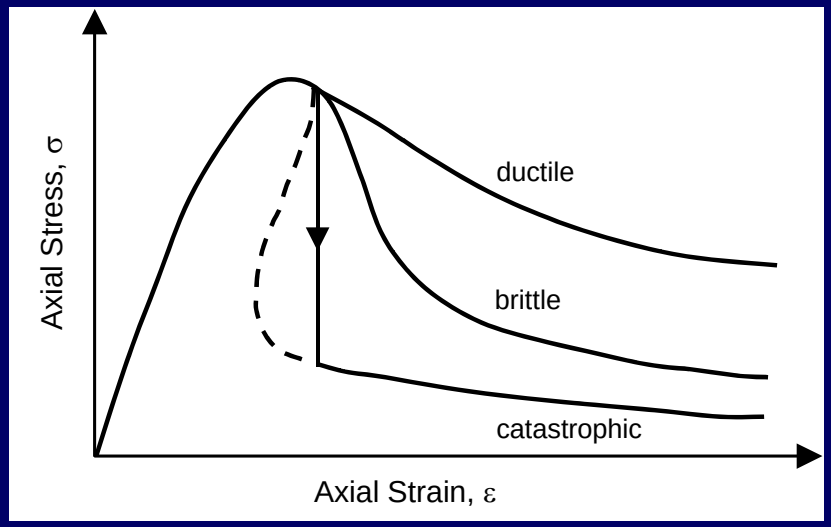


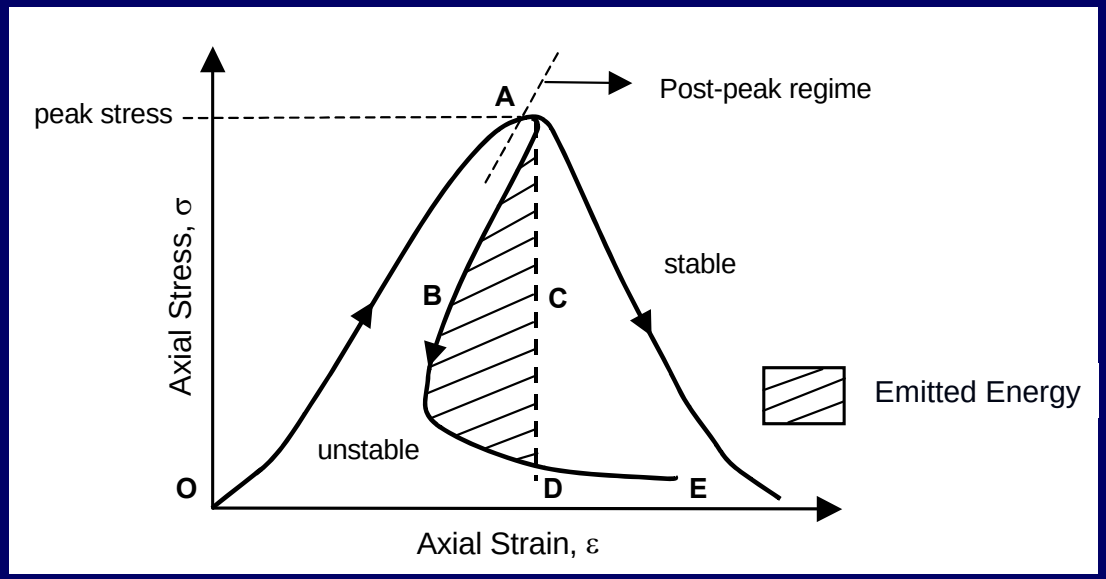
Load vs. time and cps curve for P3 test specimen of granite.

Neutron emissions were measured on nine Green Luserna stone cylindrical specimens, of different size and shape (D=28, 56, 112 mm; λ= 0.5, 1.0, 2.0)



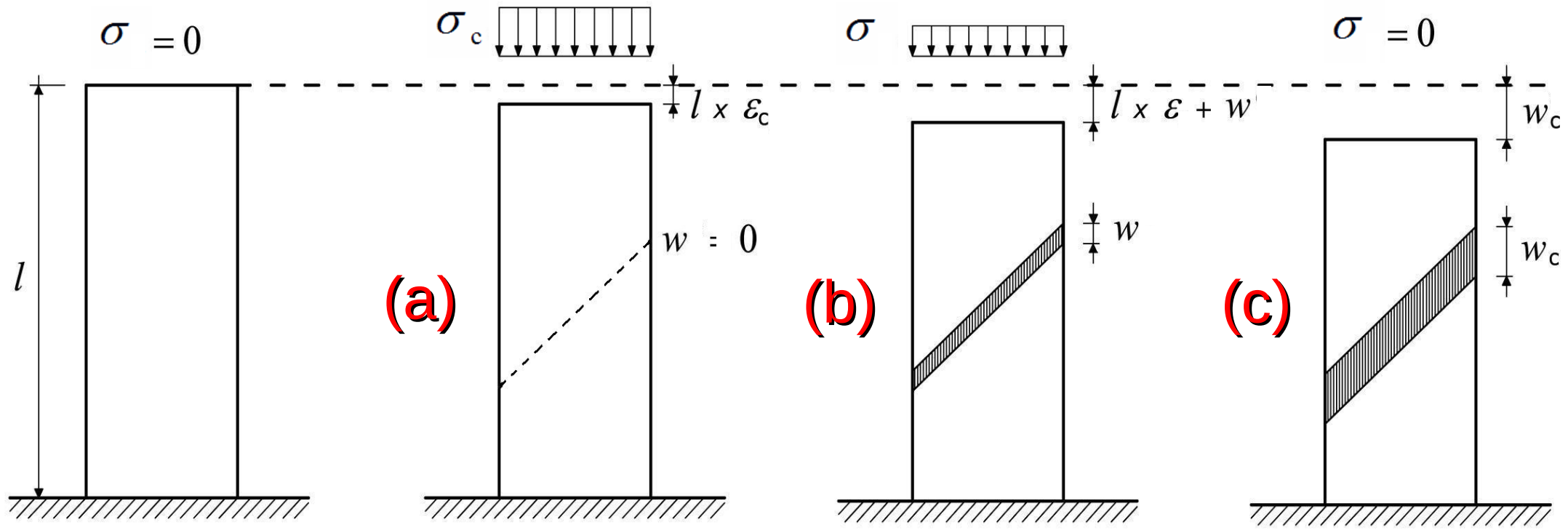
DUCTILE, BRITTLE AND CATASTROPHIC BEHAVIOUR





Energy emission and stable vs. unstable stress-strain behaviour

Subsequent stages in the deformation history of a specimen in compression[I] [II]

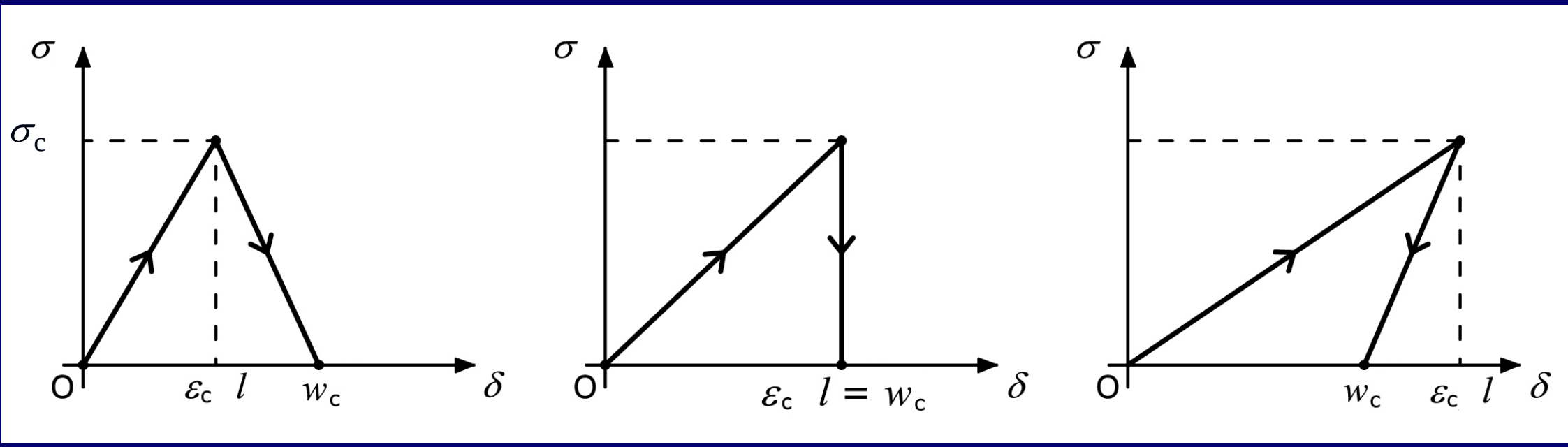


$$\delta = \varepsilon_c l = \frac{\sigma_c}{E} l; \qquad \delta = \frac{\sigma}{E} l + w; \qquad \delta \geq w_c.$$

[I] Carpinteri, A., "Cusp catastrophe interpretation of fracture instability", *J. of Mechanics and Physics of Solids*, 37, 567-582 (1989).

[II] Carpinteri, A., Corrado, M., "An extended (fractal) overlapping crack model to describe crushing size-scale effects in compression", *Eng. Failure Analysis*, 16, 2529-2540 (2009).

Stress vs. displacement response of a specimen in compression



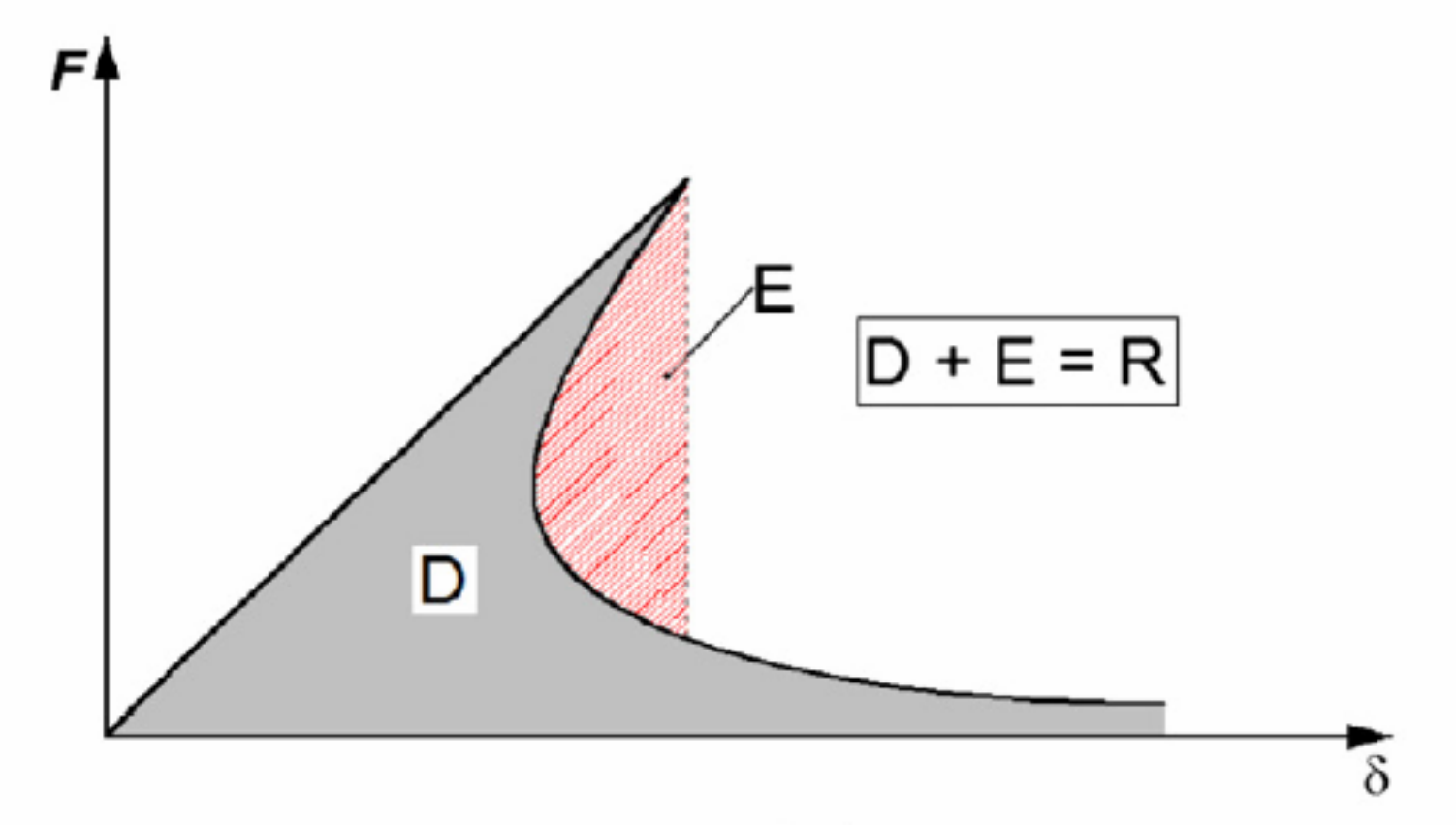
Normal softening

Vertical drop

Catastrophic behaviour

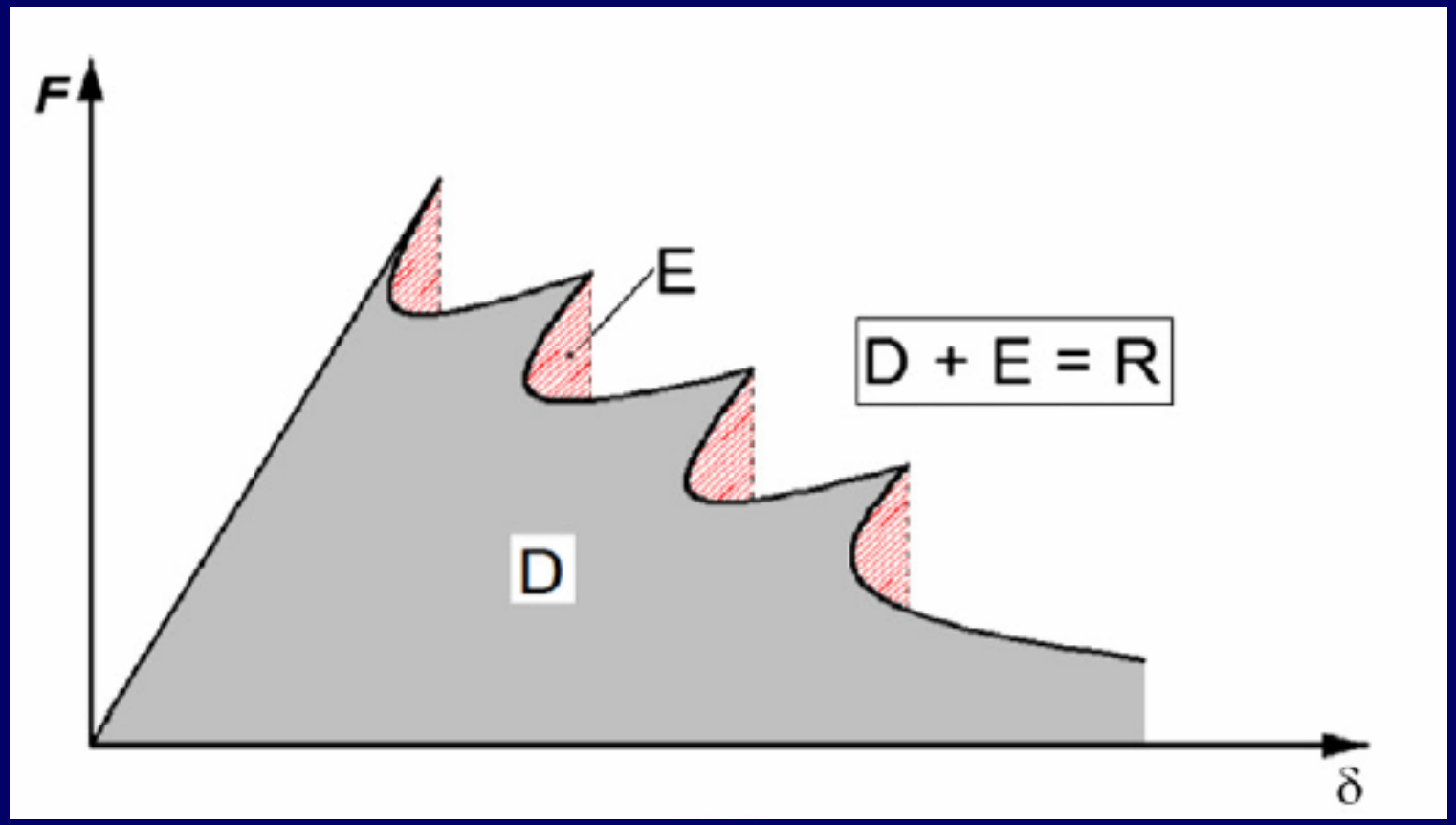
DISSIPATED AND EMITTED ENERGY

Catastrophic failure (single snap-back)



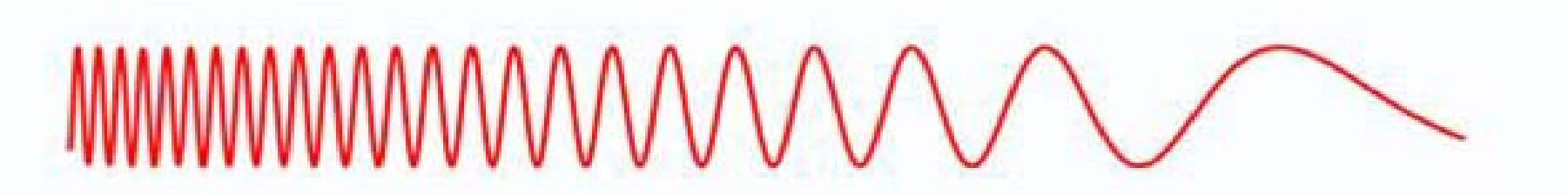
The grey area identifies the dissipated energy, D, (*namely the fracture energy in tension*) whereas the pink one represents the emitted energy, E.

A global softening behavior perturbed by multiple local instabilities (snap-back)



The total released energy, R, is the sum of the dissipated and emitted energy: D + E = R.

WAVELENGTH vs FREQUENCY



f (Hertz) 10^{12} 10^{9} 10^{6} 10^{3} 10^{0}

Proteins

Bacteria

Insects

Humans

Earthquakes

λ (Metre) 10^{-9} 10^{-6} 10^{-3} 10^{0} 10^{3}

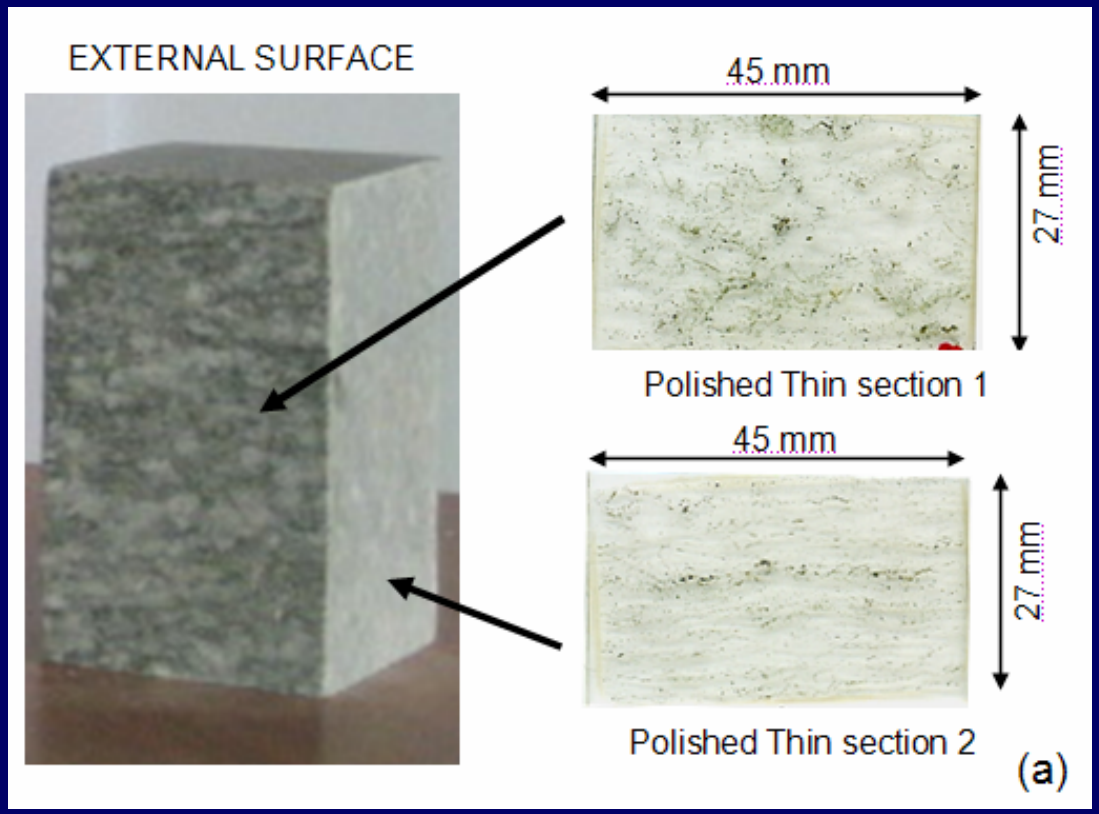
$$\textit{wave velocity} = \lambda \times f \approx 10^{3}\ \mathrm{m\ s^{-1}}$$

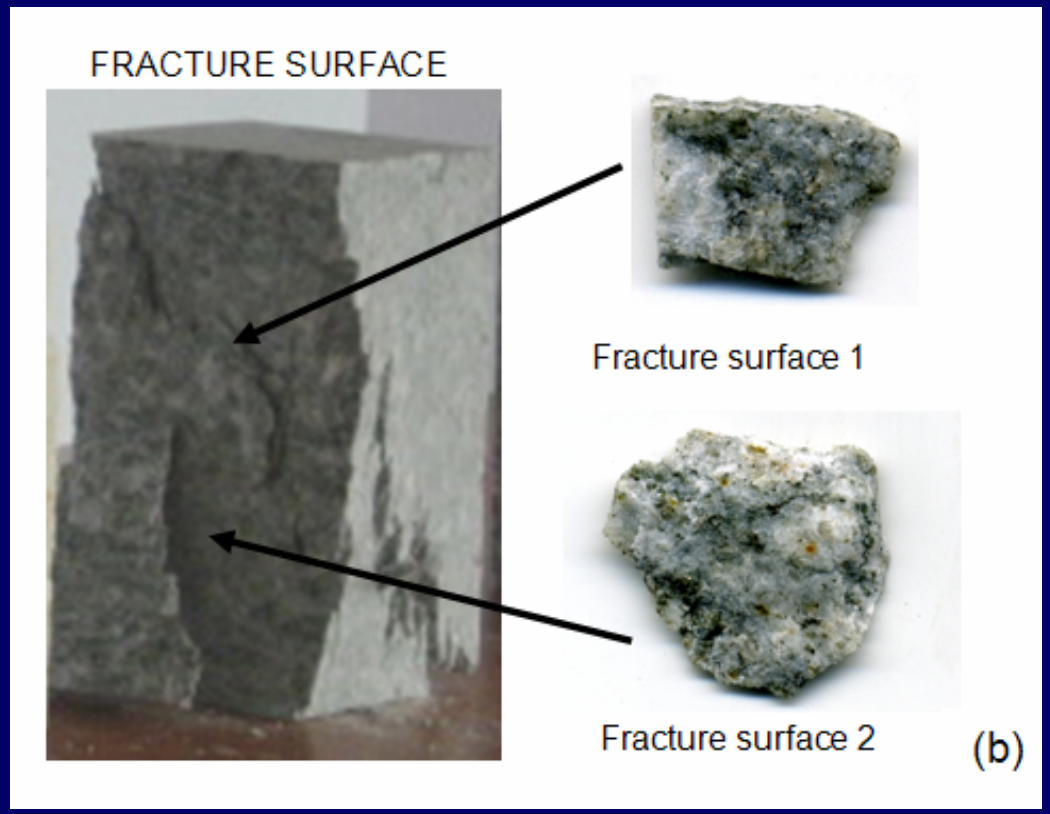
NEUTRON EMISSION FROM CAVITATION IN LIQUIDS AND FRACTURE IN SOLIDS

MATERIAL		NEUTRON EMISSION
LIQUIDS – **Cavitation**		
Iron chloride	→	up to 2.5 times the Background Level
SOLIDS – **Fracture**		
Steel	→	up to 2.5 times the Background Level
Granite (Fe ~ 1.5%)	→	up to 10^1 times the Background Level
Basalt (Fe ~ 15%)	→	up to 10^2 times the Background Level
Magnetite (Fe ~ 75%)	→	up to 10^3 times the Background Level
Marble	→	Background Level

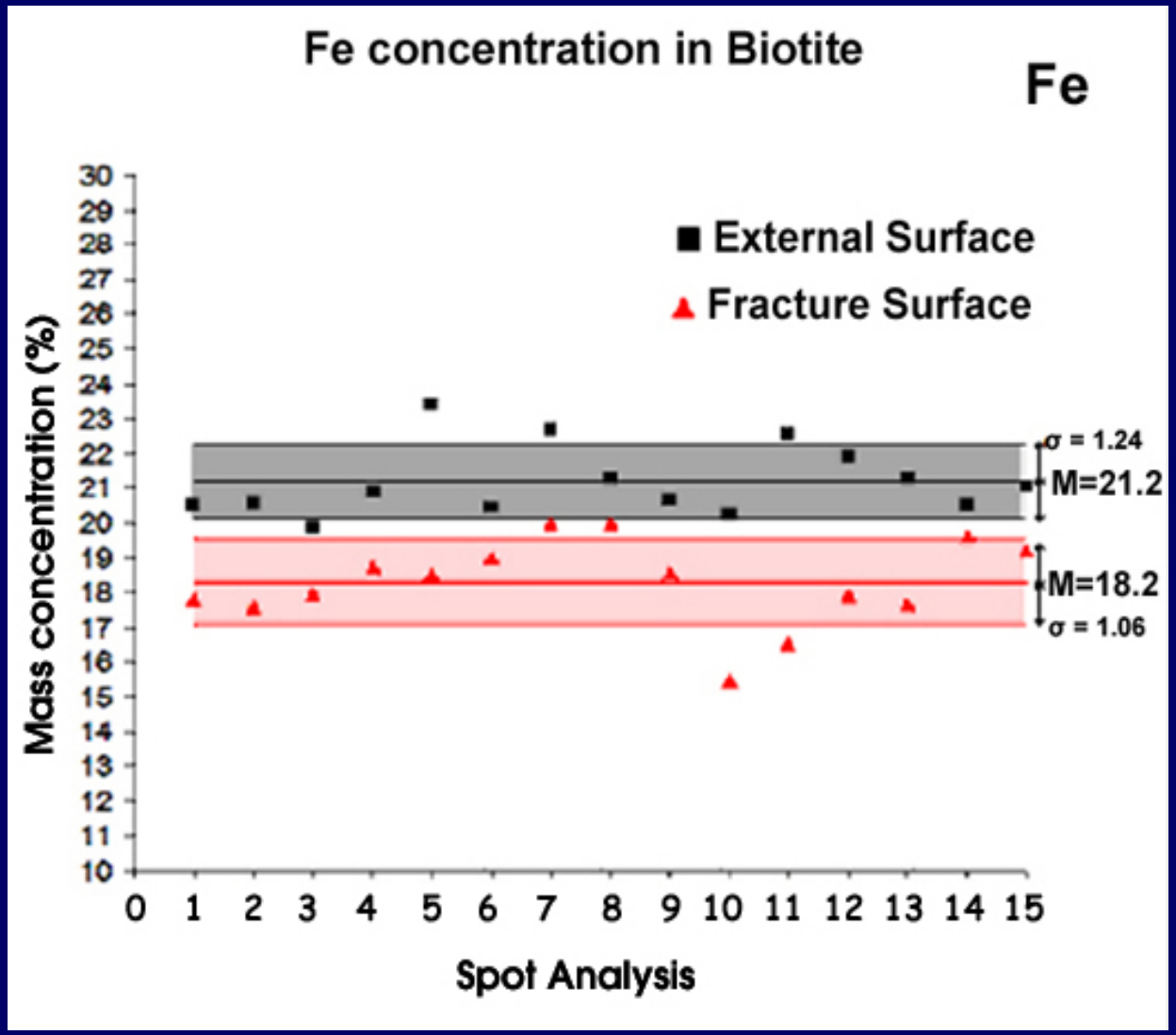
MICROCHEMICAL ANALYSIS: ENERGY DISPERSIVE X-RAY SPECTROSCOPY

Two different kinds of samples were examined: (i) polished thin sections from the external surface; (ii) small portions from the fracture surface.





Biotite (Granite): Fe concentration change



External Surf.:

Fe content = 21.2%

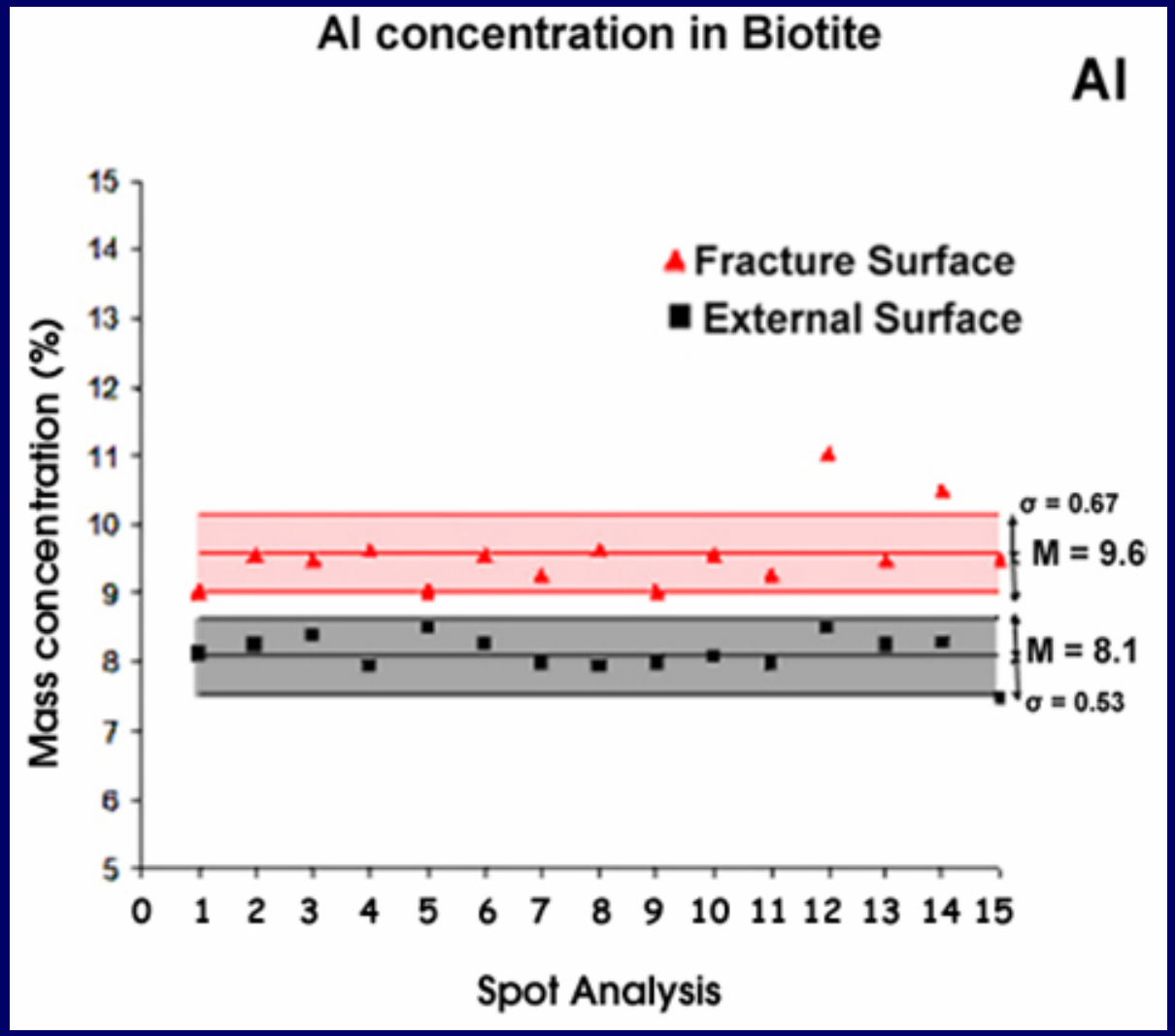
Fracture Surf.:

Fe content = 18.2%

Fe content decrease

–3.0%

Biotite (Granite): Al concentration change



Fracture Surf.:

Al content = 9.6%

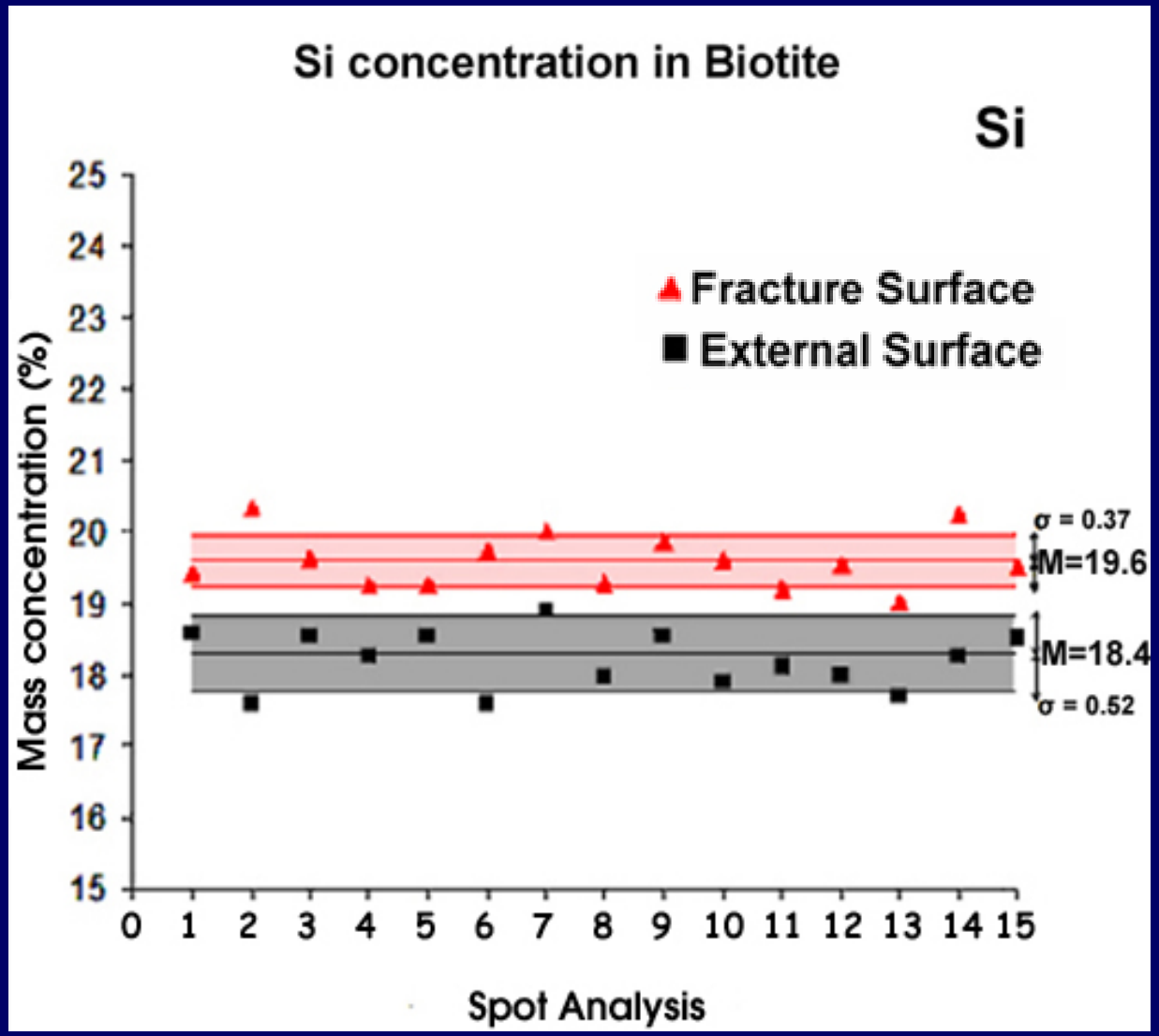
External Surf.:

Al content = 8.1%

Al content increase

+1.5%

Biotite (Granite): Si concentration change



Fracture Surf.:

Si content = 19.6%

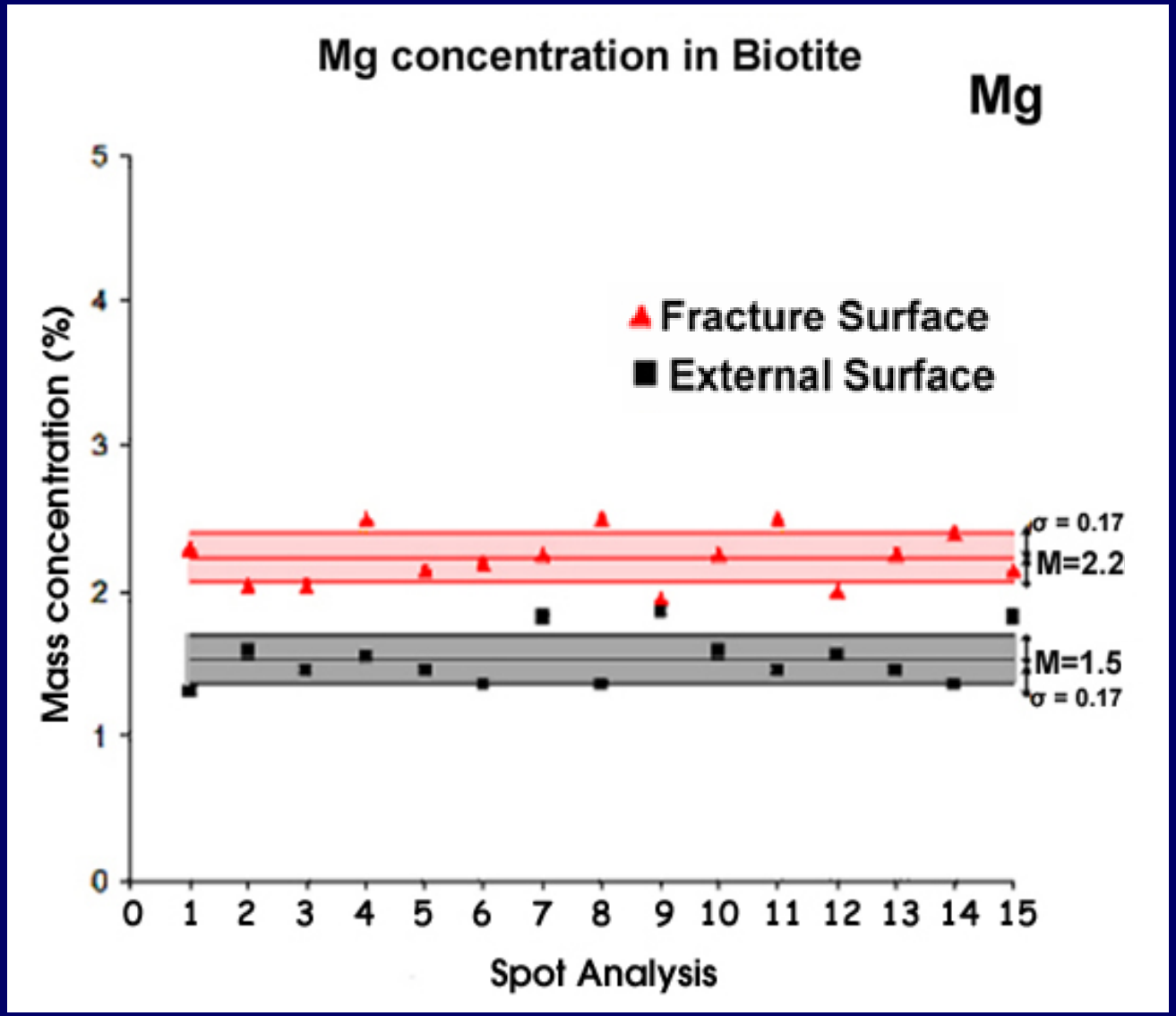
External Surf.:

Si content = 18.4%

Si content increase

+1.2%

Biotite (Granite): Mg concentration change



Fracture Surf.:

Mg content = 2.2%

External Surf.:

Mg content = 1.5%

Mg content increase

+0.7%

Biotite (Granite)

	External surface mean value (wt%)	Fracture surface mean value (wt%)	Increase/ decrease with respect to biotite	Increase/ decrease with respect to the same element
Fe	21.2	18.2	–3.0 %	–14%
Al	8.1	9.6	+1.5 %	+18%
Si	18.4	19.6	+1.2 %	+6%
Mg	1.5	2.2	+0.7 %	+46%
K	6.9	7.1	NO VARIATIONS	NO VARIATIONS

$$Fe_{26}^{56} \rightarrow 2\,Al_{13}^{27} + 2n$$

$$Fe_{26}^{56} \rightarrow Si_{14}^{28} + Mg_{12}^{24} + 4n$$

Carrara Marble

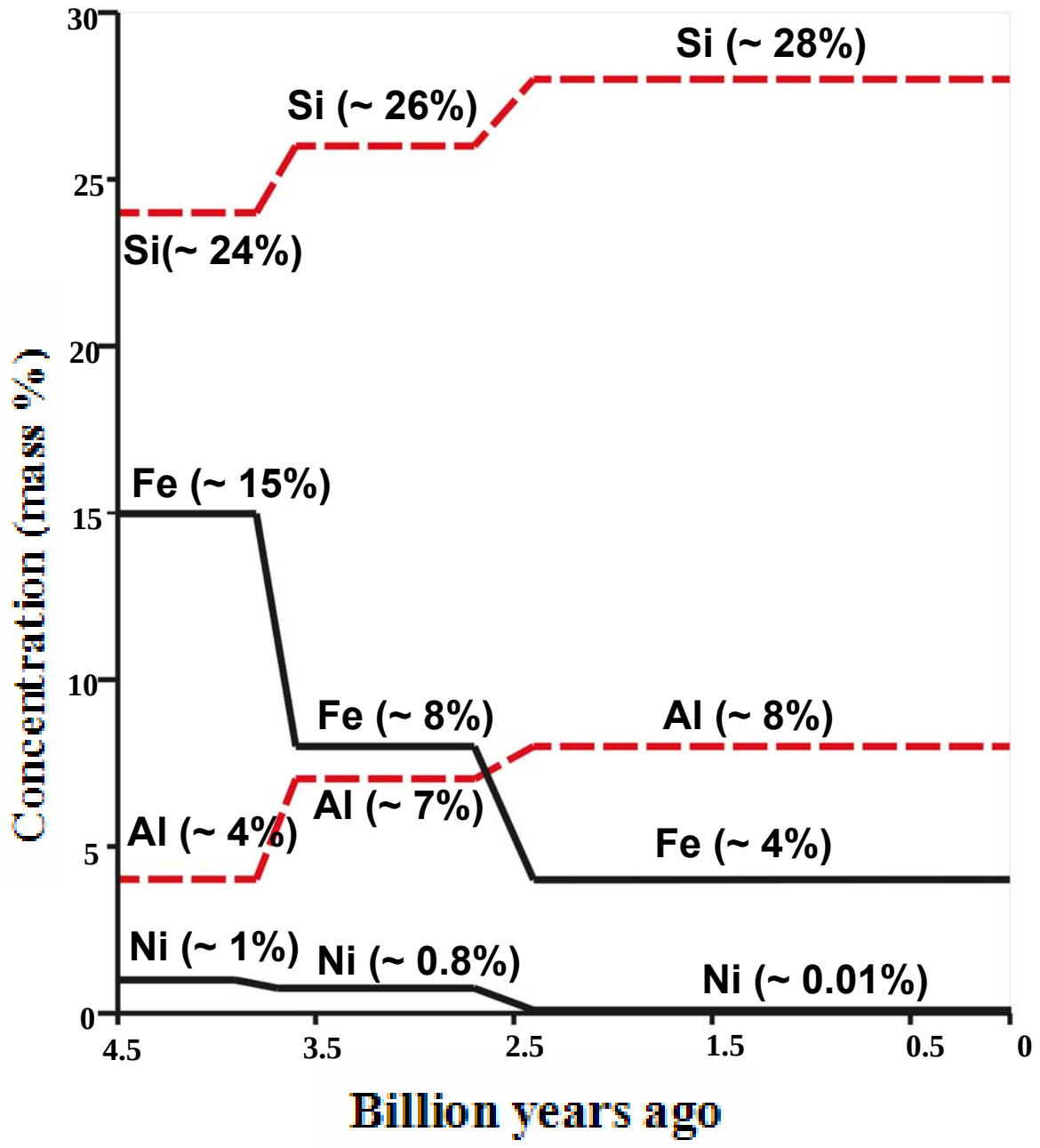
	External surface mean value (wt%)	Fracture surface mean value (wt%)	Increase/ decrease with respect to Carrara Marble	Increase/ decrease with respect to the same element
Ca	13.4	9.8	– 3.6%	– 26%
Mg	0.7	0.3	– 0.4%	– 57%
O	45.8	36.8	– 9.0%	– 19%
C	40.1	53.1	+ 13.0%	+ 32%

$$Ca_{20}^{40} \rightarrow 3C_{6}^{12} + He_{2}^{4}$$

$$Mg_{12}^{24} \rightarrow 2C_{6}^{12}$$

$$O_{8}^{16} \rightarrow C_{6}^{12} + He_{2}^{4}$$

IRON DEPLETION vs CARBON POLLUTION



Tectonic plate formation

(3.8 Billion years ago):
Fe (–7%) + Ni (–0.2%) =
=Al (+3%) + Si (+2.4%) + Mg (+1.8%)

Most severe tectonic activity

(2.5 Billion years ago):
Fe (–4%) + Ni (–0.8%) =
=Al (+1%) + Si (+2.4%) + Mg (+1.4%)

Conjecture about ferrous elements' transformations in the Earth Crust

(1) $Fe_{26}^{56} \rightarrow 2\,Al_{13}^{27} + 2n$

(2) $Fe_{26}^{56} \rightarrow Mg_{12}^{24} + Si_{14}^{28} + 4n$

(3) $Ni_{28}^{59} \rightarrow 2\,Si_{14}^{28} + 3n$

Magnesium depletion and Carbon increment in the primordial atmosphere

The estimated Mg increase (~3.2%) is equivalent to the Carbon content in the primordial atmosphere:

$$Fe_{26}^{56} \rightarrow Mg_{12}^{24} + Si_{14}^{28} + 4n$$

$$Mg_{12}^{24} \rightarrow 2C_{6}^{12}$$

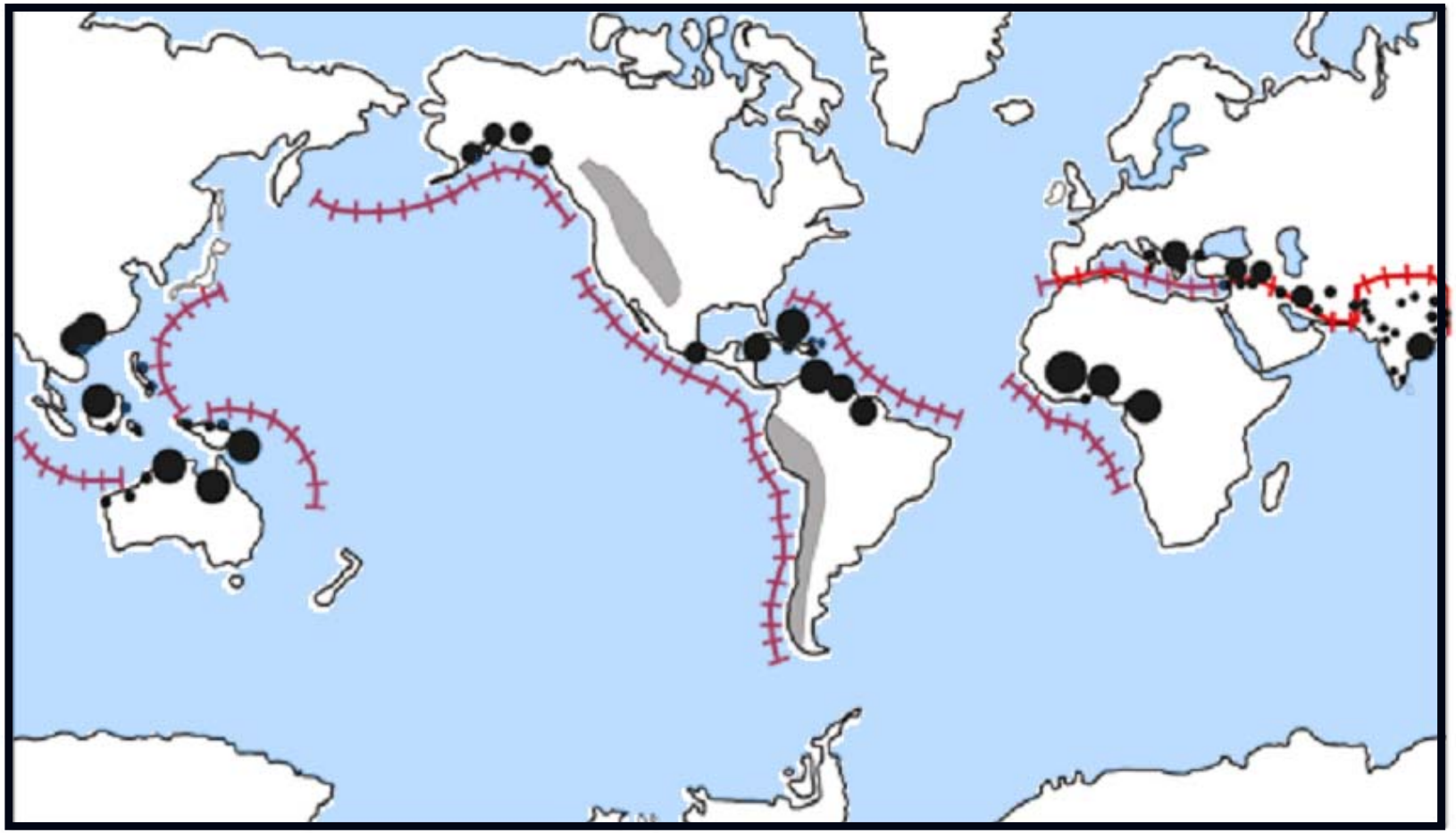
Assuming a mean density of the Earth Crust equal to 3.6 g/cm^3 and a thickness of ~60 km, the mass increase in Mg (~3.5×10^{21} kg), and therefore in C, implies a very high atmospheric pressure.

Primordial atmospheric pressure due to C increase = ~660 atm

Primordial atmospheric pressure reported by other authors = ~650 atm (Liu, 2004)

Liu, L., "The inception of the oceans and CO_2-atmosphere in the early history of the Earth". *Earth Planet. Sci. Lett.*, 227, 179–184 (2004)

Localization of Aluminum mines



Aluminum reservoirs

- More than 10 Mt/year
- from 5 to 10 Mt/year
- from 1 to 5 Mt/year
- from 0.5 to 1 Mt/year

Subduction lines and tectonic plate trenches

Large Andesitic formations (the Rocky Mountains and the Andes)

(*) World Iron Ore producers. Available at http://www.mapsofworld.com/minerals/world-iron-ore-producers.html.

(**) World Mineral Resources Map. Available at http://www.mapsofworld.com/world-mineral-map.html.

HIERARCHY OF PIEZONUCLEAR FISSION REACTIONS

Two piezonuclear fission reaction jumps typical of the Earth Planet:

$Fe_{26}, Co_{27}, Ni_{28}$ (NI-FE)

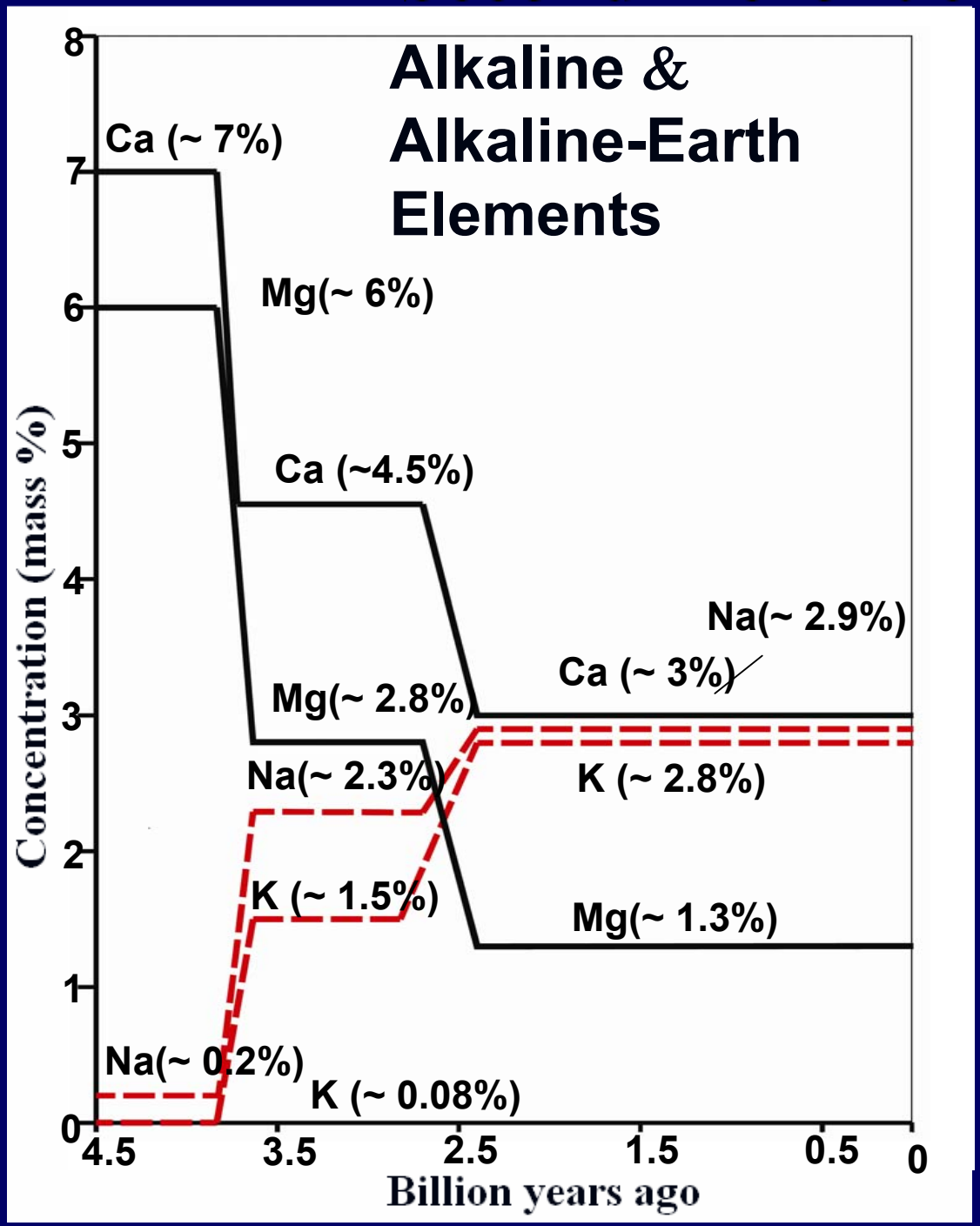
↓

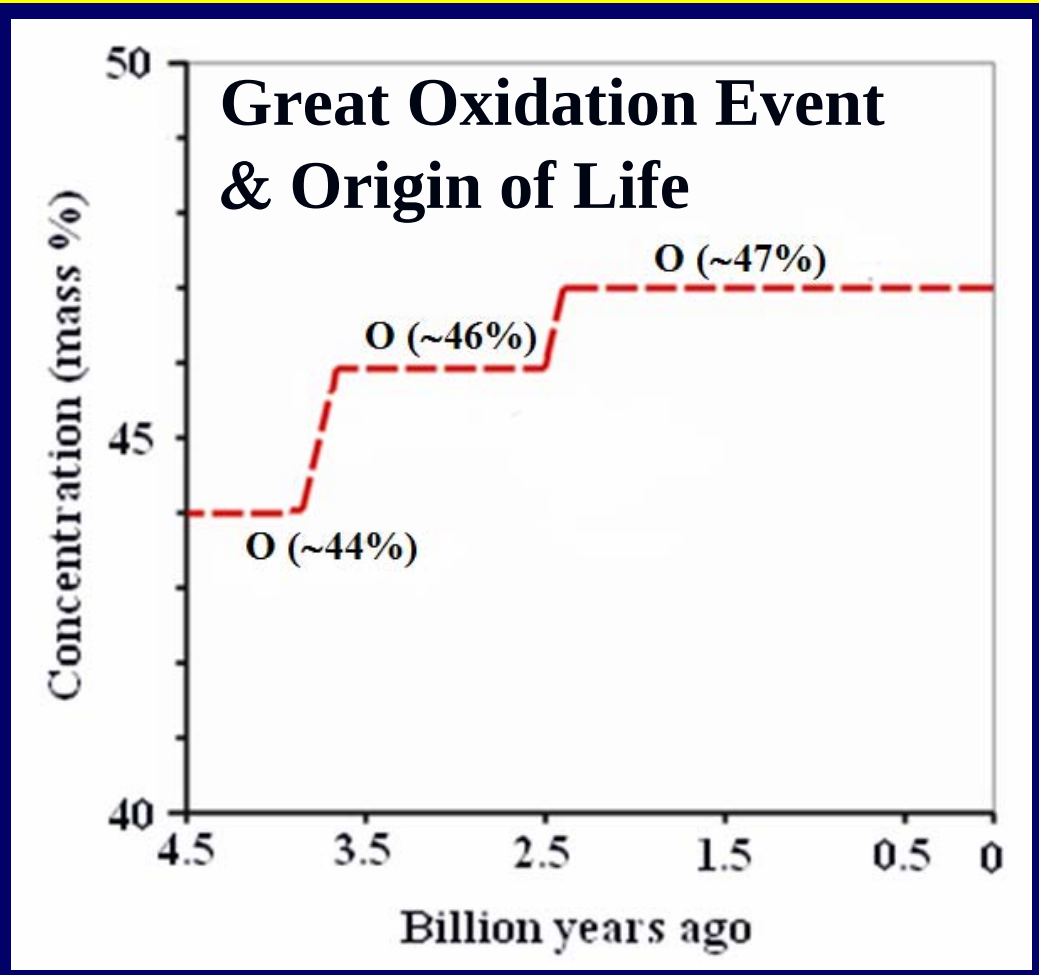
$Mg_{12}, Al_{13}, Si_{14}$ (SI-MA, SI-AL)

↓

C_6, N_7, O_8 (Atmosphere)

CALCIUM DEPLETION vs OCEAN FORMATION





3.8 Billion years ago:
Ca (–2.5%) + Mg(–3.2%) =
= K (+1.4%) + Na (+2.1%) + O (+2.2%)

2.5 Billion years ago:
Ca (–1.5%) + Mg(–1.5%) =
=K (+1.3%) + Na (+0.6%) + O (+1.1%)

Conjecture about Alkaline-Earth elements' transformations

(1) $$Mg_{12}^{24} \rightarrow Na_{11}^{23} + H_1^1$$

(2) $$Mg_{12}^{24} \rightarrow O_8^{16} + 2H_1^1 + He_2^4 + 2n$$

(3) $$Ca_{20}^{40} \rightarrow K_{19}^{39} + H_1^1$$

(4) $$Ca_{20}^{40} \rightarrow 2O_8^{16} + 4H_1^1 + 4n$$

Alberto Carpinteri · Giuseppe Lacidogna
Amedeo Manuello *Editors*

Acoustic, Electromagnetic, Neutron Emissions from Fracture and Earthquakes

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