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Fracture Mechanics for Durability, Reliability, and Safety
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Piezonuclear Reactions Produced by Brittle Fracture: From Laboratory to Planetary Scale

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FRACTURE OF FISSILE AND DEUTERATED MATERIALS

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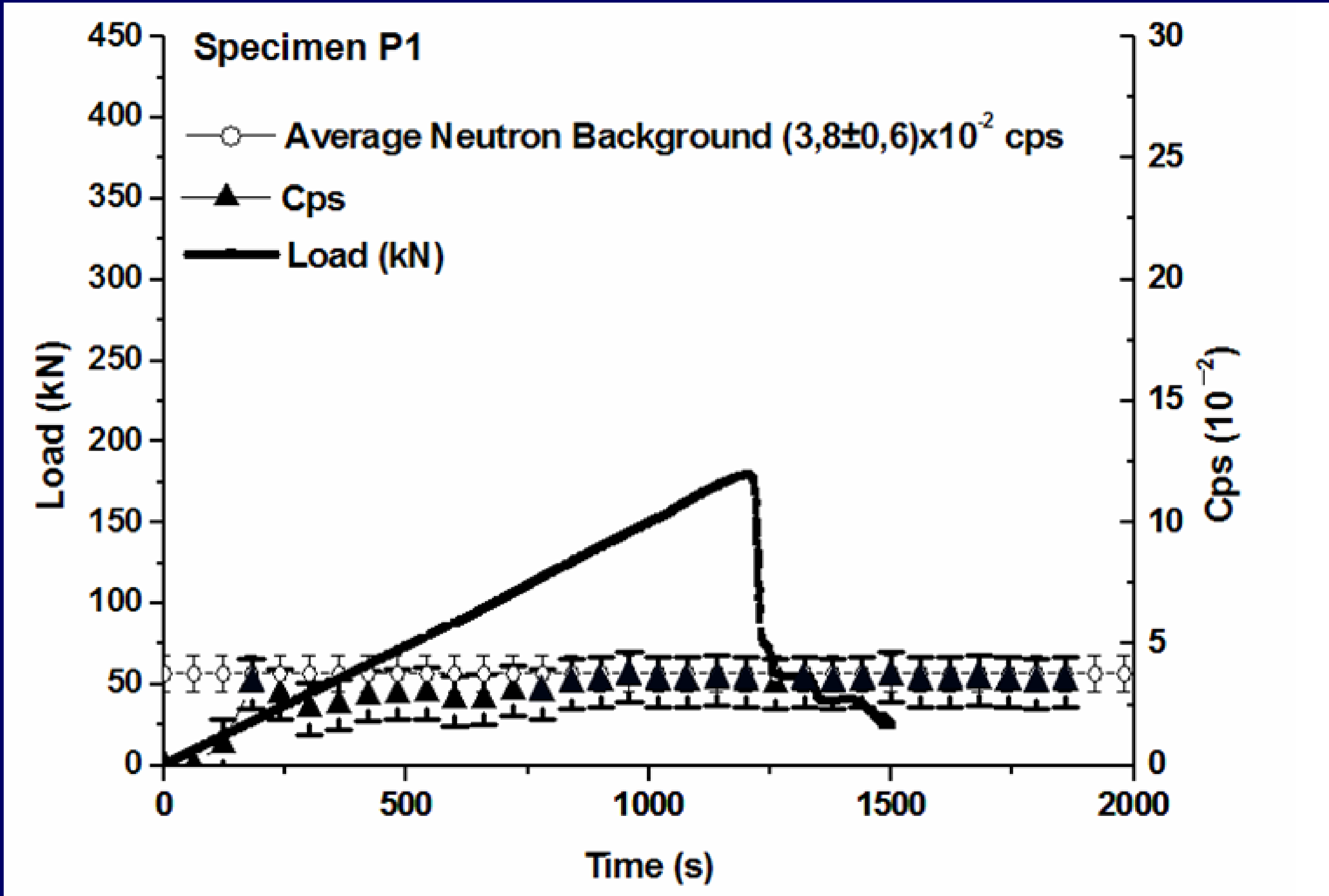
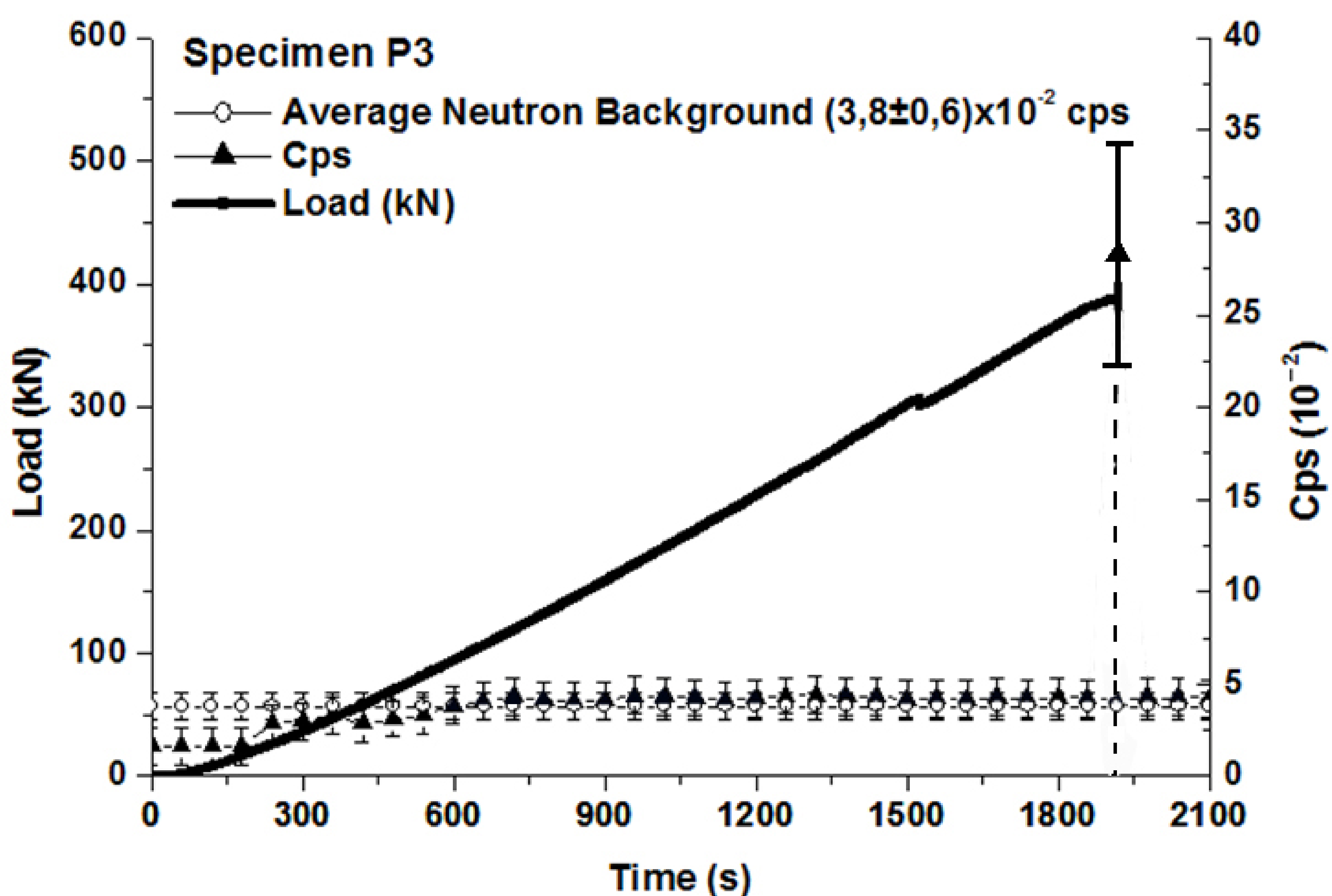
LABORATORY EXPERIMENTS

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

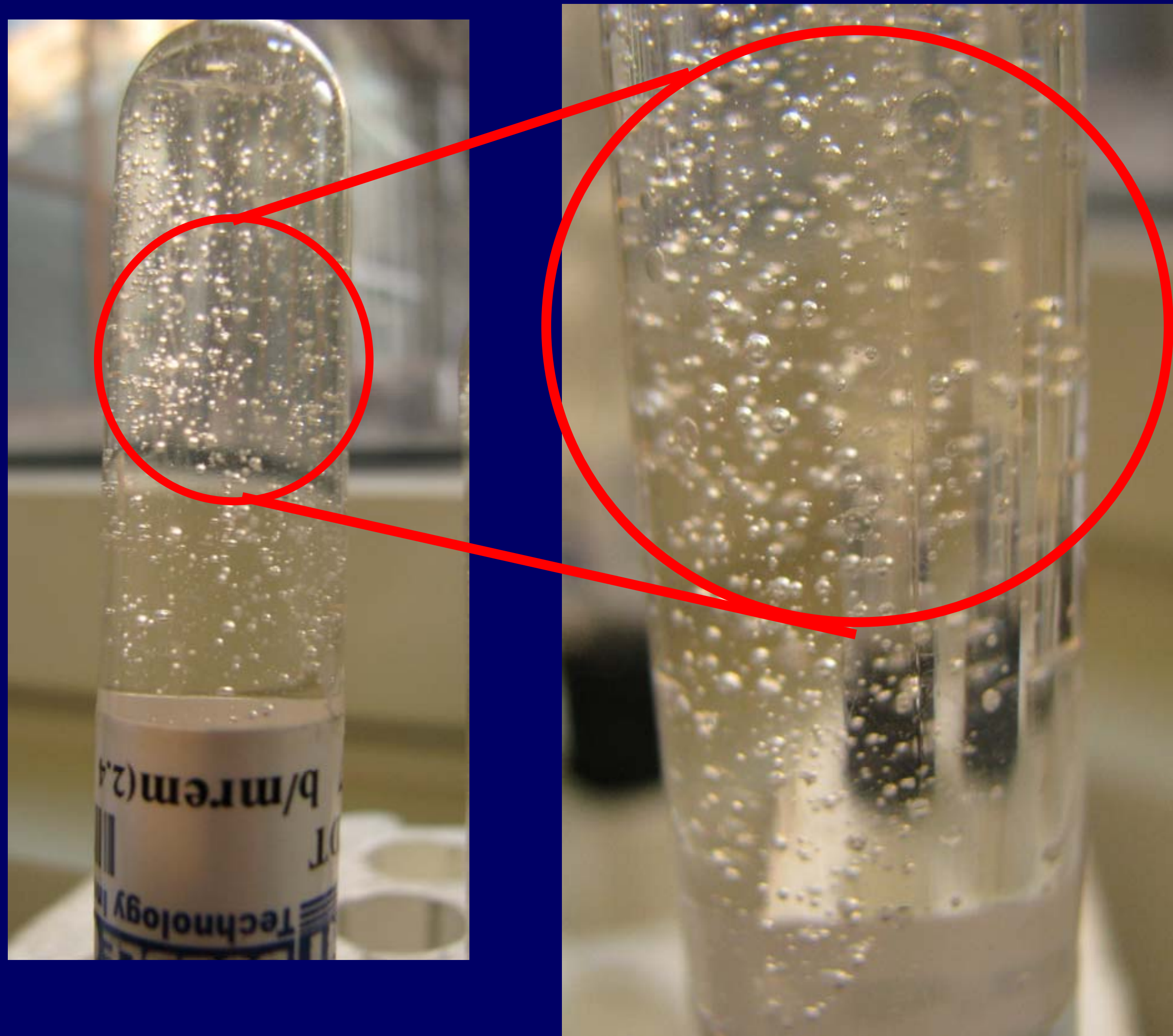


Load vs. time and cps curve for P3 test specimen of granite.

NEUTRON EMISSION FROM CAVITATION OF LIQUIDS AND FRACTURE OF 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**
Basalts (Fe ~ 15%)	→	**up to 10^2 times the Background Level**
Magnetite (Fe ~ 75%)	→	**up to 10^3 times the Background Level**
Marble	→	**Background Level**

Cyclic Loading Experiments on Basaltic Rocks

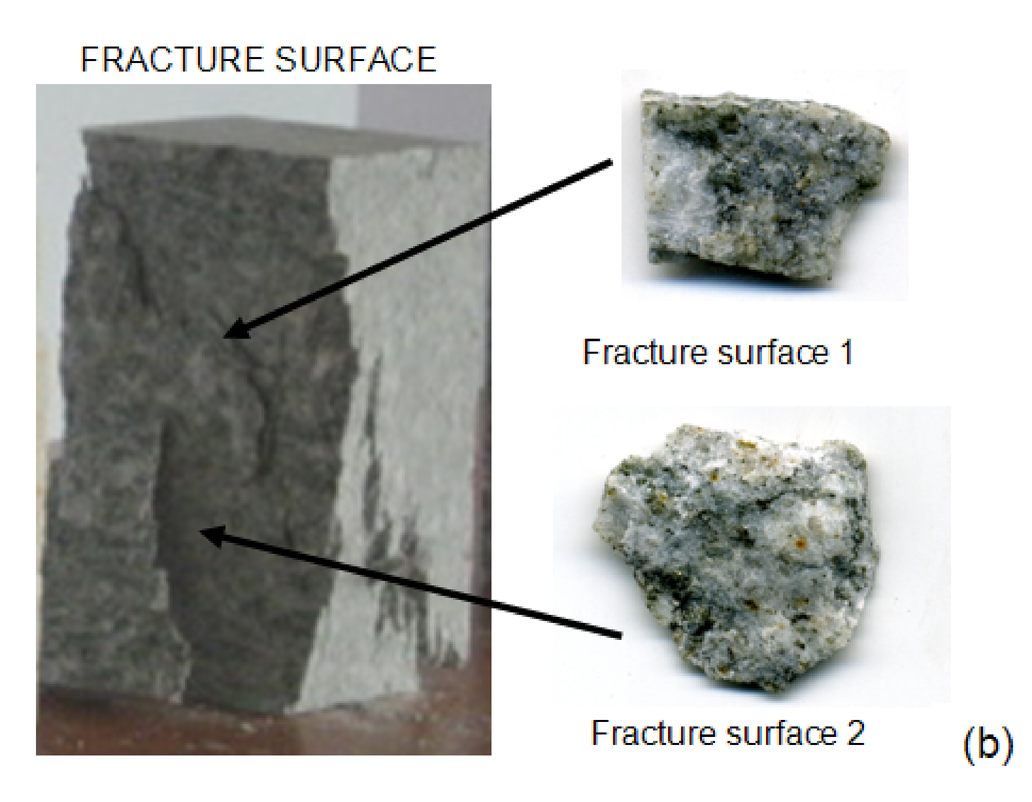


The equivalent neutron dose, at the end of the test on basaltic rock, was 2.62 ± 0,53 μSv/h (Average Background Dose = 41.95 ± 0,85 nSv/h).

$$\frac{\textbf{Effective Neutron Dose}}{\textbf{Average Background Dose}} \cong 50$$

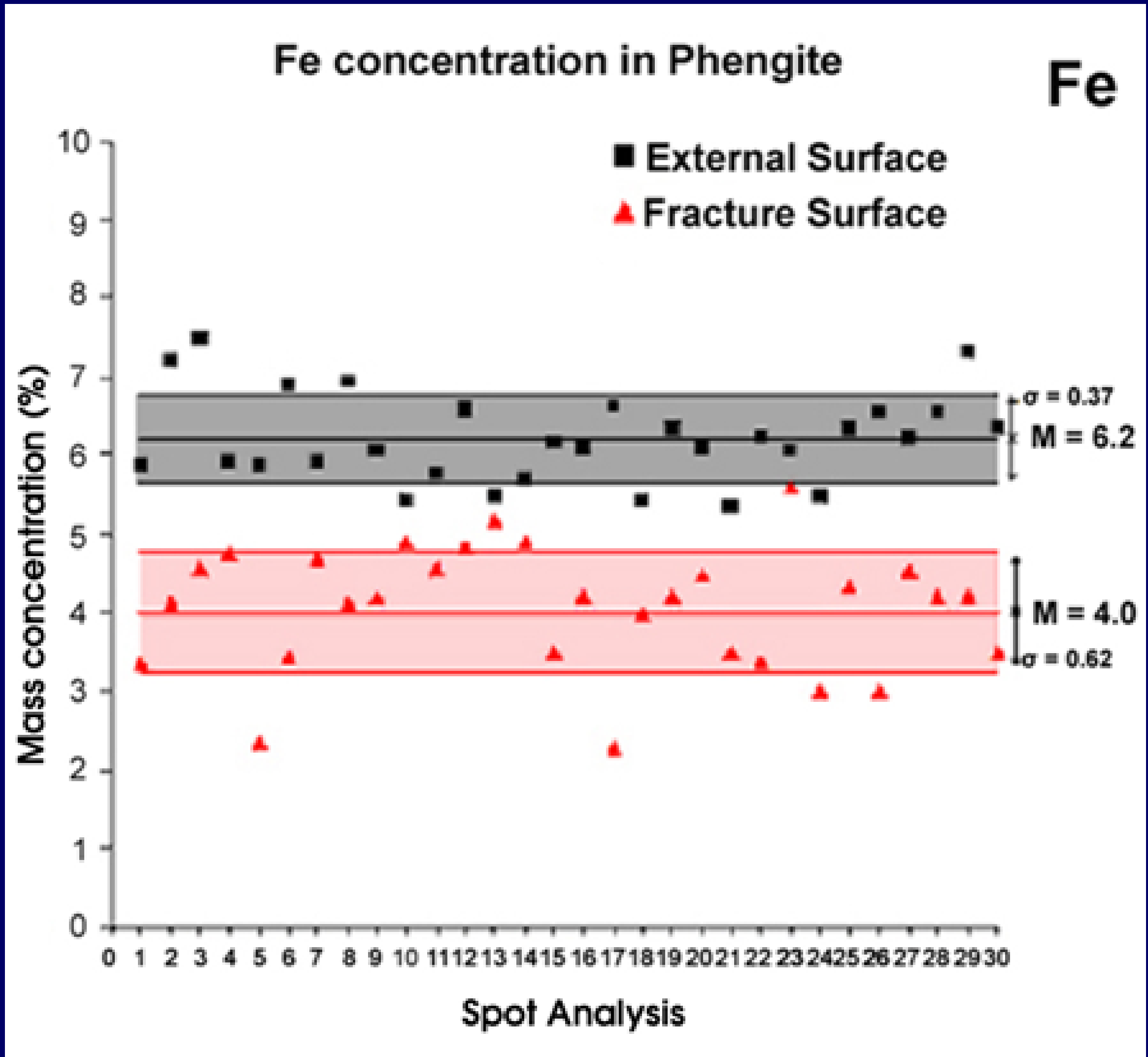
ENERGY DISPERSIVE X-RAY SPECTROSCOPY: COMPOSITIONAL ANALYSIS OF PRODUCT ELEMENTS

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



A quantitative analysis was performed on the collected spectra in order to recognize specific variations in each element between external and fracture surfaces.

Phengite: Fe concentrations



External Surf.:

Fe content = 6.2%

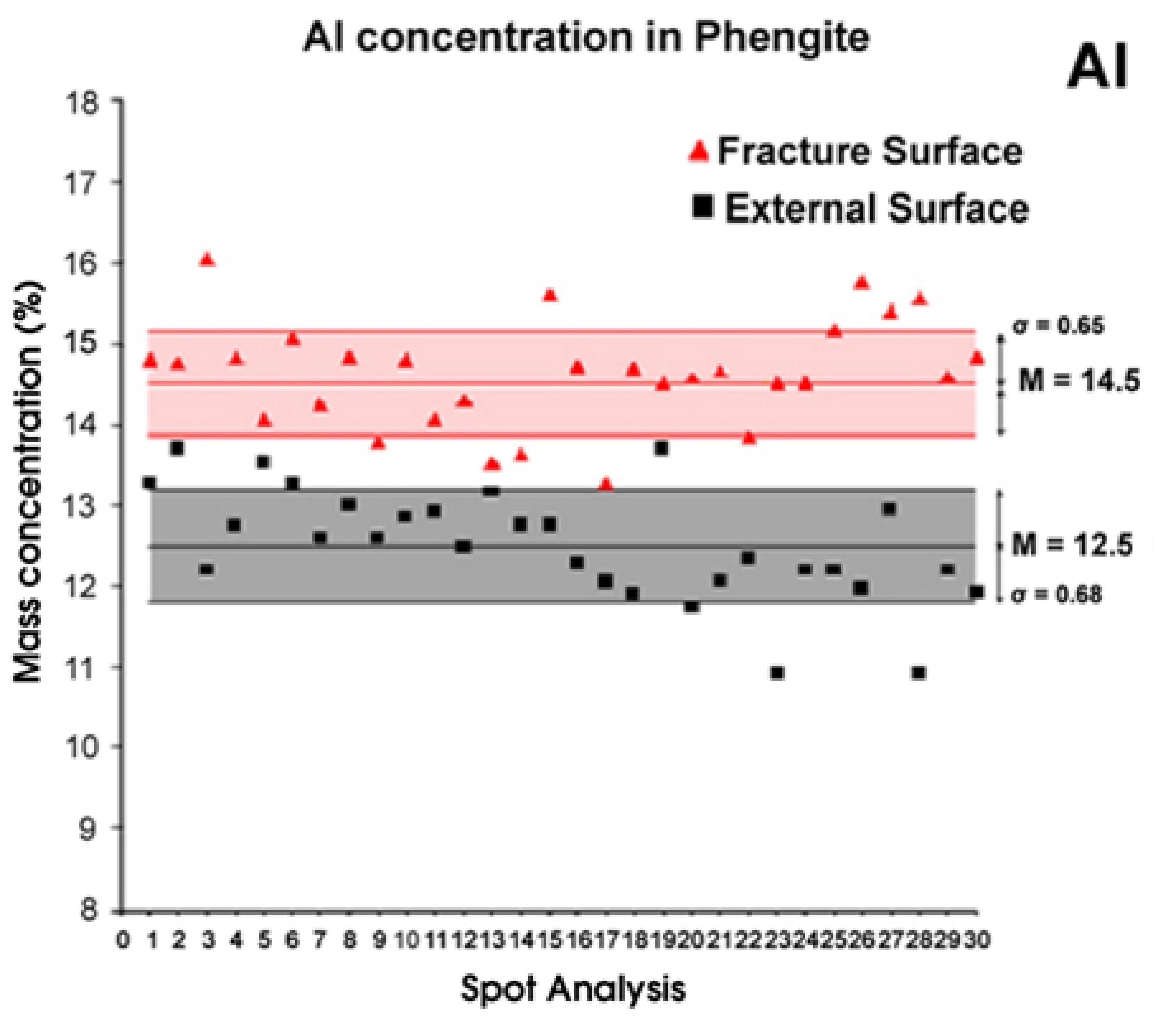
Fracture Surf.:

Fe content = 4.0%

Fe content decrease

–2.2%

Phengite: Al concentration



Fracture Surf.:

Al content = 14.5%

External Surf.:

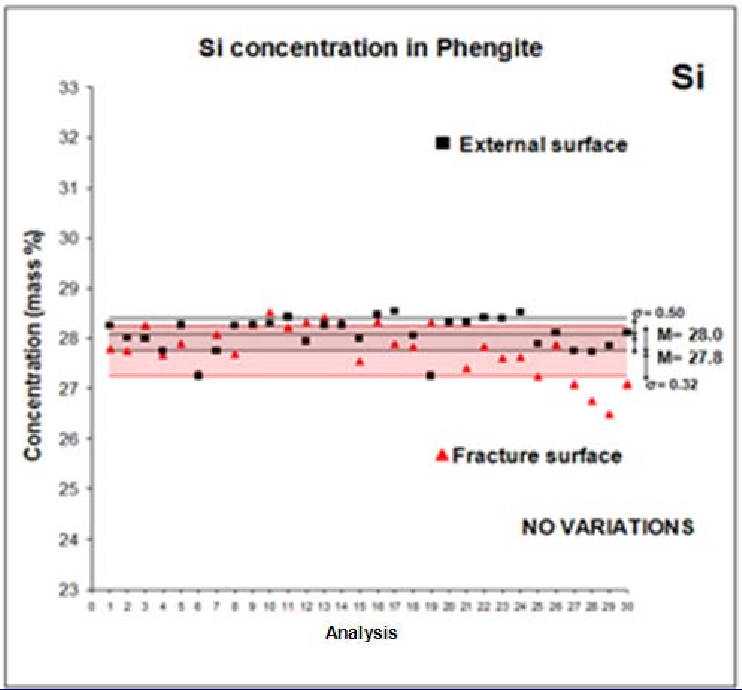
Al content = 12.5%

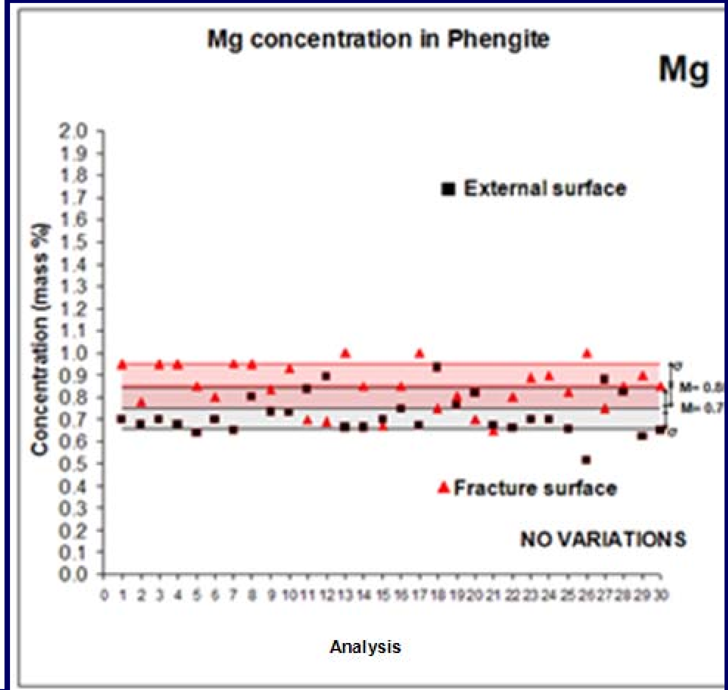
Al content increase

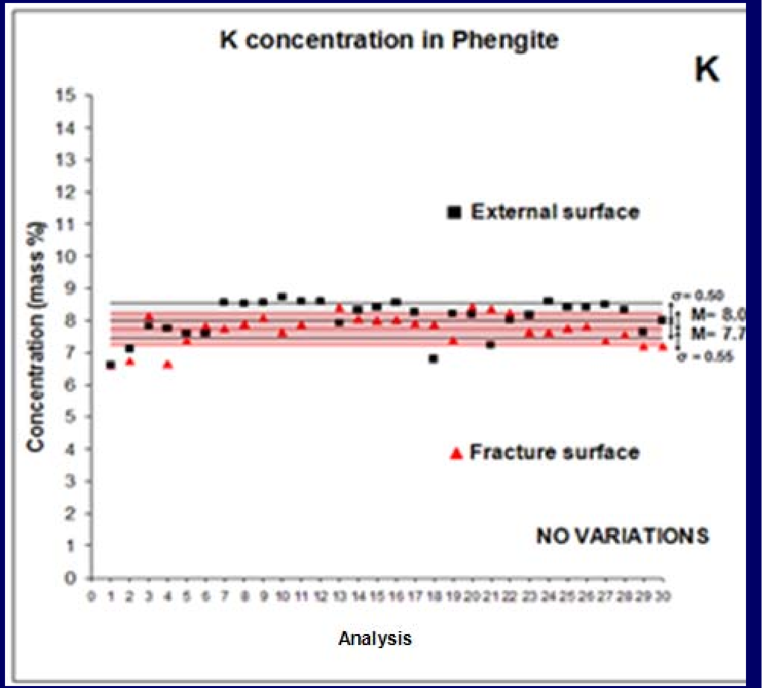
+2.0%

Phengite: Si, Mg and K concentrations

Trends of the other chemical elements constituting the mineral chemistry in phengite are considered.







The Si, Mg, and K concentrations are reported for external and fracture surfaces. In this case, no appreciable variations can be recognized between the average values.

Phengite

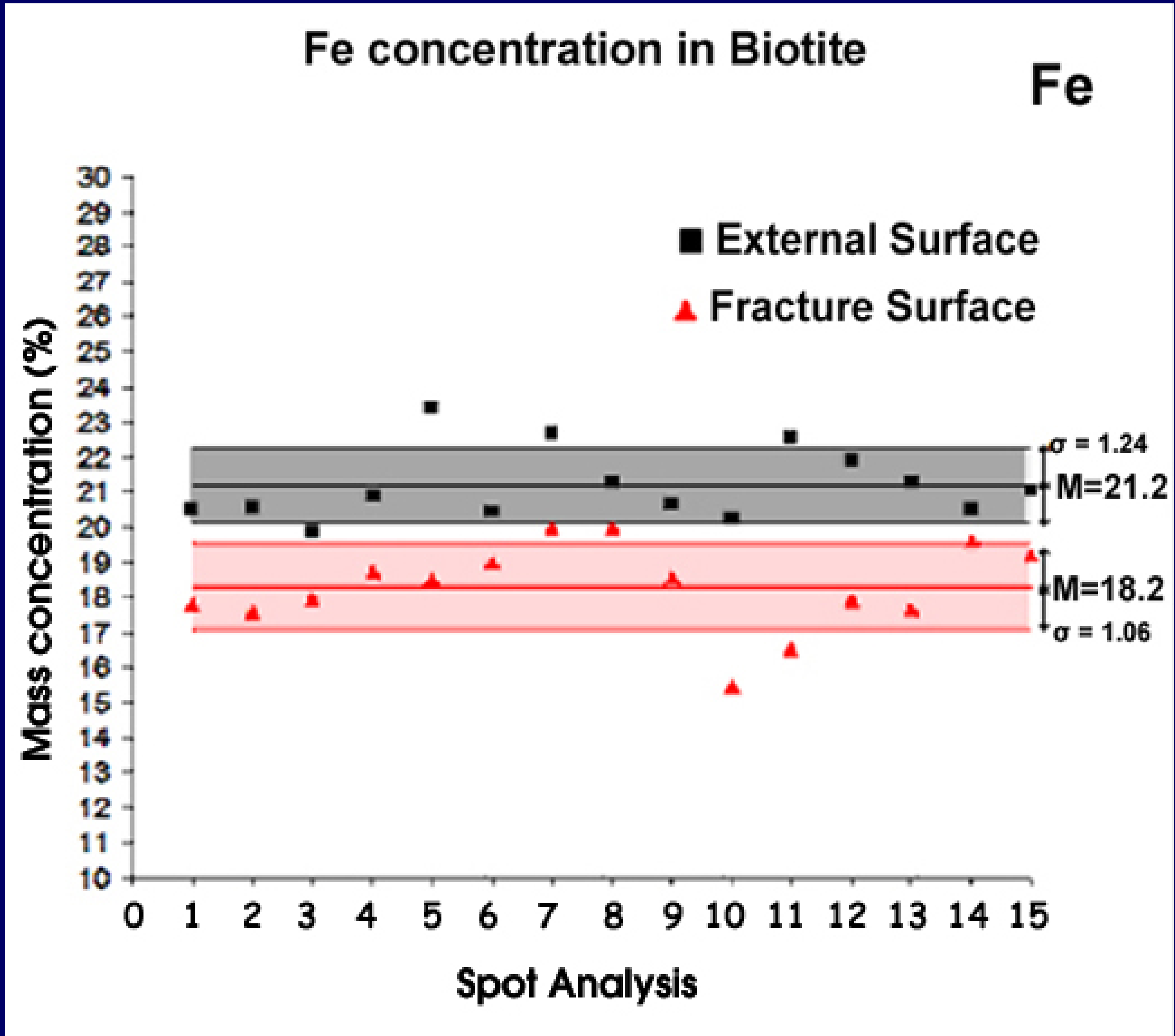
	External surface mean value (wt%)	Fracture surface mean value (wt%)	Increase/ decrease with respect to phengite	Increase/ decrease with respect to the same element
Fe	6.2	4.0	–2.2%	–35%
Al	12.5	14.5	+2.0%	+16%
Si	28.0	27.8	NO VARIATIONS	NO VARIATIONS
Mg	0.7	0.8	NO VARIATIONS	NO VARIATIONS
K	8.0	7.7	NO VARIATIONS	NO VARIATIONS

The results of these quantitative analysis represent a direct evidence that piezonuclear reaction

$$Fe^{56}_{26} \rightarrow 2\,Al^{27}_{13} + 2\ \text{neutrons}$$

has occurred in the rock specimens.

Biotite: Fe concentrations



External Surf.:

Fe content = 21.2%

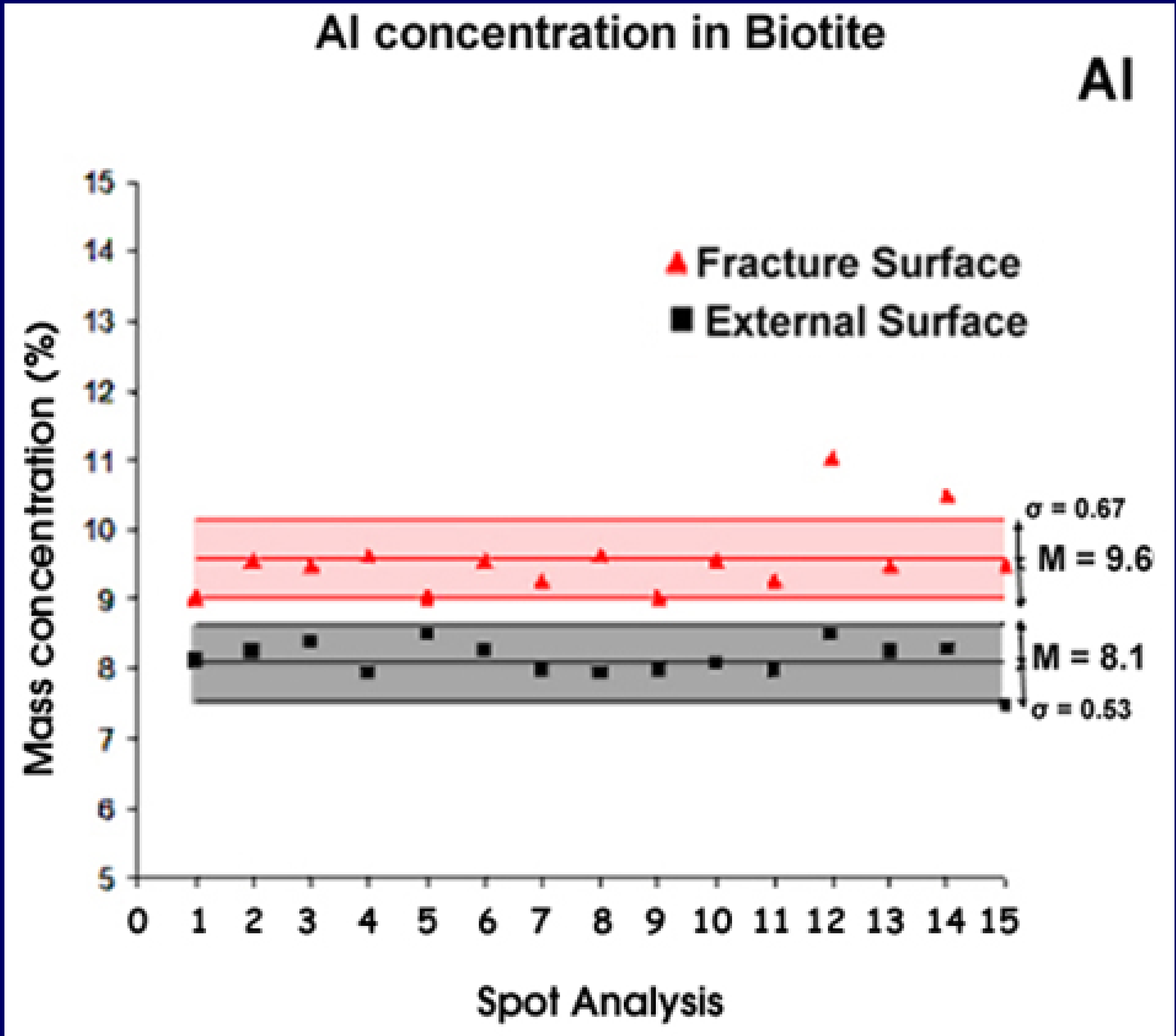
Fracture Surf.:

Fe content = 18.2%

Fe content decrease

–3.0%

Biotite: Al concentrations



Fracture Surf.:

Al content = 9.6%

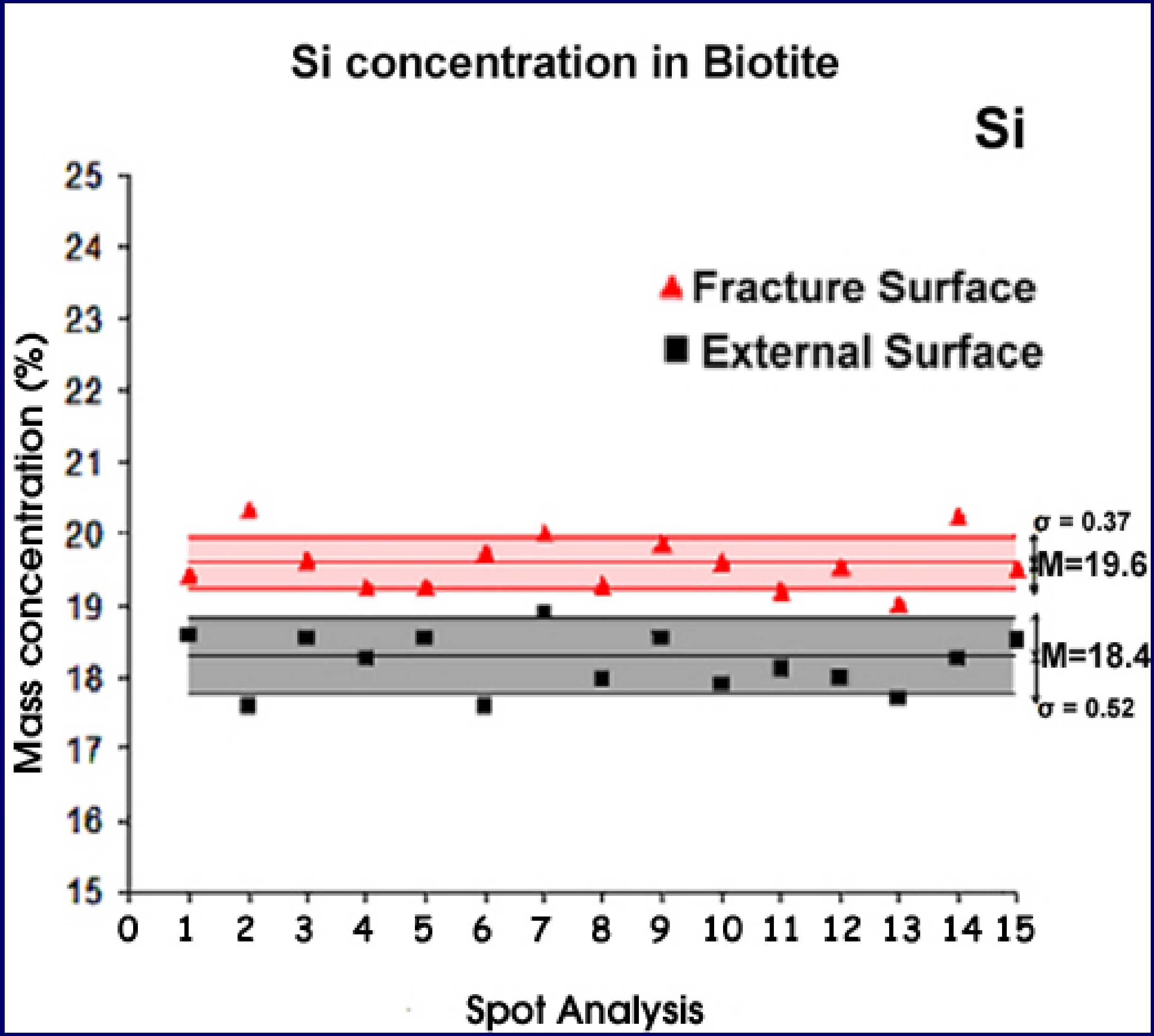
External Surf.:

Al content = 8.1%

Al content increase

+1.5%

Biotite: Si concentrations



Fracture Surf.:

Si content = 19.6%

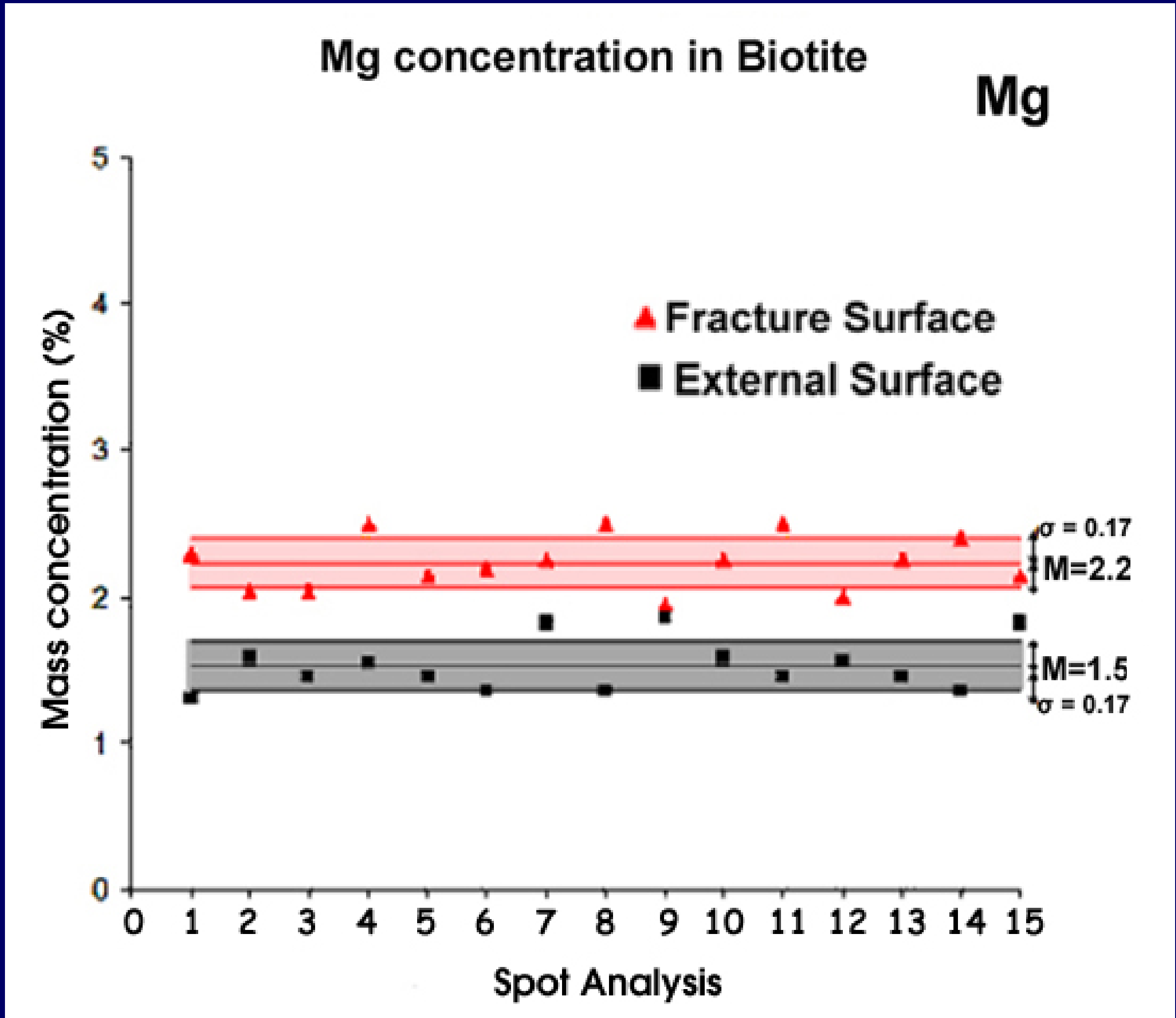
External Surf.:

Si content = 18.4%

Si content increase

+1.2%

Biotite: Mg concentrations



Fracture Surf.:

Mg content = 2.2%

External Surf.:

Mg content = 1.5%

Mg content increase

+0.7%

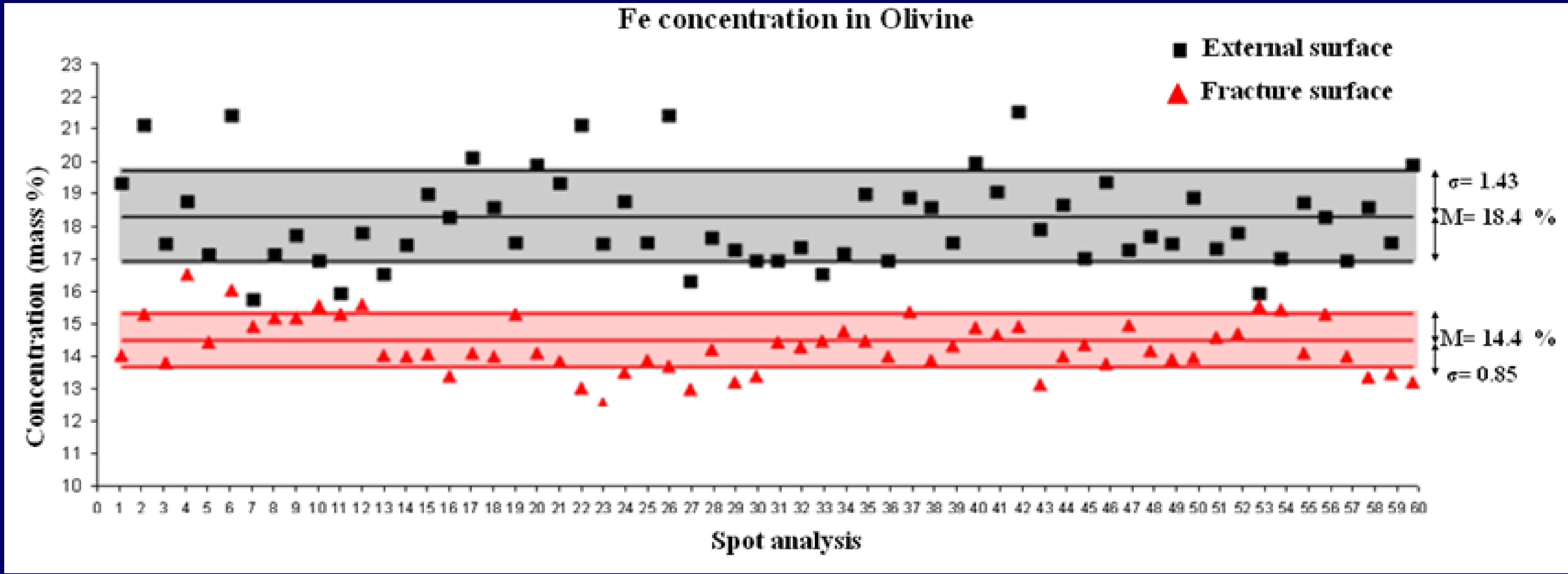
Biotite

	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

Therefore, the Fe decrease (–3.0%) in biotite is counterbalanced by an increase in Al (+1.5%), Si (+1.2%), and Mg (+0.7%). Considering these evidences, in analogy to the previous results, it is possible to conjecture that another piezonuclear reaction has been occurred in the biotite crystalline phase during the tests:

$$Fe^{56}_{26} \rightarrow Si^{28}_{14} + Mg^{24}_{12} + 4 \ \text{neutrons}$$

Basalt (Olivine): Fe concentrations



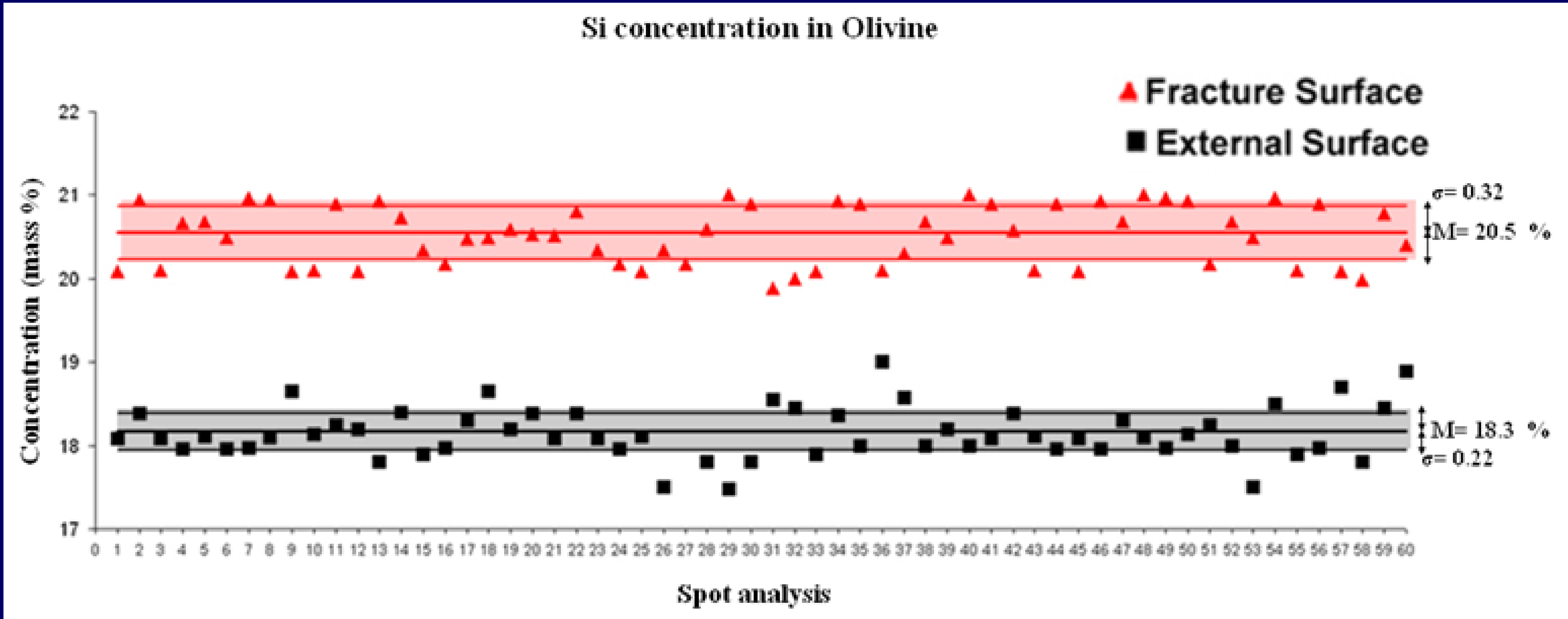
External Surf.: Fe content = 18.4%

Fracture Surf.: Fe content = 14.4%

Fe content decrease

– 4.0%

Basalt (Olivine): Si concentrations



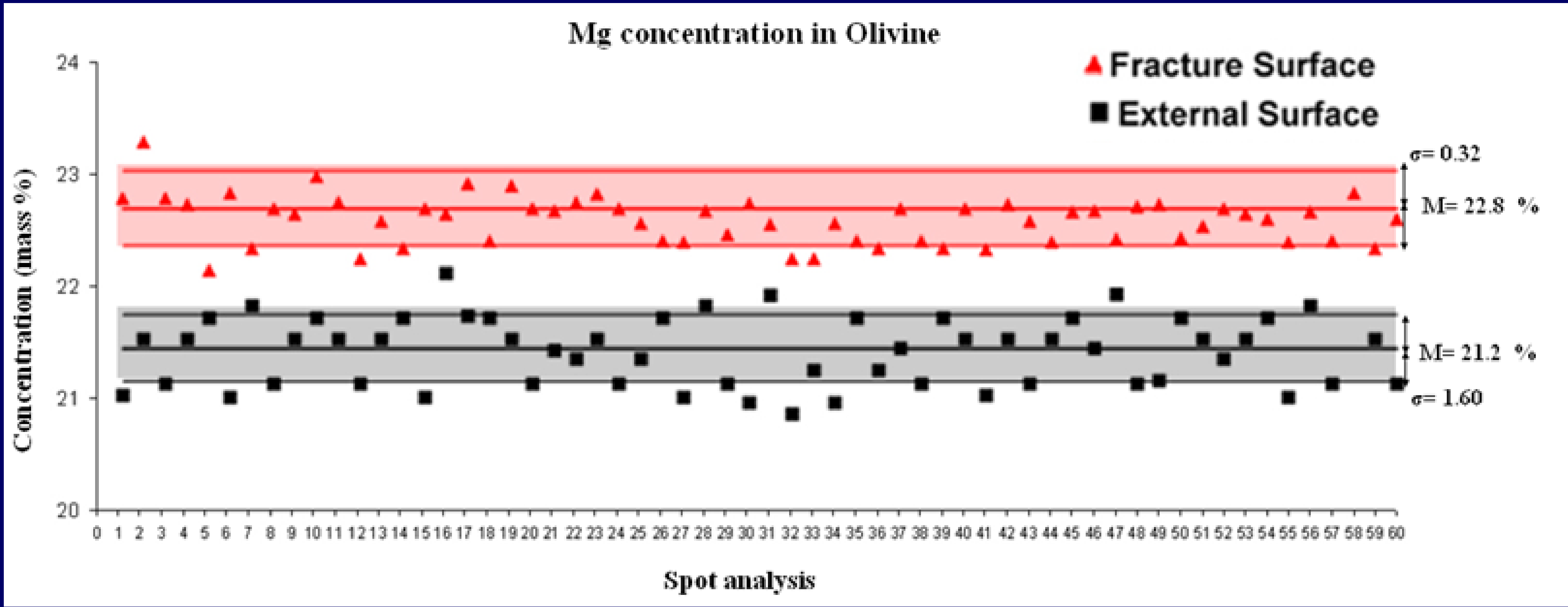
Fracture Surf.: Fe content = 20.5%

External Surf.: Fe content = 18.3%

Si content increase

+ 2.2%

Basalt (Olivine): Mg concentrations



Fracture Surf.: Fe content = 22.8%

External Surf.: Fe content = 21.2%

Si content increase

+ 1.6%

Olivine

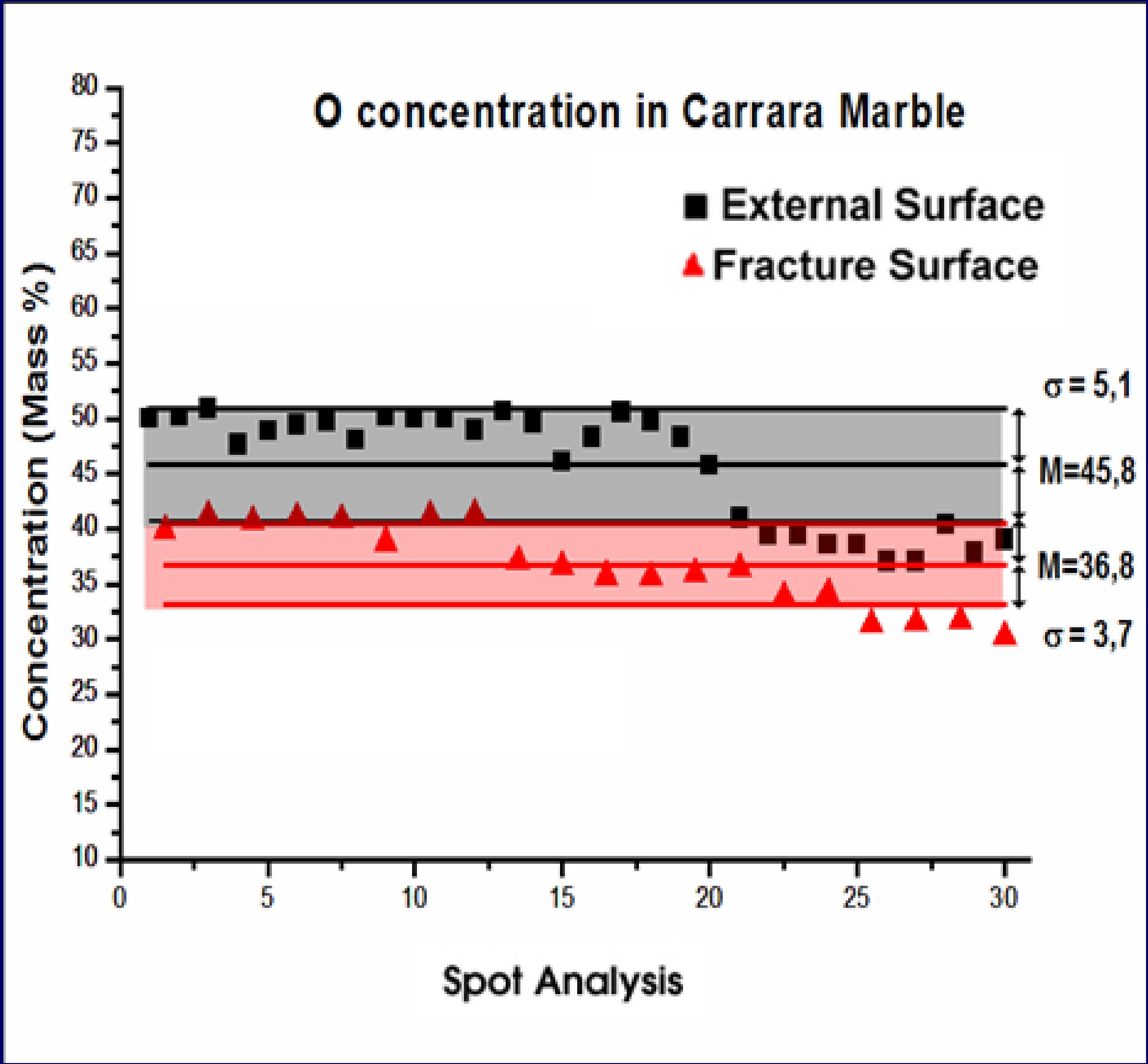
	External surface mean value (wt%)	Fracture surface mean value (wt%)	Increase/ decrease with respect to Olivine	Increase/ decrease with respect to the same element
Fe	18.4	14.4	–4.0 %	–21%
Si	18.3	20.5	+2.2 %	+12%
Mg	21.2	22.8	+1.6 %	+4%
Ca	0.5	0.5	NO VARIATIONS	NO VARIATIONS

Therefore, the Fe decrease (–4.0%) in olivine is counterbalanced by an increase in Si (+2.2%) and Mg (+1.6%). Considering these evidences, in analogy to the previous results, the following piezonuclear reaction is conjectured :

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

Carrara Marble: O concentrations

X-ray Photoelectron Spectroscopy



External Surf.:

O content = 45.8%

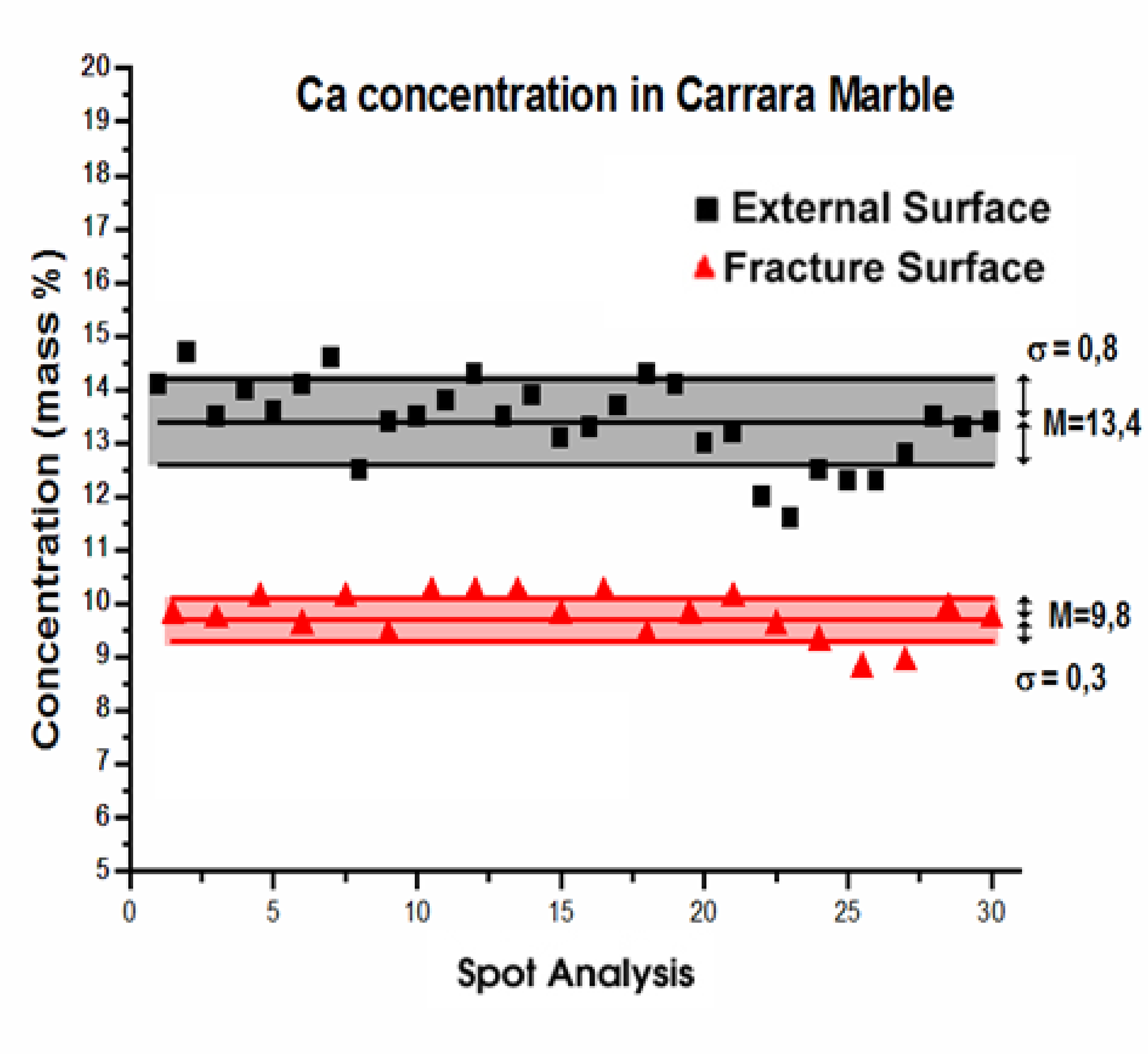
Fracture Surf.:

O content = 36.8%

O content decrease

–9.0%

Carrara Marble: Ca concentrations



External Surf.:

Ca content = 13.4%

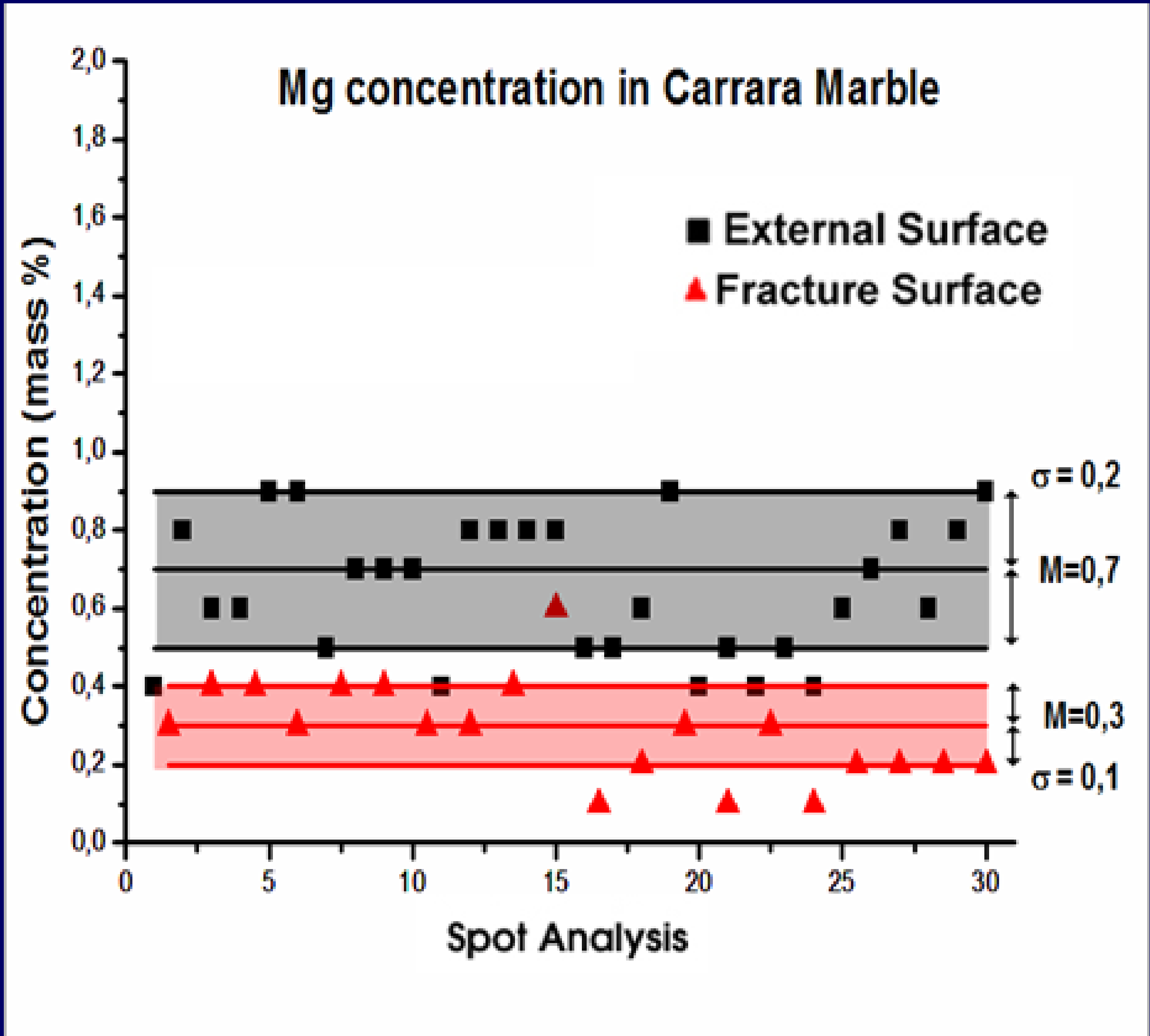
Fracture Surf.:

Ca content = 9.8%

Ca content decrease

–3.6%

Carrara Marble: Mg concentrations



External Surf.:

Mg content = 0.7%

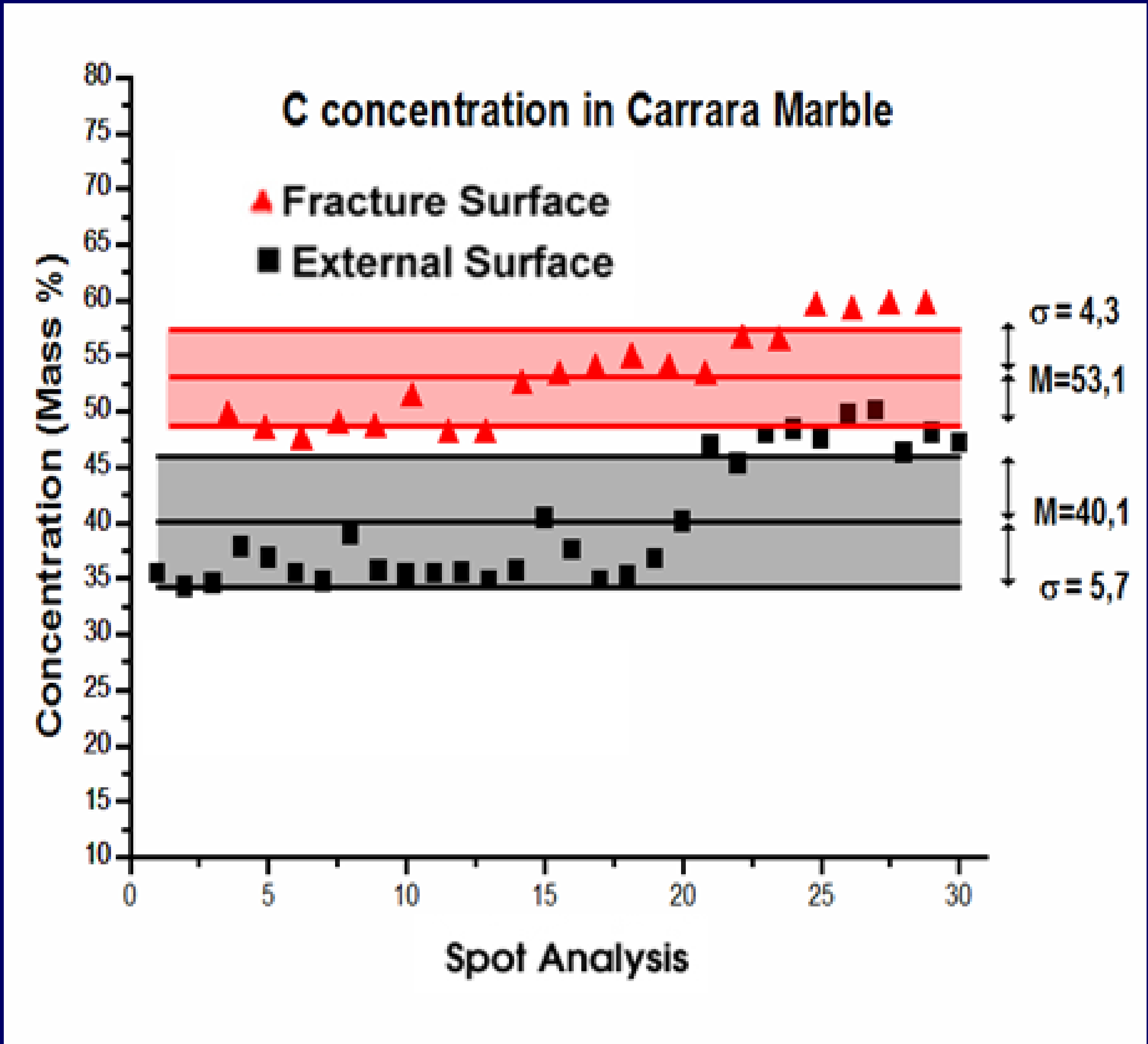
Fracture Surf.:

Mg content = 0.3%

Mg content decrease

–0.4%

Carrara Marble: C concentrations



Fracture Surf.:

C content = 53.1%

External Surf.:

C content = 40.1%

C content increase

+13.0%

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%

The Ca, Mg and O decreases (–3.6%), (–0.4%) and (–9.0%) in marble are counterbalanced by an increase in C (+13.0%). It is possible to conjecture that the following piezonuclear reactions have been occurred:

$$Mg^{24}_{12} \rightarrow 2C^{12}_{6}$$

$$Ca^{40}_{20} \rightarrow 3C^{12}_{6} + He^{4}_{2}$$

$$O^{16}_{8} \rightarrow C^{12}_{6} + He^{4}_{2}$$

EARTH CRUST EVOLUTION

NEUTRON EMISSIONS FROM EARTHQUAKES

- Sobolev, G.A., Shestopalov, I.P., Kharin, E.P. "Implications of Solar Flares for the Seismic Activity of the Earth". Izvestiya, *Phys. Solid Earth* **34**: 603-607 (1998).
- Volodichev, N.N., Kuzhevskij, B.M., Nechaev, O. Yu., Panasyuk M., and Podorolsky M.I., "Lunar periodicity of the neutron radiation burst and seismic activity on the Earth", *Proc. of the 26th International Cosmic Ray Conference*, Salt Lake City, 17-25 August, 1999.
- Kuzhevskij, M., Nechaev, O. Yu. and Sigaeva, E. A., "Distribution of neutrons near the Earth's surface", *Natural Hazards and Earth System Sciences*, **3**: 255-262 (2003).
- Kuzhevskij, M., Nechaev, O. Yu., Sigaeva, E. A. and Zakharov, V. A., "Neutron flux variations near the Earth's crust. A possible tectonic activity detection", *Natural Hazards and Earth System Sciences*, **3**: 637-645 (2003).
- Sigaeva, E., Nechaev, O., Panasyuk, M., Bruns, A., Vladimirsky, B. and Kuzmin Yu., "Thermal neutrons' observations before the Sumatra earthquake", *Geophysical Research Abstracts*, **8**: 00435 (2006).

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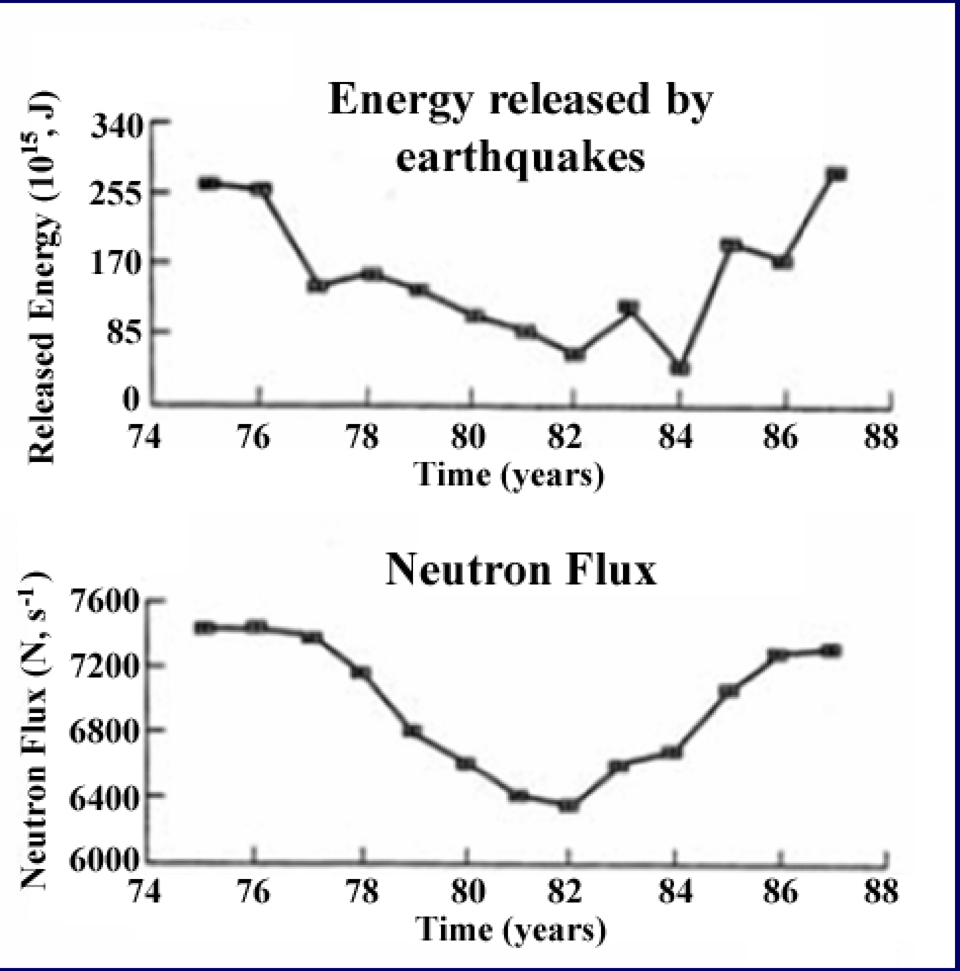
As reported in the literature, an average thermal neutron flux up to 10^0 cm^{-2} s^{-1} **(10^3 times the background level)** was detected in correspondence to earthquakes with a magnitude of the 4th degree in Richter Scale (Volodichev N.N., et al. (1999)).



Global seismic activity and neutron flux measurements in the period 1974-1988. Laboratory of Geophysical Precursors, Oblast' Murmansk, Apatity, Kola Peninsula, Russia (Sobolev et al. 1998).

EVOLUTION AND LOCALIZATION OF METAL ABUNDANCES IN THE EARTH CRUST

- Based on the disappearance of iron atoms (–25%) and the appearance of aluminium atoms after the experiments, our conjecture is that the following nucleolysis or piezonuclear "fission" reaction could have occurred:

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

- The present natural abundance in the Earth's Crust of aluminum (~8%) and iron (~4%) are possibly due to the above piezonuclear fission reaction.

- This reaction would be activated where the environment conditions (pressure and temperature) are particularly severe, and mechanical phenomena of fracture, crushing, fragmentation, comminution, erosion, friction, etc., may occur.

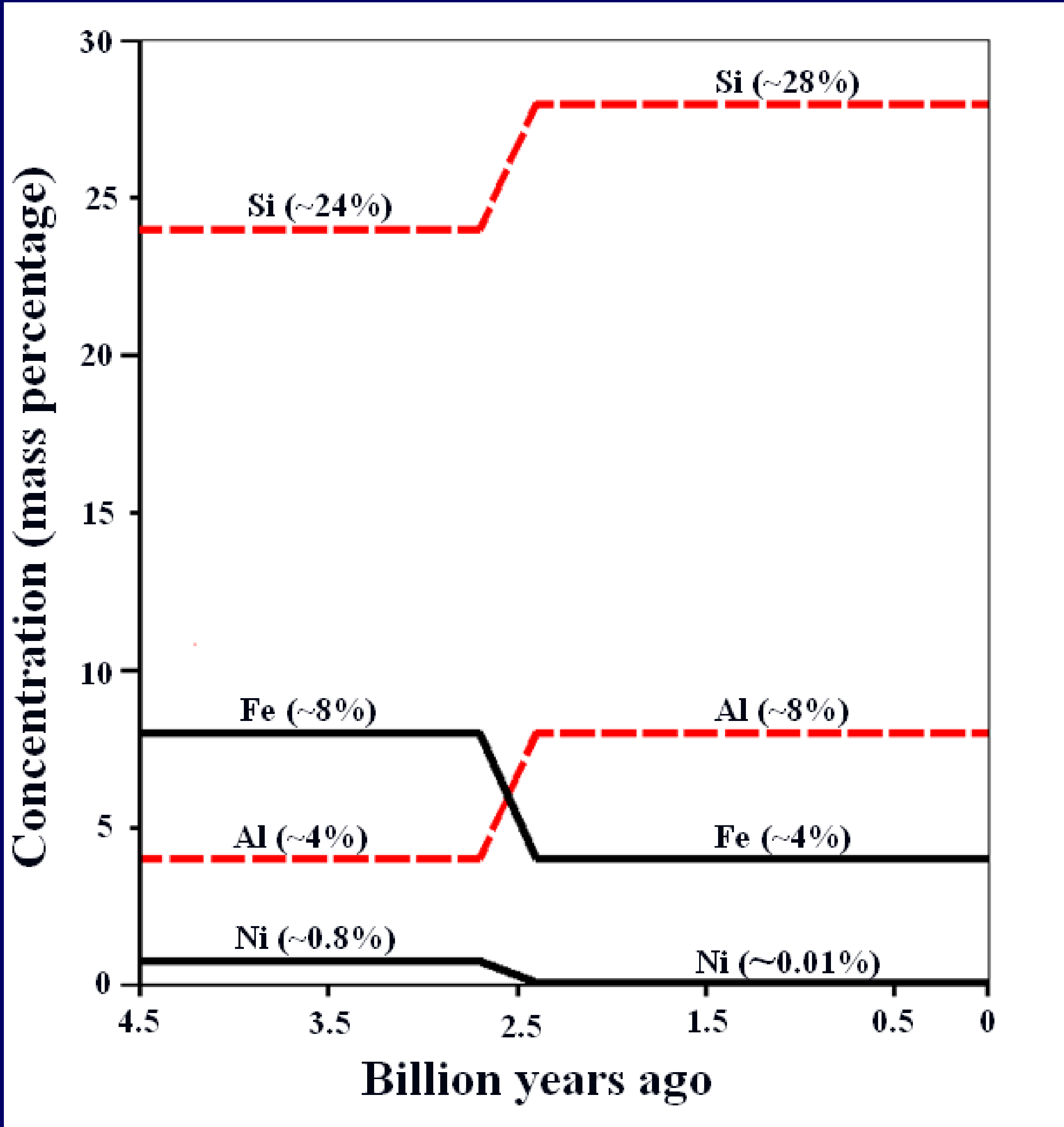
- If we consider the evolution of the percentages of the most abundant elements in the Earth Crust during the last 4 billion years, we realize that Iron and Nickel have drastically diminished, whereas Aluminum and Silicon have as much increased:

$$Fe^{56}_{26} \rightarrow Si^{28}_{14} + Mg^{24}_{12} + 4 \ \text{neutrons}$$

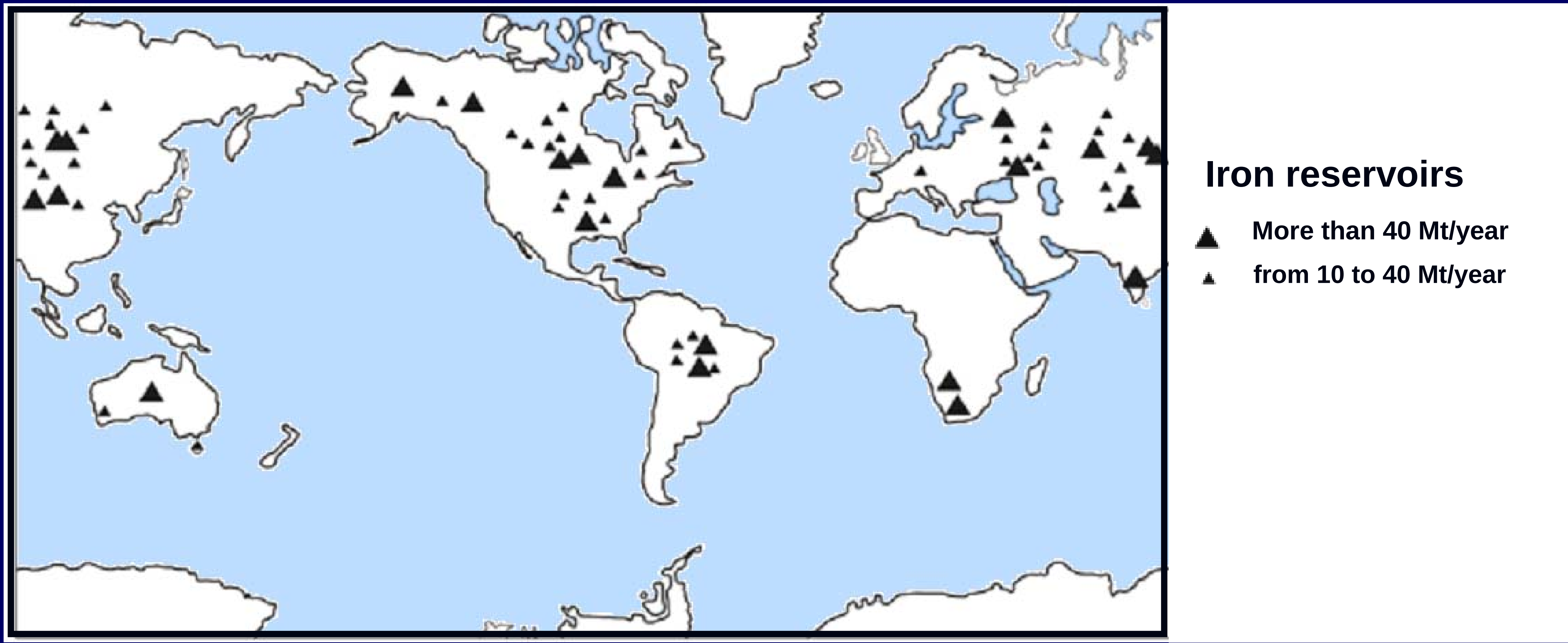
$$Ni^{59}_{28} \rightarrow 2Si^{28}_{14} + 3 \ \text{neutrons}$$

- It is also interesting to realize that such increases have developed mainly in the tectonic regions, where frictional phenomena between the continental plates occurred.

Most severe tectonic activity (~2.5×10^9 years ago)



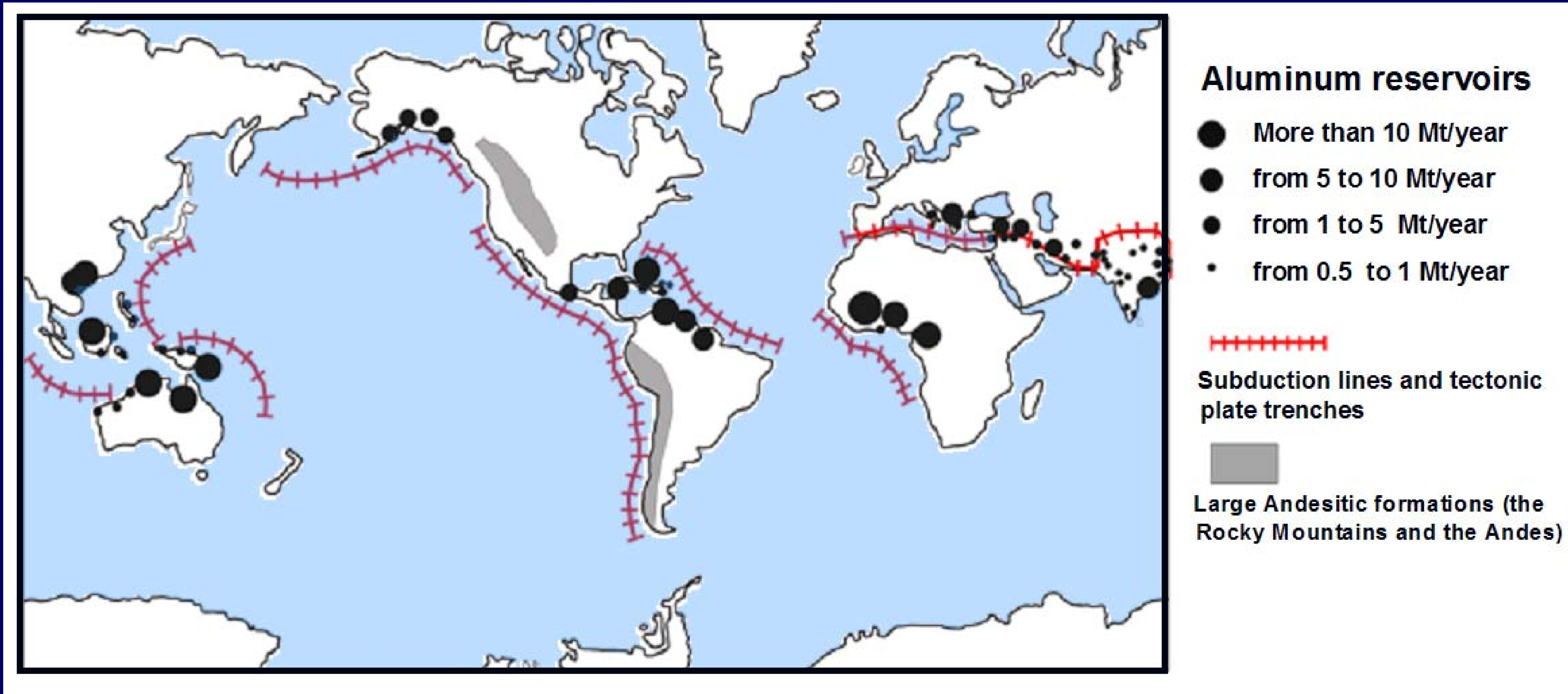
Localization of iron mines



(*) 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.

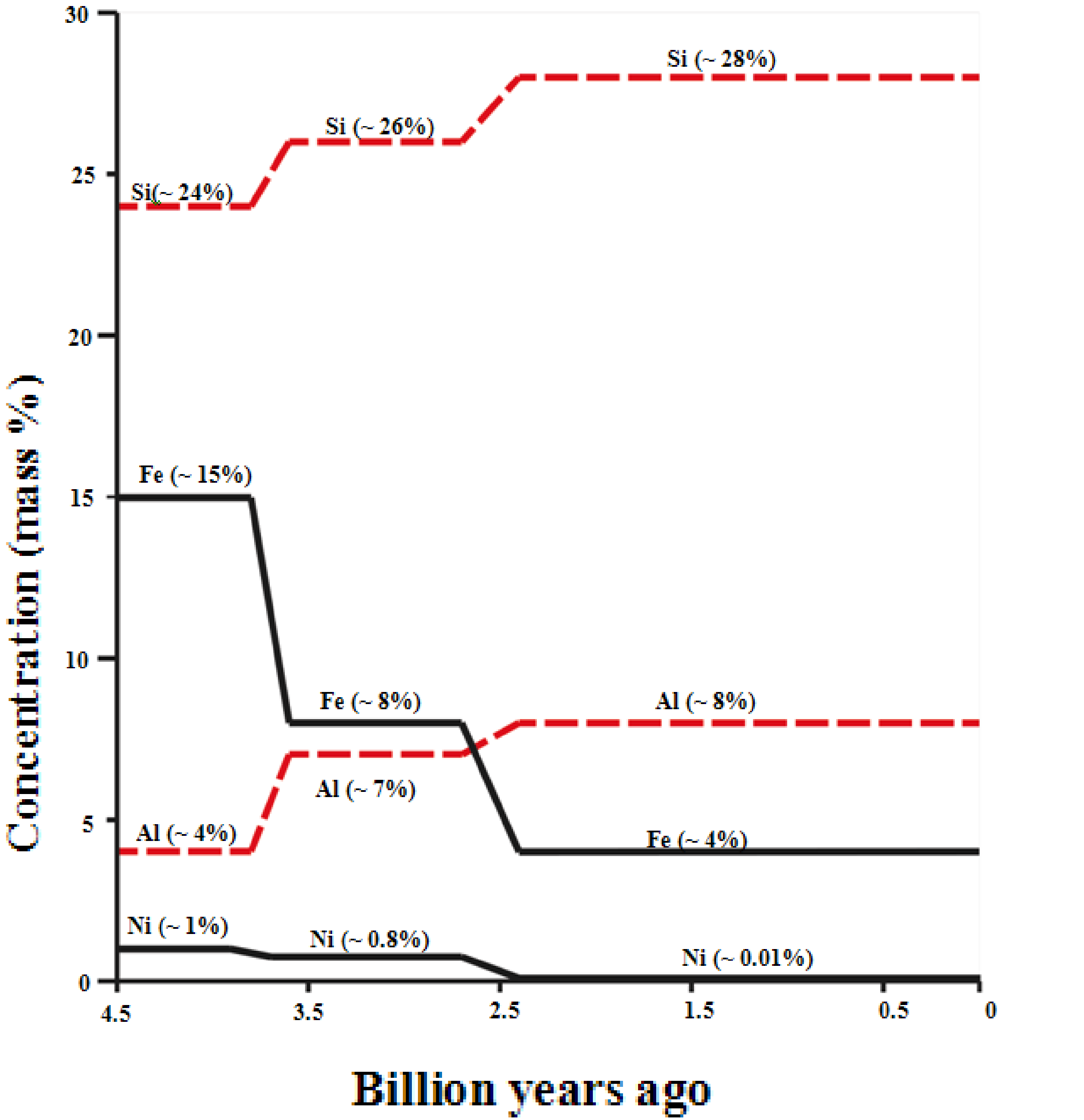
Localization of Aluminum mines



(*) 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.

Tectonic plate formation (~3.8×10^9 years ago)



3.8 Billion years ago:
Fe (–7%) + Ni (–0.2%) =
=Al (+3%) + Si (+2.2%) + Mg (+2%)

2.5 Billion years ago:
Fe (–4%) + Ni (–0.8%) =
=Al (+1%) + Si (+2.3%) + Mg (+1.5%)

Earth's Crust Evolution

(1) $Fe^{56}_{26} \rightarrow 2\,Al^{27}_{13} + 2$ neutrons

(2) $Fe^{56}_{26} \rightarrow Si^{28}_{14} + Mg^{24}_{12} + 4$ neutrons

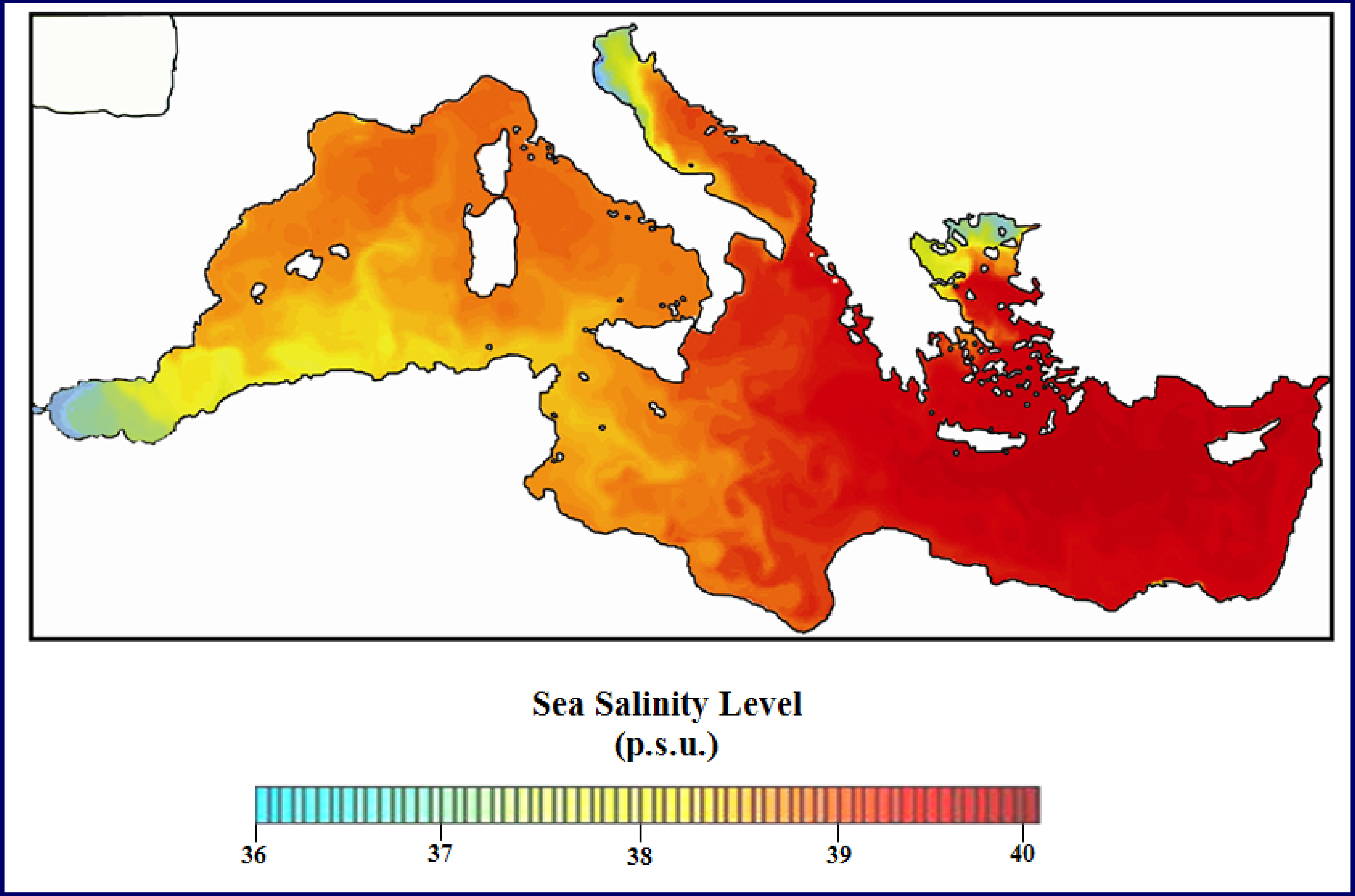
(3) $Fe^{56}_{26} \rightarrow Ca^{40}_{20} + C^{12}_{6} + 4$ neutrons

(4) $Co^{59}_{27} \rightarrow Si^{28}_{14} + Al^{27}_{13} + 4$ neutrons

(5) $Ni^{59}_{28} \rightarrow 2\,Si^{28}_{14} + 3$ neutrons

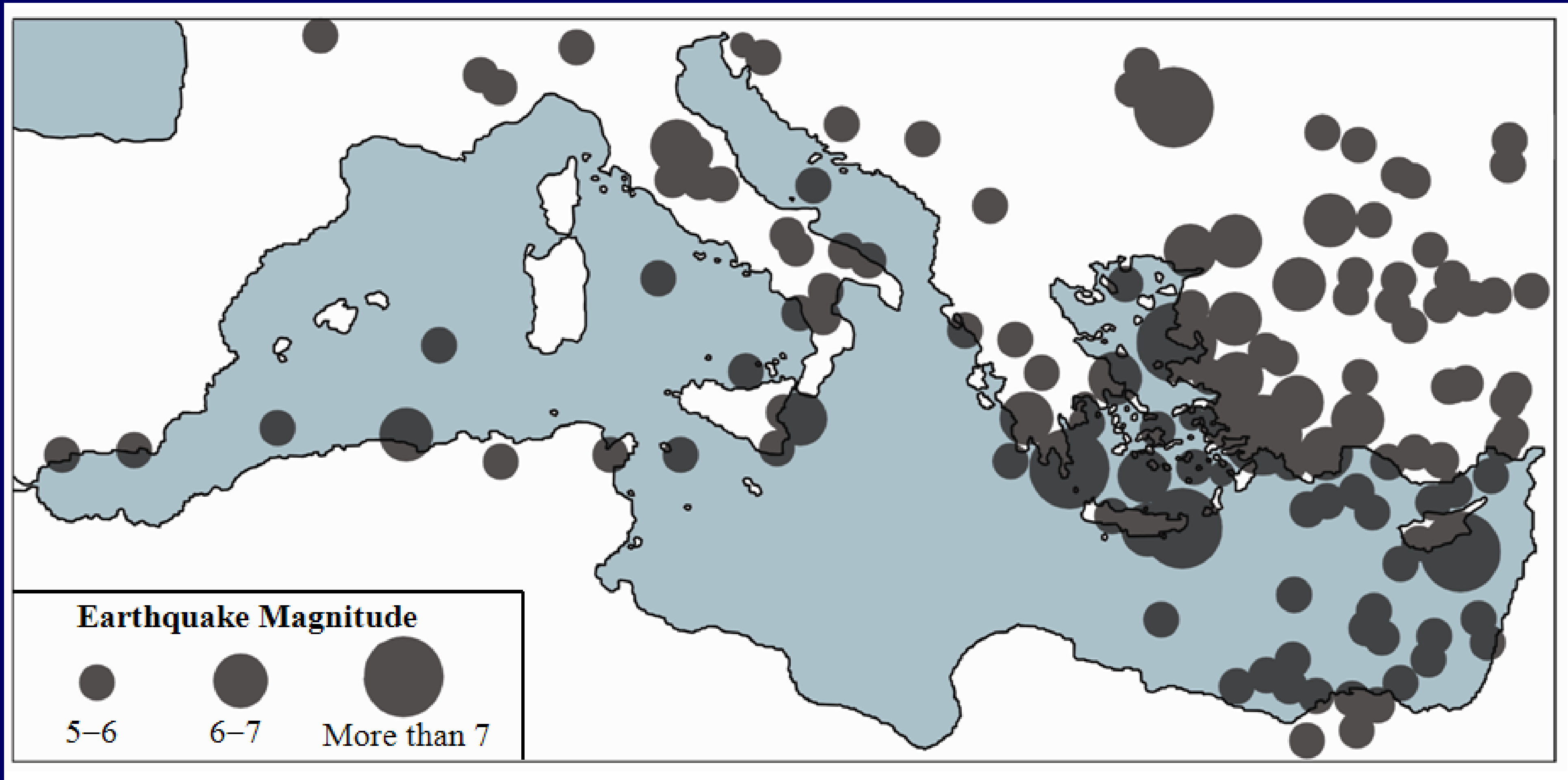
(6) $Ni^{59}_{28} \rightarrow Na^{23}_{11} + Cl^{35}_{17} + 1$ neutron

Nickel depletion and salinity level increase in the Mediterranean Sea

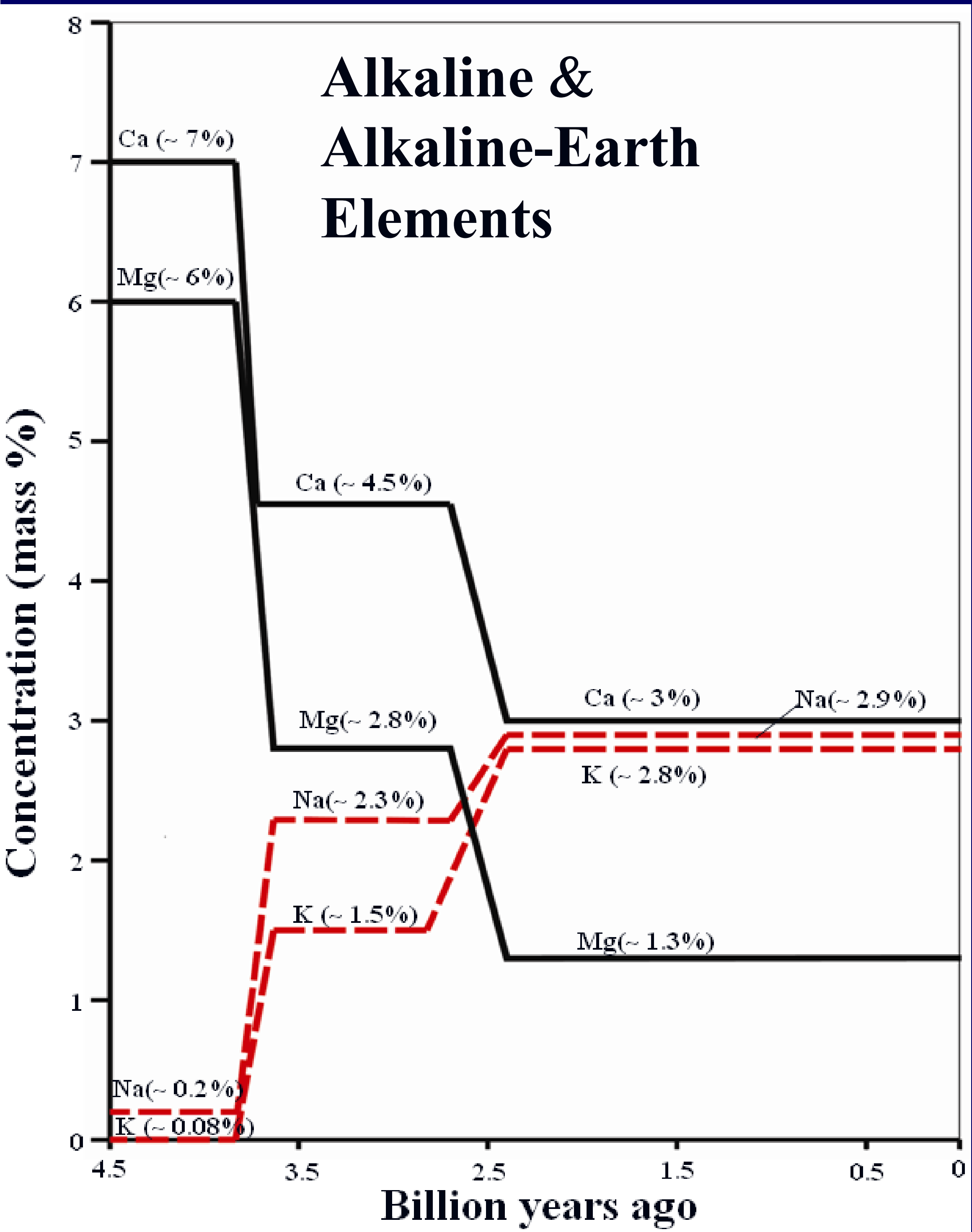


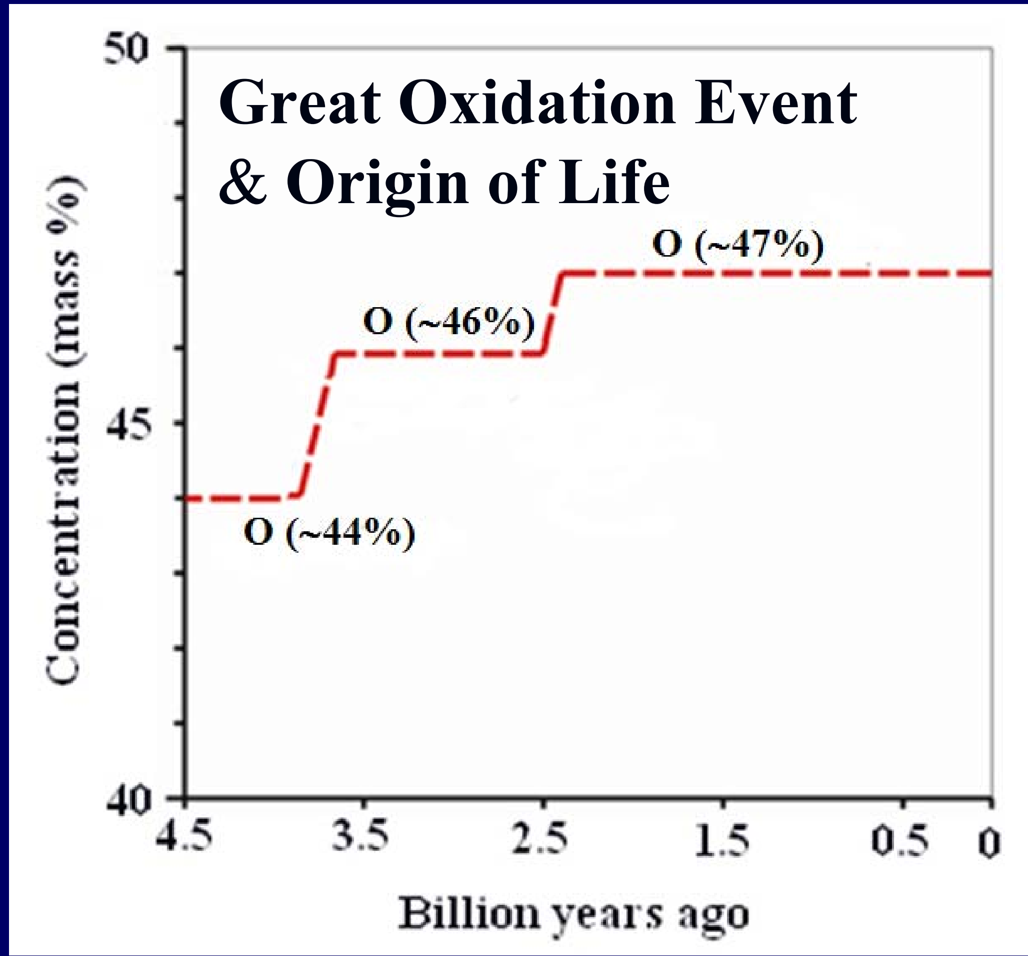
Map of the salinity level in the Mediterranean Sea expressed in p.s.u.
The Mediterranean basin is characterized by the highest sea salinity level in the World.

Seismic map of the major earthquakes that have occurred over the last fifteen years in the Mediterranean Fault area.



$$Ni^{59}_{28} \rightarrow Na^{23}_{11} + Cl^{35}_{17} + 1 \text{ neutron}$$





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%)

Atmosphere Evolution, Ocean Formation and Origin of Life

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

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

(9) $Mg_{12}^{24} \rightarrow O_{8}^{16} + 2H_{1}^{1} + He_{2}^{4} + 2n$

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

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

(12) $Ca_{20}^{40} \rightarrow 2O_{8}^{16} + 4H_{1}^{1} + 4\ n$

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← **Primordial Atmosphere**

Magnesium depletion in the Earth Crust and Carbon concentration in the primordial atmosphere

The assumed virtual Mg increase (~3.5%) can be confirmed by the Carbon content in the primordial atmosphere:

$$Fe^{56}_{26} \rightarrow Mg^{24}_{12} + Si^{28}_{14} + 4 \text{ neutrons}$$

$$Mg^{24}_{12} \rightarrow 2C^{12}_{6}$$

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) implies a very high atmospheric pressure due to the transformed carbon.

Primordial atmospheric pressure due to piezonuclear C content = ~650 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)

Atmosphere Evolution, Ocean Formation and Origin of Life

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Ocean Formation

<u>Calcium depletion</u> in the Earth Crust and ocean formation

Global decrease in Ca (–4.0%) is counterbalanced by an increase in K (+2.7%) and in H_2O (+1.3%).

$$Ca^{40}_{20} \rightarrow K^{39}_{19} + H^{1}_{1}$$

$$Ca^{40}_{20} \rightarrow 2O^{16}_{8} + 4H^{1}_{1} + 4 \text{ neutrons}$$

Considering a mean density of the Earth Crust equal to 3.6 g/cm^3 and an average thickness of ~60 km, the partial mass decrease in Ca is about 1.41×10^{21} kg.

Considering a global ocean surface of 3.607×10^{14} m^2, and an average depth of 3950 m, we obtain a mass of water of about 1.35×10^{21} kg.

Partial decrease in Ca
1.41×10^{21} kg

→

Mass of H_2O in the oceans today
1.35×10^{21} kg

Greenhouse Gas Formation

(13) $O_8^{16} \rightarrow C_6^{12} + He_2^4$

(14) $Al_{13}^{27} \rightarrow C_6^{12} + N_7^{14}$ + 1 neutron

(15) $Si_{14}^{28} \rightarrow 2\ N_7^{14}$

(16) $Si_{14}^{28} \rightarrow C_6^{12} + O_8^{16}$

(17) $Si_{14}^{28} \rightarrow 2C_6^{12} + He_2^4$

(18) $Si_{14}^{28} \rightarrow O_8^{16} + 2H_1^1 + 2He_2^4$ + 2 neutrons

SOLAR SYSTEM EVOLUTION

FROM THE EARTH TO THE SOLAR SYSTEM: PIEZONUCLEAR REACTIONS ON MARS?

Mars Odissey, Nasa 2001
Mars Global Surveyor, Nasa 1996

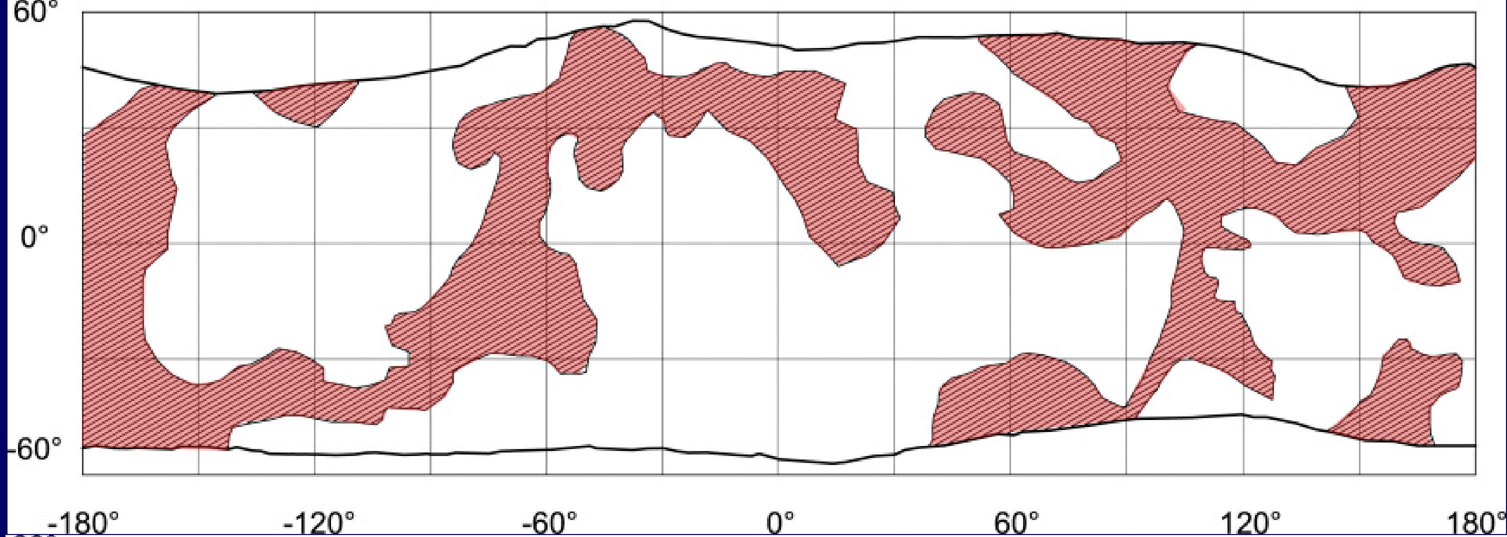
- **Seismicity monitoring by the laser altimeter analysis**
- **Elemental Abundance by the Gamma-Ray Spectrometer**
- **Neutron Emissions**

Knapmeyer M. et al. "Working Models for Spatial Distribution and Level of Mars Seismicity" *J. of Geophys. Res.*, 111, E11006, (2006).

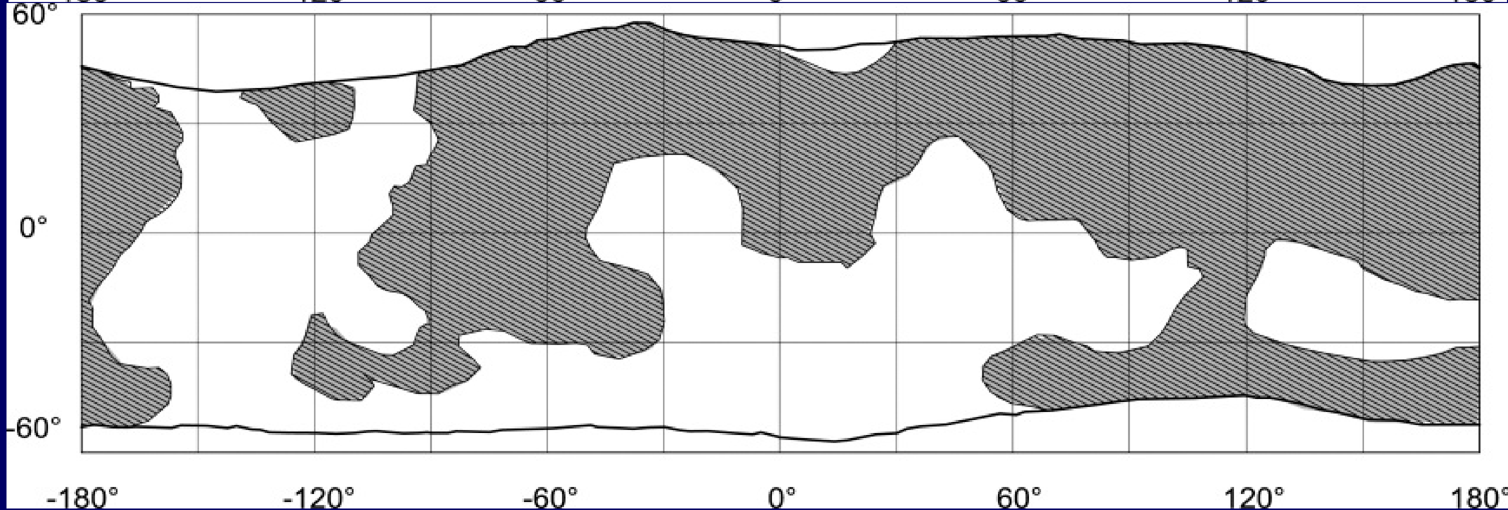
Hahn, B., McLennan, S., "Gamma-Ray Spectometer Elemental Abundance Correlation with Martian Surface Age: Implication for Martian Crustal Evolution". *Lunar and Planet. Sci.* 37,1904 (2006).

Mitrofanov, I. et al., "Maps of Subsurface Hydrogen from the High Energy Neutron Detector, Mars Odyssey", *Science*, 297, 78-81, (2002).

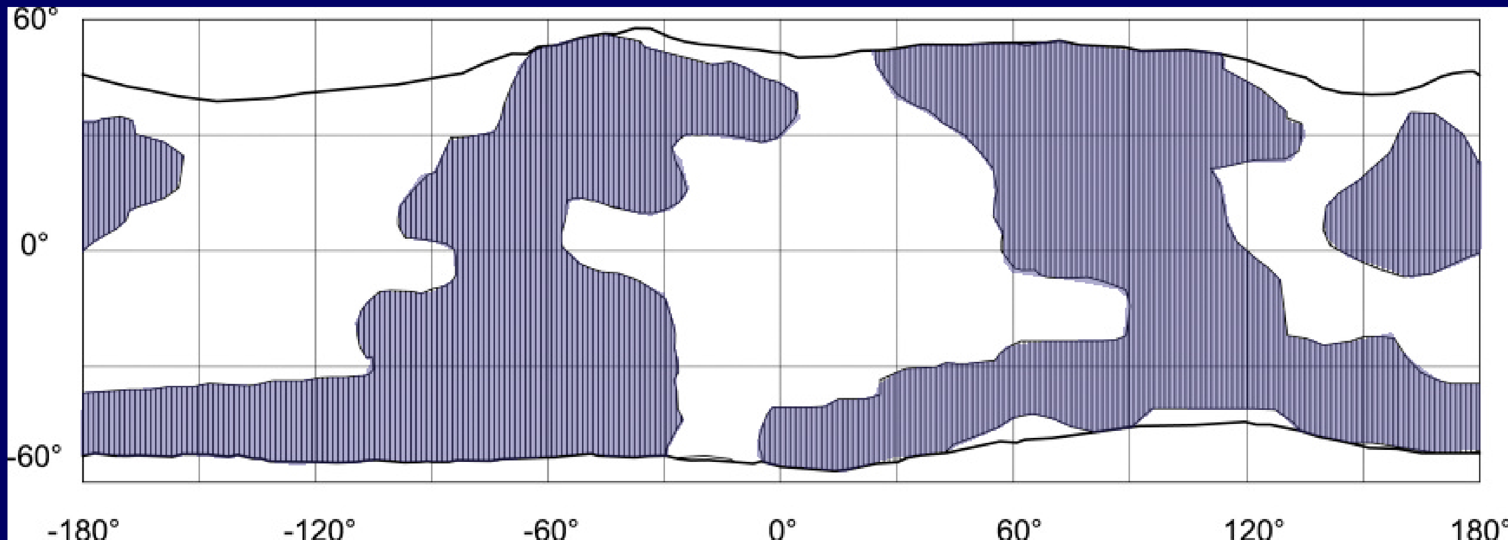
Faults



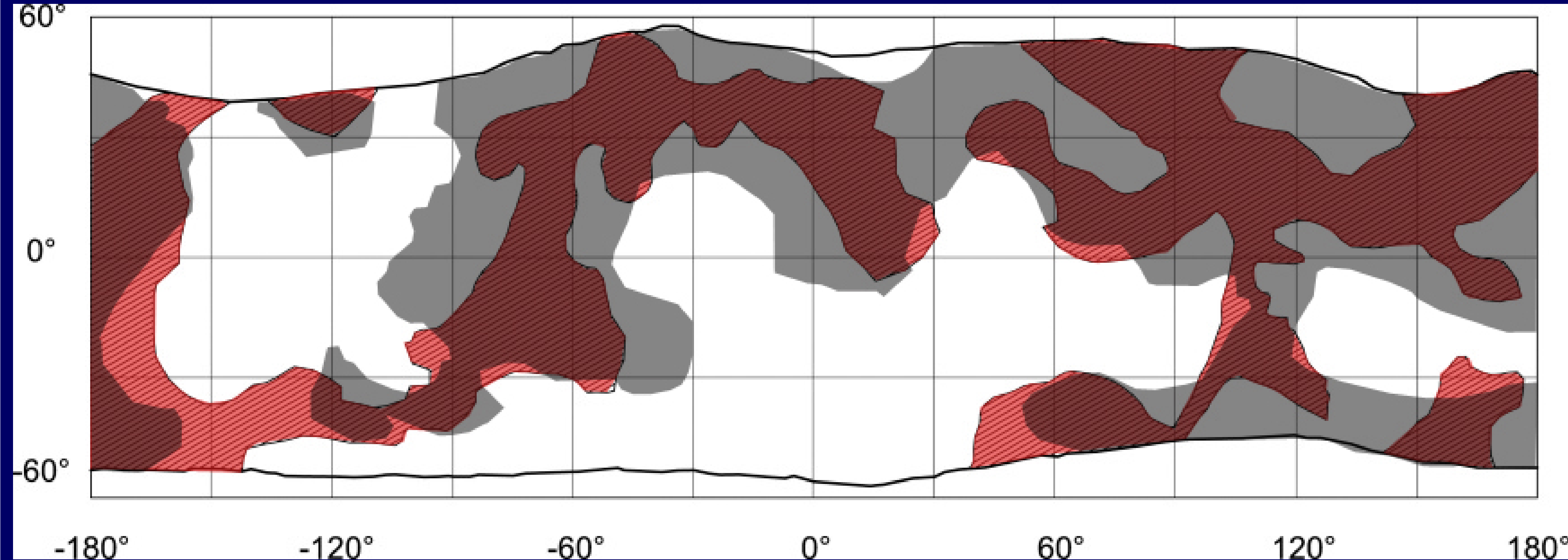
Iron
(≥ 15%)



Neutrons
(> 0.18 cps)



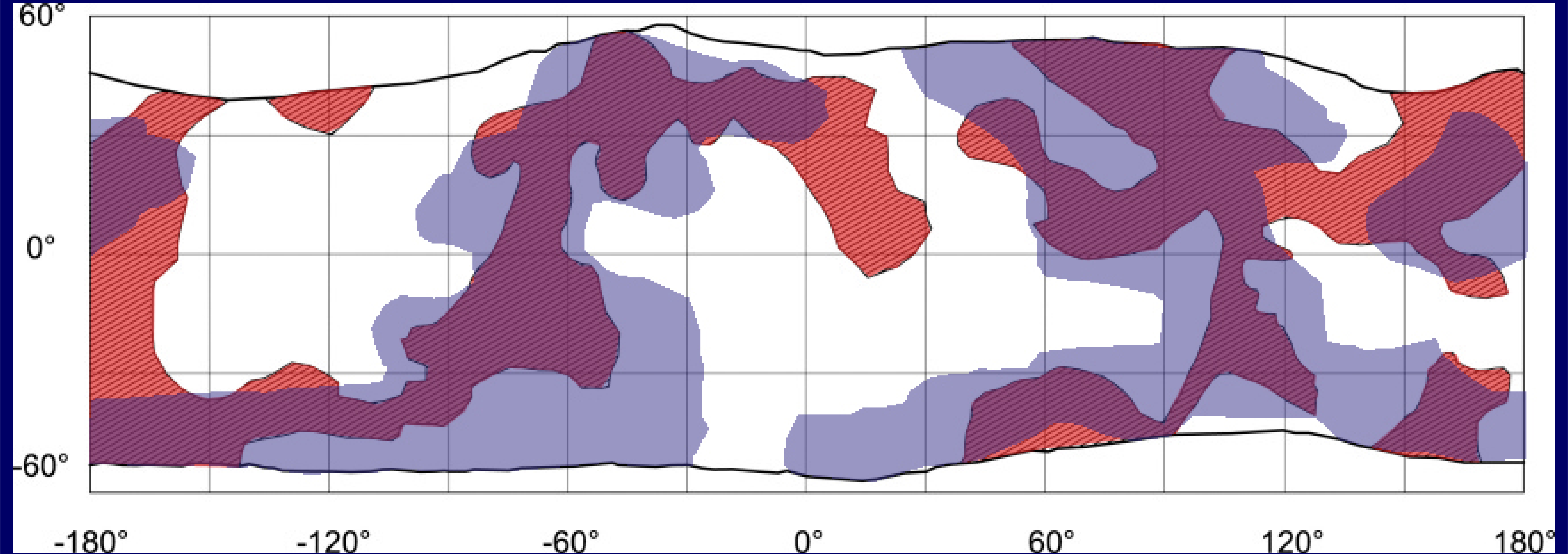
Faults vs Iron



Faults

Iron (≥ 15%)

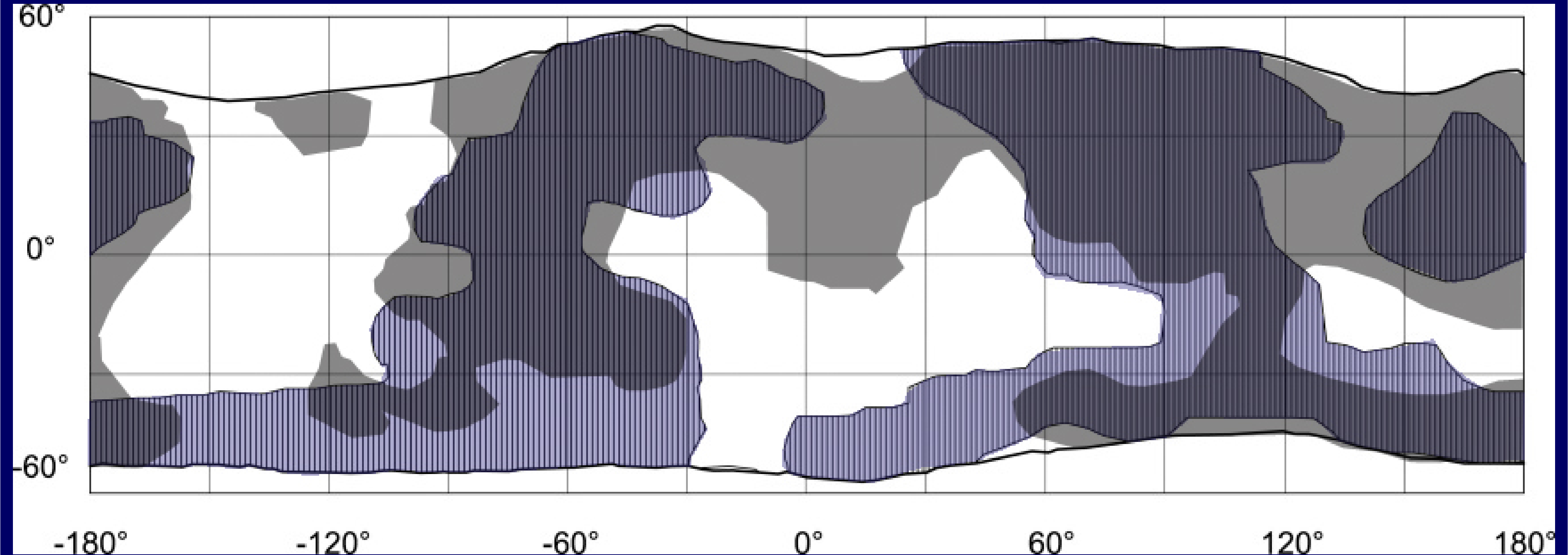
Faults vs Neutrons



Faults

Neutrons (> 0.18 cps)

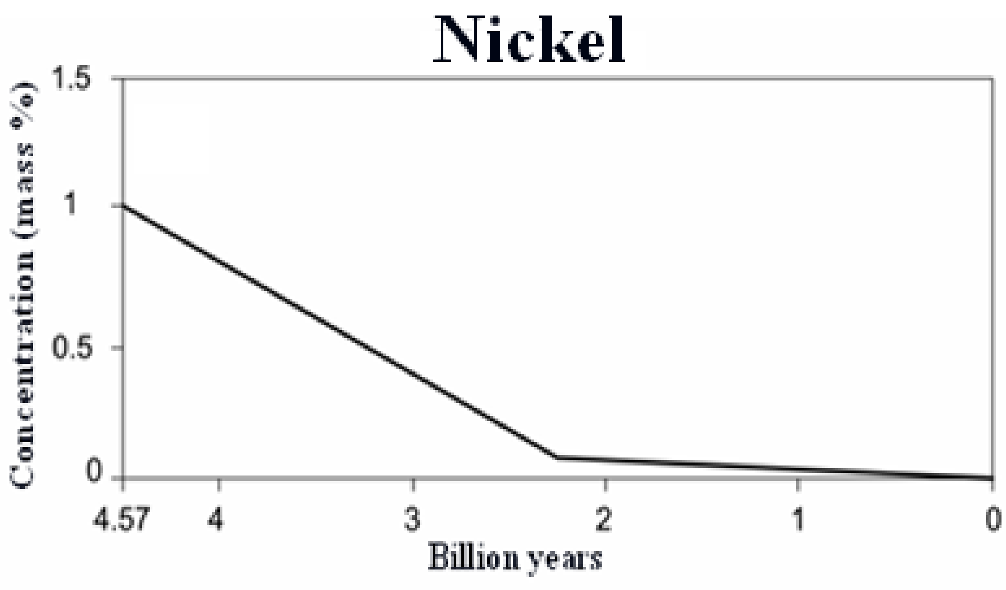
Iron vs Neutrons

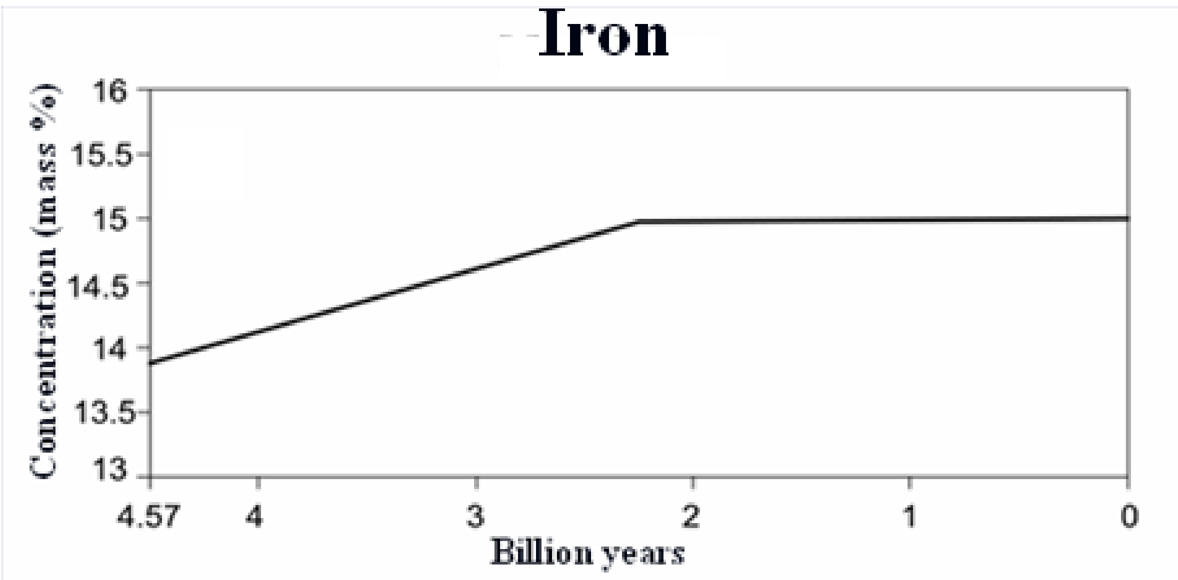


Iron (≥ 15%)

Neutrons (> 0.18 cps)

Element evolution on Mars and piezonuclear reactions

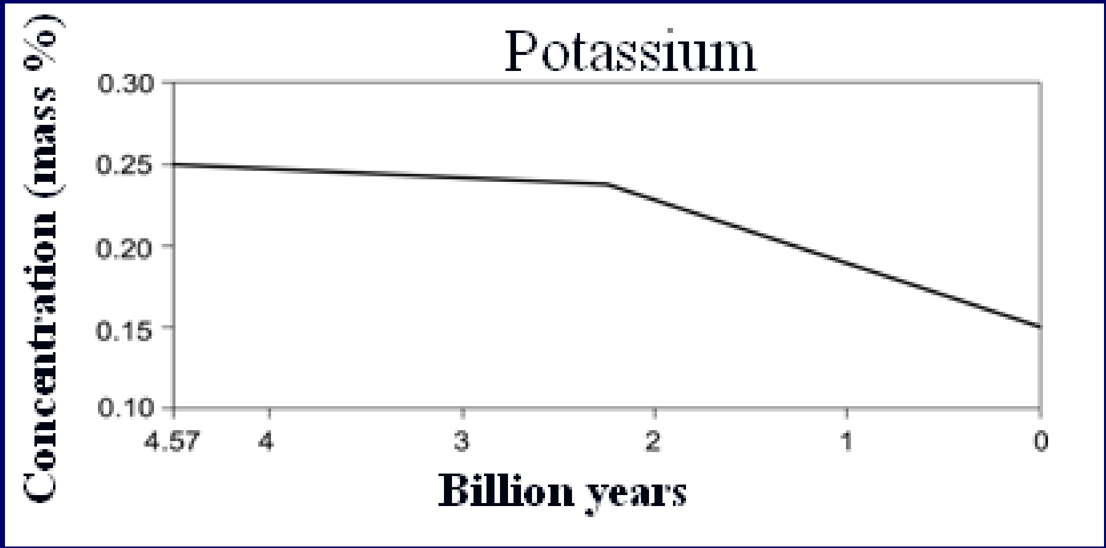


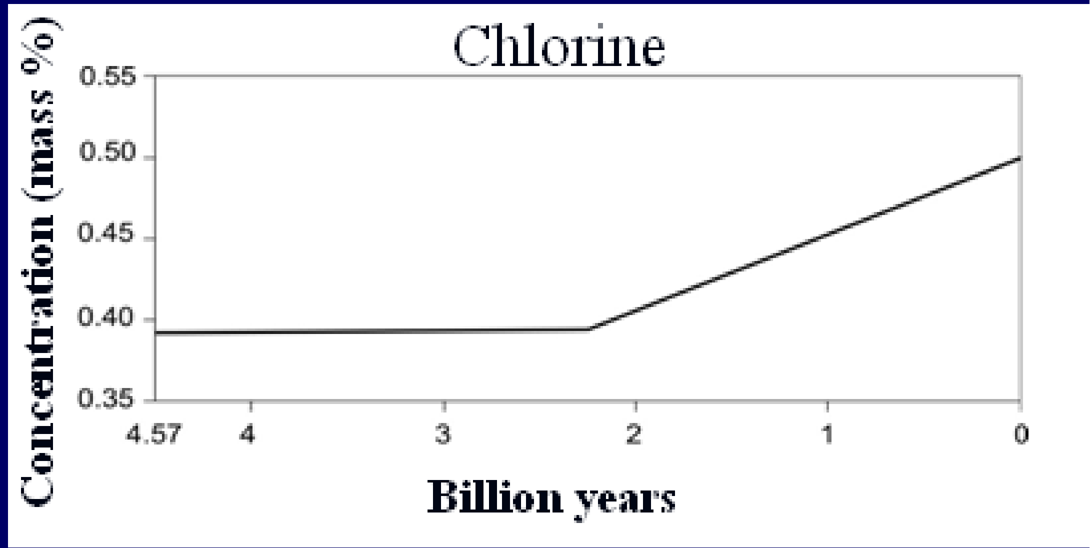


Ni decrease ~ Fe increase ~ 1.0%

$$Ni^{59}_{28} \rightarrow Fe^{56}_{26} + 2H^{1}_{1} + 1\,n$$

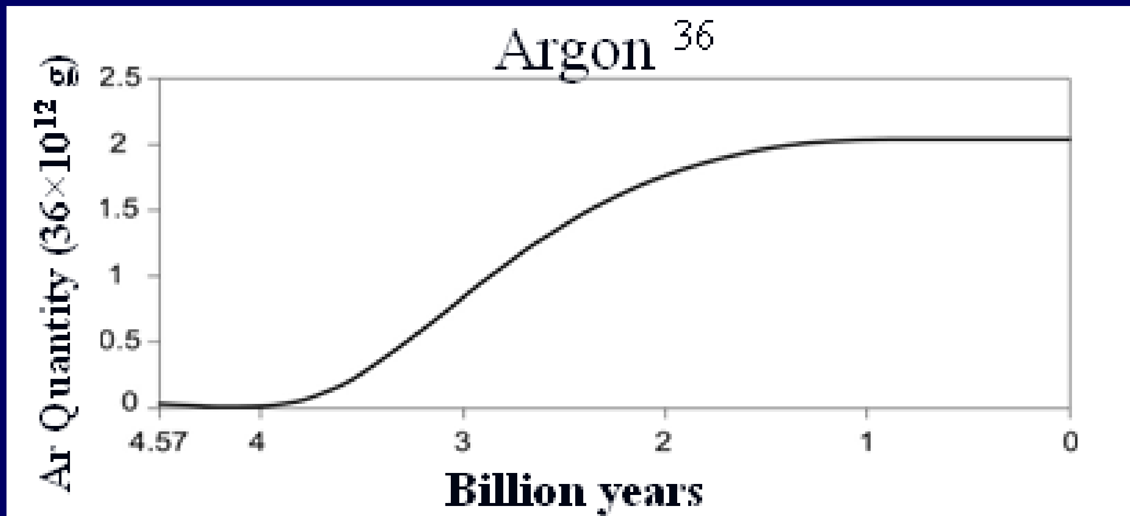
Hahn B. C., McLennan S. M. (2006) Gamma-Ray Spectometer Elemental Abundance Correlation with Martian Surface Age: Implication for Martian Crustal Evolution. *Lunar and Planetary Science* XXXVII.





$$K^{39}_{19} \rightarrow Cl^{35}_{17} + 2H^{1}_{1} + 2\,n$$

A small quantity of the K decrease may be responsible for the Ar concentration evolution in the Mars athmosphere.



$$K^{39}_{19} \rightarrow Ar^{36}_{18} + H^{1}_{1} + 2\,n$$

CONCLUSIONS

Two piezonuclear fission reaction jumps typical of the Earth Crust:

$$Fe_{26}, Co_{27}, Ni_{28} \longrightarrow Mg_{12}, Al_{13}, Si_{14} \longrightarrow C_6, N_7, O_8$$

Explanation for:

- Sudden variations in the most abundant elements (including Na_{11}, K_{19}, Ca_{20})
- Localization of the resources on the Earth's Crust
- Very high Carbon content in the primordial atmosphere
- Great Oxidation Event (2.5 Billion years ago) and origin of oceans and life
- Production of neutrons (Rn, CO_2) during earthquakes
- Evolution of the planets of the Solar System: Mercury, Mars, Jupiter, Saturn (and the Sun itself)

POSSIBLE APPLICATION FIELDS

- Short-term prediction and monitoring of **earthquakes**
- Evaluation of natural production of black carbon and CO_2 with their effects on global **pollution**
- Acceleration in the disposal of **radioactive wastes**
- Clean nuclear **energy production** (?)