

ECF19

August 26-31 2012
Kazan / Russia

19th EUROPEAN CONFERENCE ON FRACTURE
Fracture Mechanics for Durability, Reliability, and Safety
August 26-31 2012, Kazan Russia



Piezonuclear Reactions Produced by Brittle Fracture: From Laboratory to Planetary Scale

A. Carpinteri, O. Borla, G. Lacidogna, A. Manuello

**Department of Structural Engineering & Geotechnics, Politecnico di
Torino, Italy**



ACKNOWLEDGEMENTS

Dr. S. Invernizzi

Dept. of Structural Engineering & Geotechnics



Prof. R. Sandrone

Dept. of Environment, Land and Infrastructure Engineering



**Prof. M. Ferraris, Dr. F. Smeacetto, Prof. C. Pirri,
Dr. S. Guastella**

Dept. of Applied Science and Technology



Prof. F. M. Curà, Dr. R. Sesana

Dept. of Mechanical and Aerospace Engineering



(Continued)

Dr. A. Zanini

National Institute of Nuclear Physics, INFN



Prof. C. Pirri, Dr. A. Chiodoni

Italian Institute of Technology, IIT



Prof. F. Cardone

National Research Council, CNR



Ing. M. Sepielli

**Italian National Agency for New Technologies, Energy
and Sustainable Economic Development, ENEA**



**Dr. G. Niccolini, Dr. A. Troia, Dr. M. Bergoglio,
Dr. R. Malvano, Dr. P.G. Spazzini, Dr. A. Piccato,
Mr. F. Alasia**

National Research Institute of Metrology, INRIM



FRACTURE OF FISSILE AND DEUTERATED MATERIALS

- Diebner, K. Fusionsprozesse mit hilfe konvergenter stosswellen – einige aeltere und neuere versuche und ueberlegungen, *Kerntechnik* 3, 89-93 (1962).
- Derjaguin, B. V., et al., “Titanium fracture yields neutrons?”, *Nature*, 34, 492 (1989).
- Preparata, G., “A new look at solid-state fractures, particle emissions and «cold» nuclear fusion”, *Il Nuovo Cimento*, 104 A, 1259-1263 (1991).
- Fujii, M. F., et al., “ Neutron emission from fracture of piezoelectric materials in deuterium atmosphere”, *Jpn. J. Appl. Phys.*, Pt.1, 41, 2115-2119 (2002).

CAVITATION OF LIQUID SOLUTIONS

- Taleyarkhan, R.P., West, C.D., Cho, J.S., Lahey, R.T., Nigmatulin, R.I., Block, R.C. Evidence for nuclear emissions during acoustic cavitation. *Science*. 295, 1868–1873 (2002).
- Cardone, F. & Mignani, R. Piezonuclear reactions and Lorentz invariance breakdown. *Int. Jour. Modern Phys. E*, 15, 911, (2006).
- Cardone, F., Cherubini, G., Petrucci, A. Piezonuclear neutrons. *Phys. Lett. A*, 373(8-9), 862–866 (2009).
- Cardone, F. & Mignani, R., Petrucci, A. Piezonuclear decay of Thorium. *Phys. Lett. A*, 373(22), 1956–1958 (2009).
- Cardone, F., Cherubini, G., Mignani, R., Perconti, W., Petrucci, A., Rosetto, F., Spera, G. Neutrons from Piezonuclear Reactions. *Fondation Louis de Broglie*, 34(2), (2009).

FRACTURE OF INERT AND NON-RADIOACTIVE SOLIDS

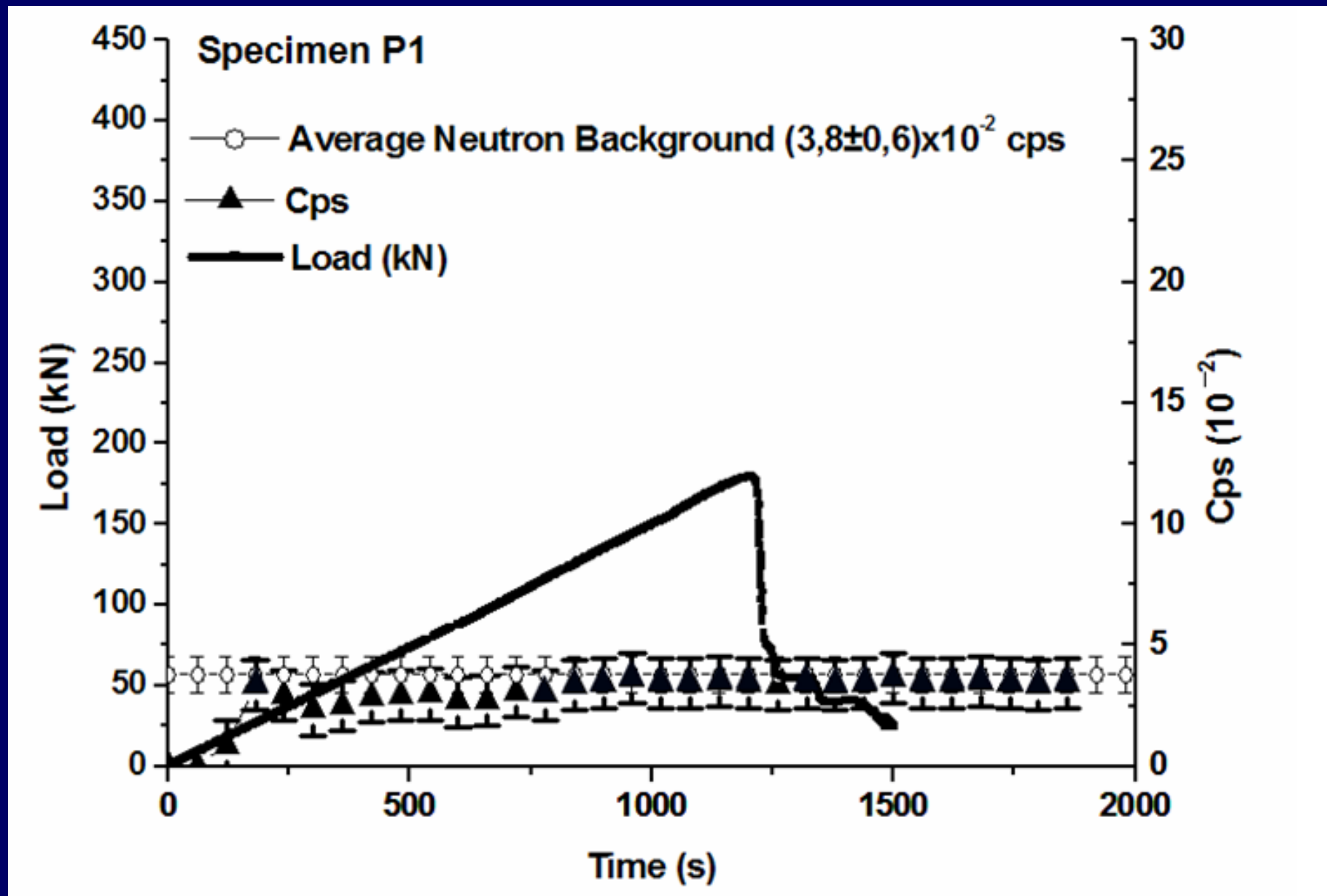
- Carpinteri, A., Cardone, F., Lacidogna, G. “Energy emissions from failure phenomena: Mechanical, electromagnetic, nuclear”, *Experimental Mechanics*, 50, 1235–1243, (2009).
- Carpinteri, A., Cardone, F., Lacidogna, G. “Piezonuclear neutrons from brittle fracture: Early results of mechanical compression tests”, *Strain*, 45, 332–339, (2009).
- Cardone, F., Carpinteri, A., Lacidogna, G. “Piezonuclear neutrons from fracturing of inert solids”, *Physics Letters A*, 373, 4158–4163, (2009).
- Carpinteri, A., Borla, O., Lacidogna, G., Manuello A. “Neutron emissions in brittle rocks during compression tests: Monotic vs. cyclic loading”, *Physical Mesomech.*, 13, 264–274, (2010).
- Carpinteri, A., Chiodoni, A., Manuello, A., Sandrone, R. “Compositional and microchemical evidence of piezonuclear fission reactions in rock specimens subjected to compression tests”, *Strain*, 47(2), 267–281, (2011).

(Continued)

- Carpinteri, A., Manuello, A. “Geomechanical and Geochemical evidence of piezonuclear fission reactions in the Earth’s Crust”, *Strain*, 47(2), 282-292, (2011).
- Carpinteri, A., Lacidogna, G., Manuello, A., Borla O. “Energy emissions from brittle fracture: Neutron measurements and geological evidences of piezonuclear reactions”, *Strength, Fracture and Complexity*, 7, 13-31, (2011).
- Carpinteri, A., Lacidogna, G., Borla, O., Manuello, A., Niccolini, G. “Electromagnetic and neutron emissions from brittle rocks failure: Experimental evidence and geological implications”, *Sadhana*, 37(1), 59–78, (2012).
- Carpinteri, A., Lacidogna G., Manuello A., Borla O. “Piezonuclear fission reactions in rocks: Evidences from microchemical analysis, neutron emission, and geological transformation”, *Rock Mech. and Rock Eng.*, 45(4), 445–459, (2012).
- Carpinteri, A., Lacidogna, G., Manuello, A., Borla O. “Piezonuclear fission reactions from earthquakes and brittle rocks failure: Evidence of neutron emission and nonradioactive product elements”, *Exp. Mech.*, doi: 10.1007/s11340-012-9629-x.

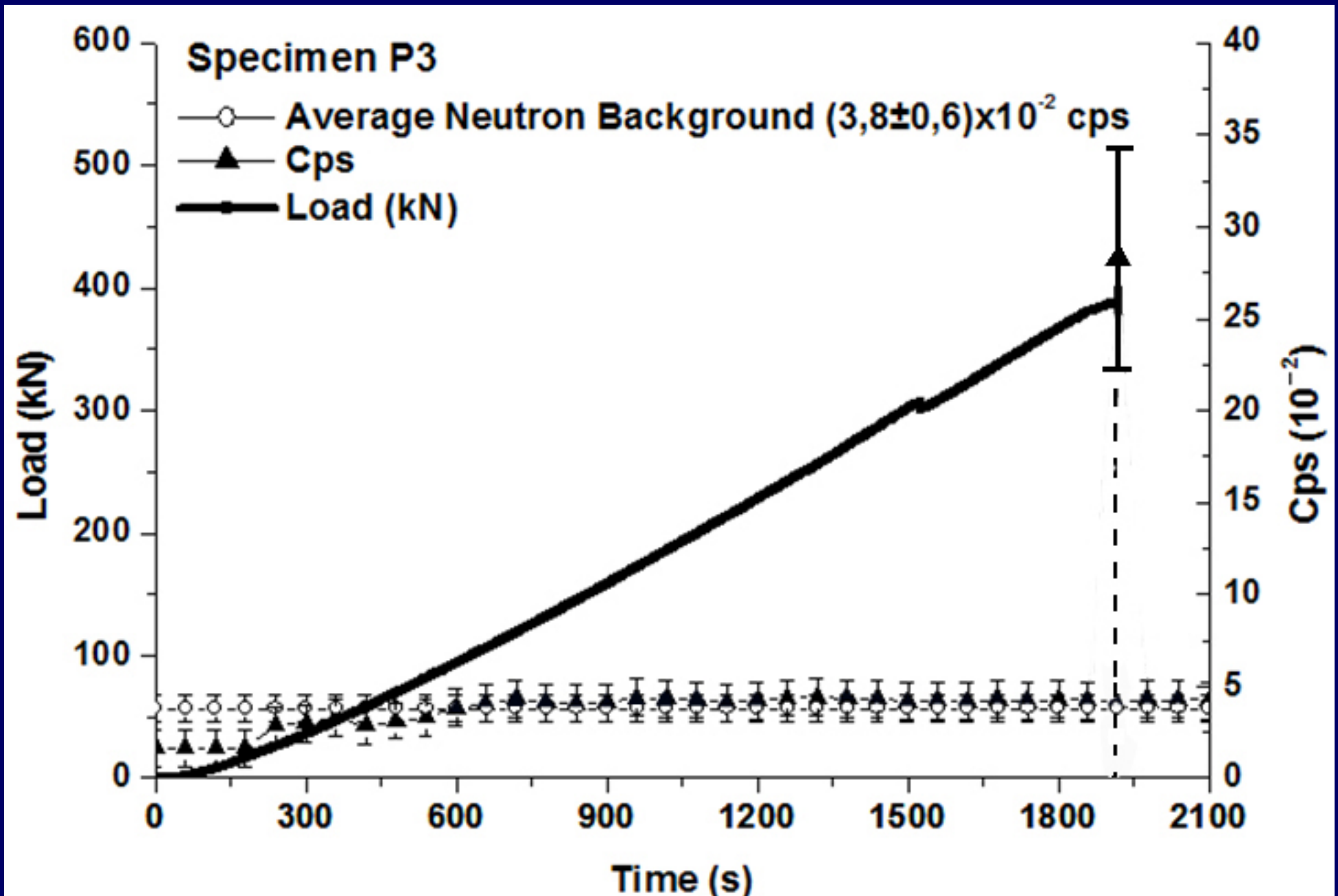
LABORATORY EXPERIMENTS

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

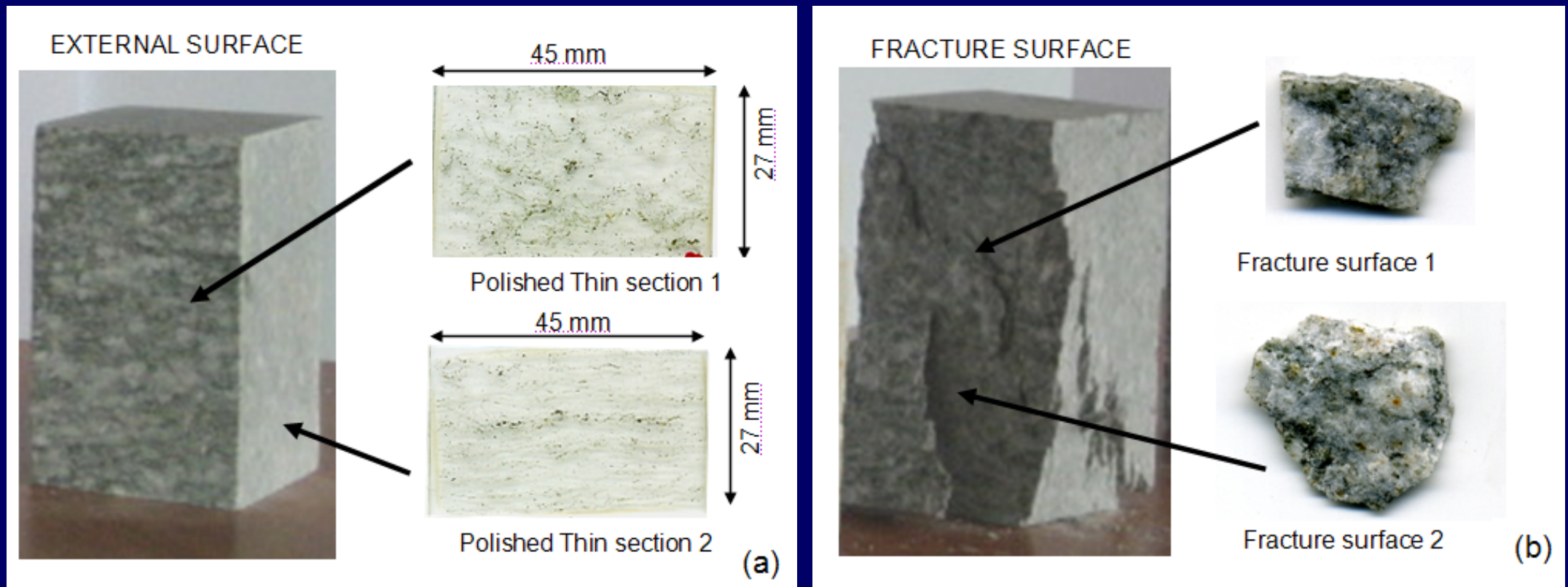


The equivalent neutron dose, at the end of the test on basaltic rock, was $2.62 \pm 0.53 \mu\text{Sv/h}$ (Average Background Dose = $41.95 \pm 0.85 \text{ nSv/h}$).

$$\frac{\text{Effective Neutron Dose}}{\text{Average Background Dose}} \approx 50$$

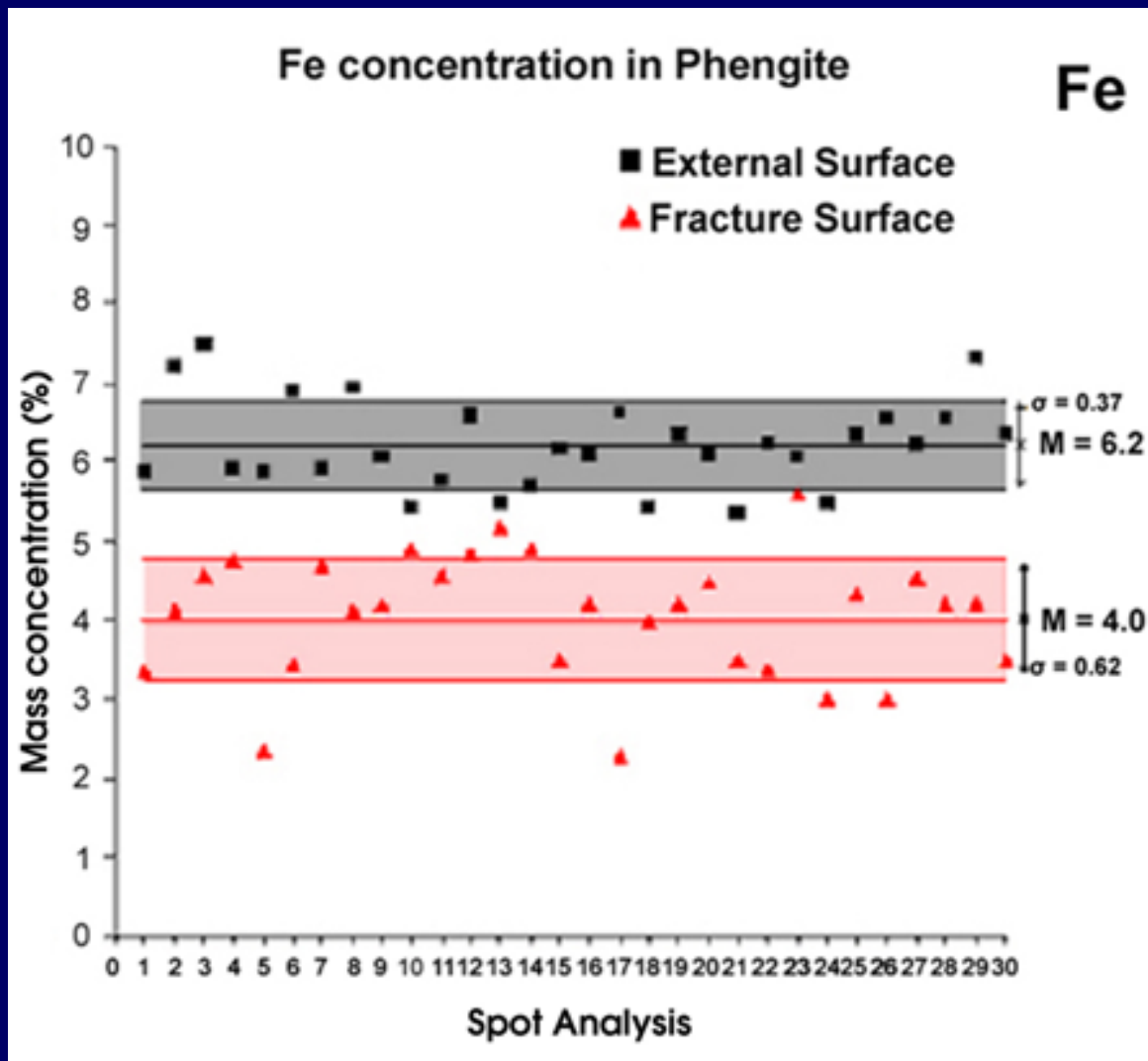
ENERGY DISPERSIVE X-RAY SPECTROSCOPY: COMPOSITIONAL ANALYSIS OF PRODUCT ELEMENTS

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%

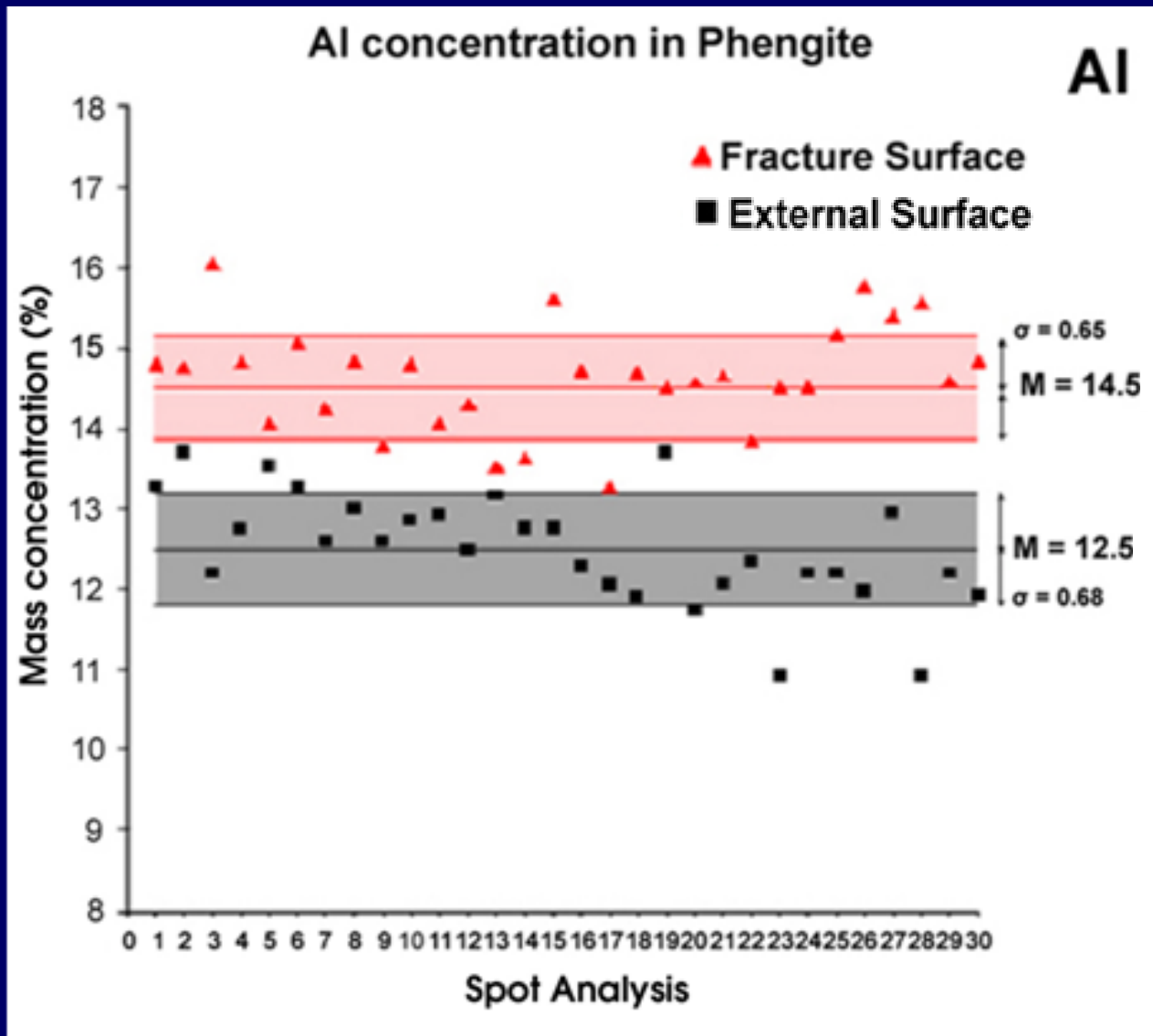
Fracture Surf.:

Fe content = 4.0%

Fe content decrease

-2.2%

Phengite: Al concentration



Fracture Surf.:

Al content = 14.5%

External Surf.:

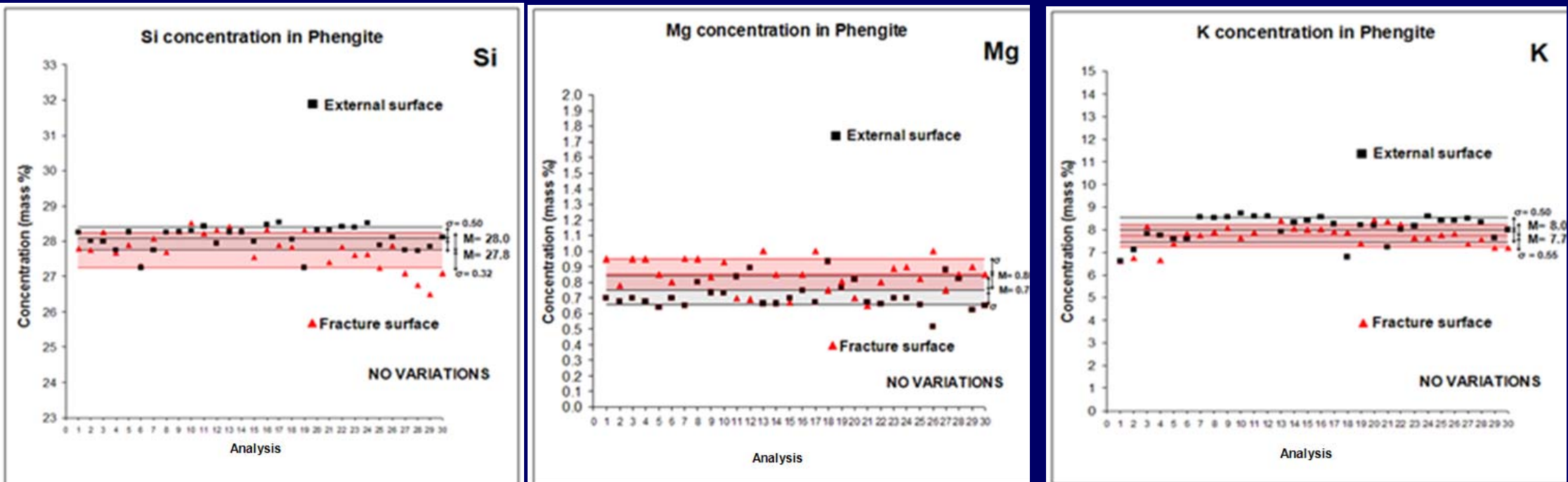
Al content = 12.5%

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.

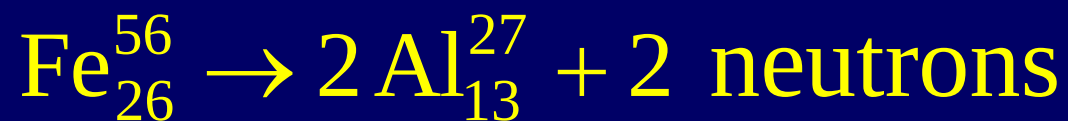


The Si, Mg, and K concentrations are reported for external and fracture surfaces. In this case, no appreciable variations can be recognized between the average values.

Phengite

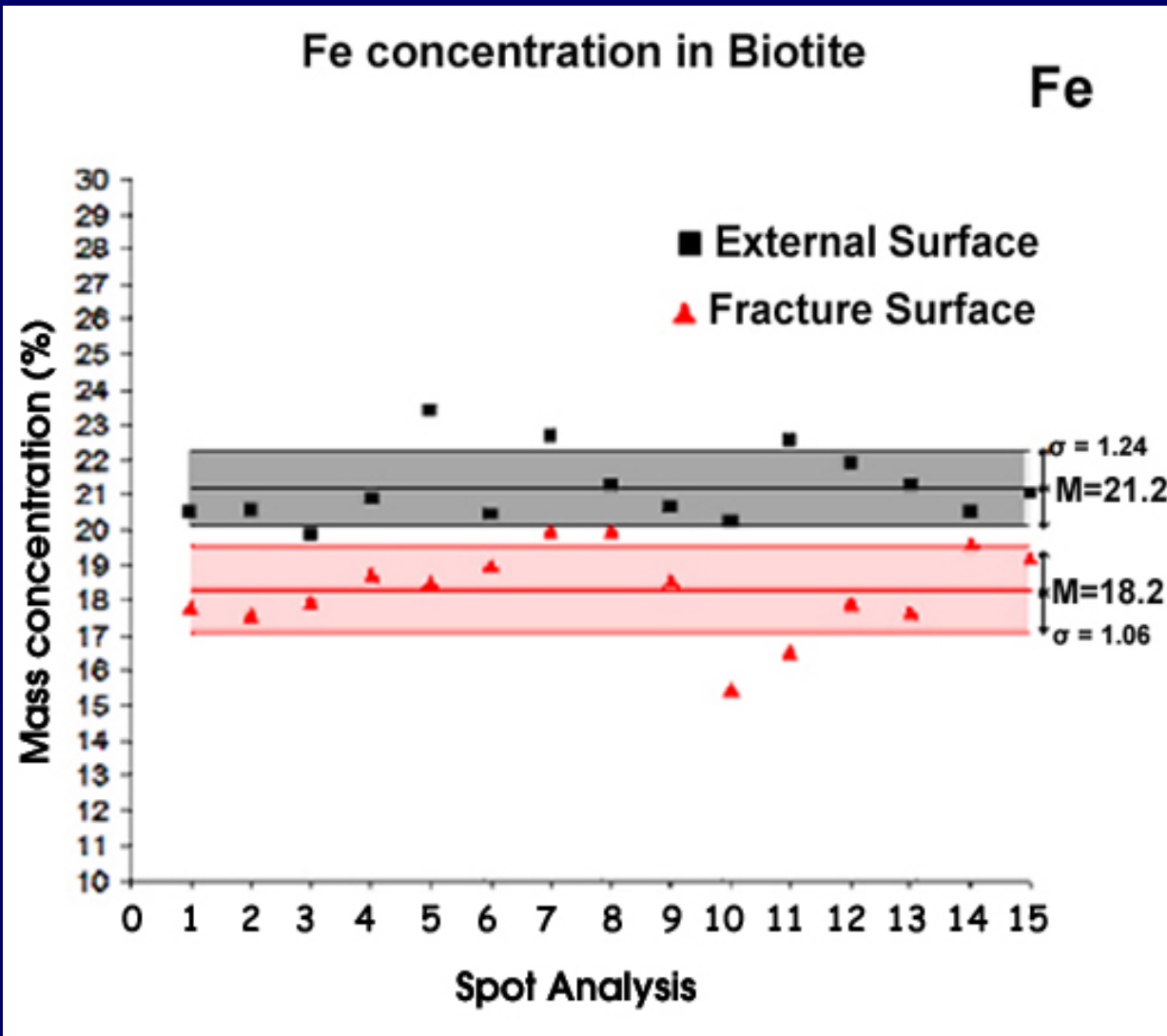
	External surface mean value (wt%)	Fracture surface mean value (wt%)	Increase/ decrease with respect to phengite	Increase/ decrease with respect to the same element
Fe	6.2	4.0	-2.2%	-35%
Al	12.5	14.5	+2.0%	+16%
Si	28.0	27.8	NO VARIATIONS	NO VARIATIONS
Mg	0.7	0.8	NO VARIATIONS	NO VARIATIONS
K	8.0	7.7	NO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

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



has occurred in the rock specimens.

Biotite: Fe concentrations



External Surf.:

Fe content = 21.2%

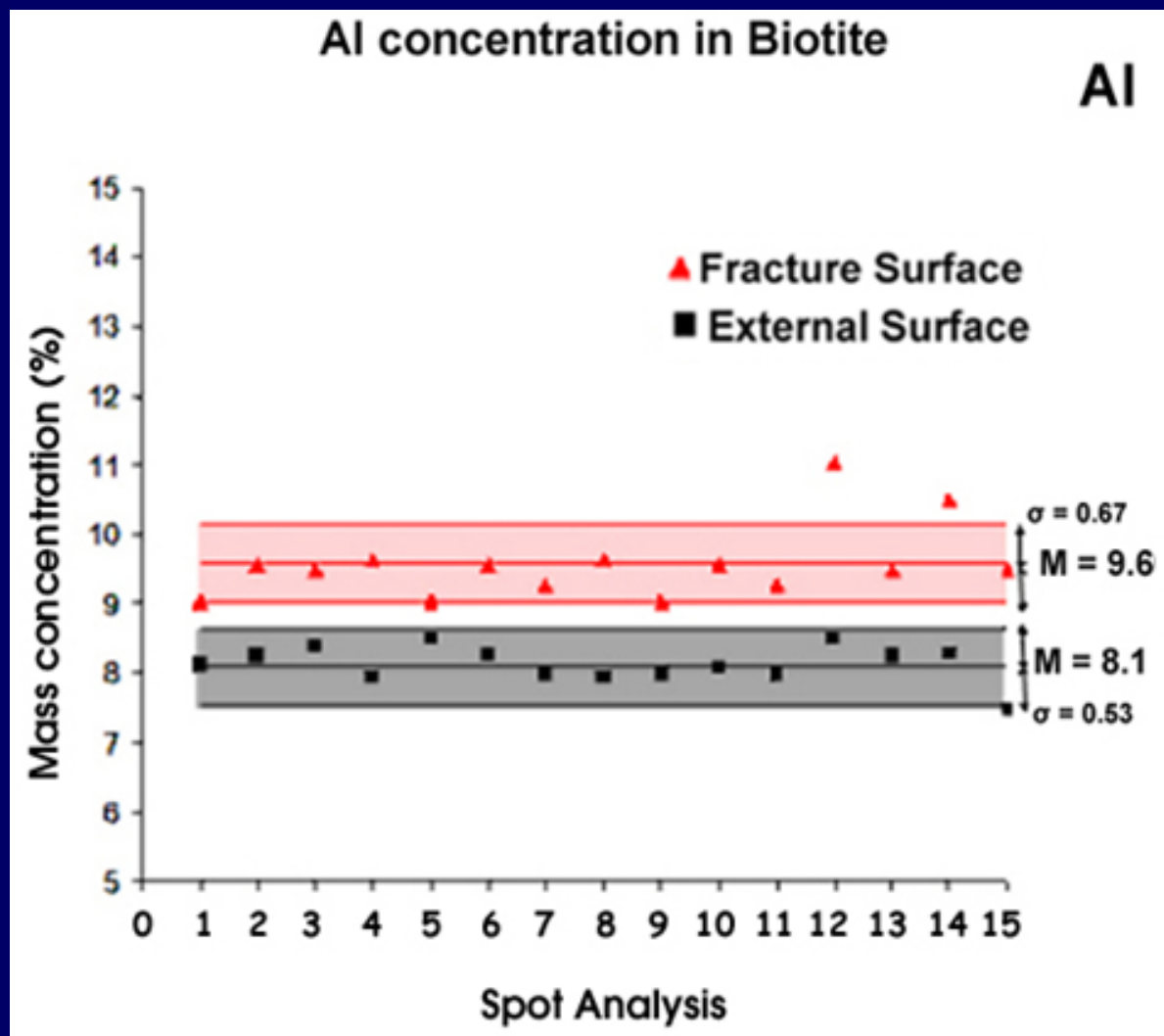
Fracture Surf.:

Fe content = 18.2%

Fe content decrease

−3.0%

Biotite: Al concentrations



Fracture Surf.:

Al content = 9.6%

External Surf.:

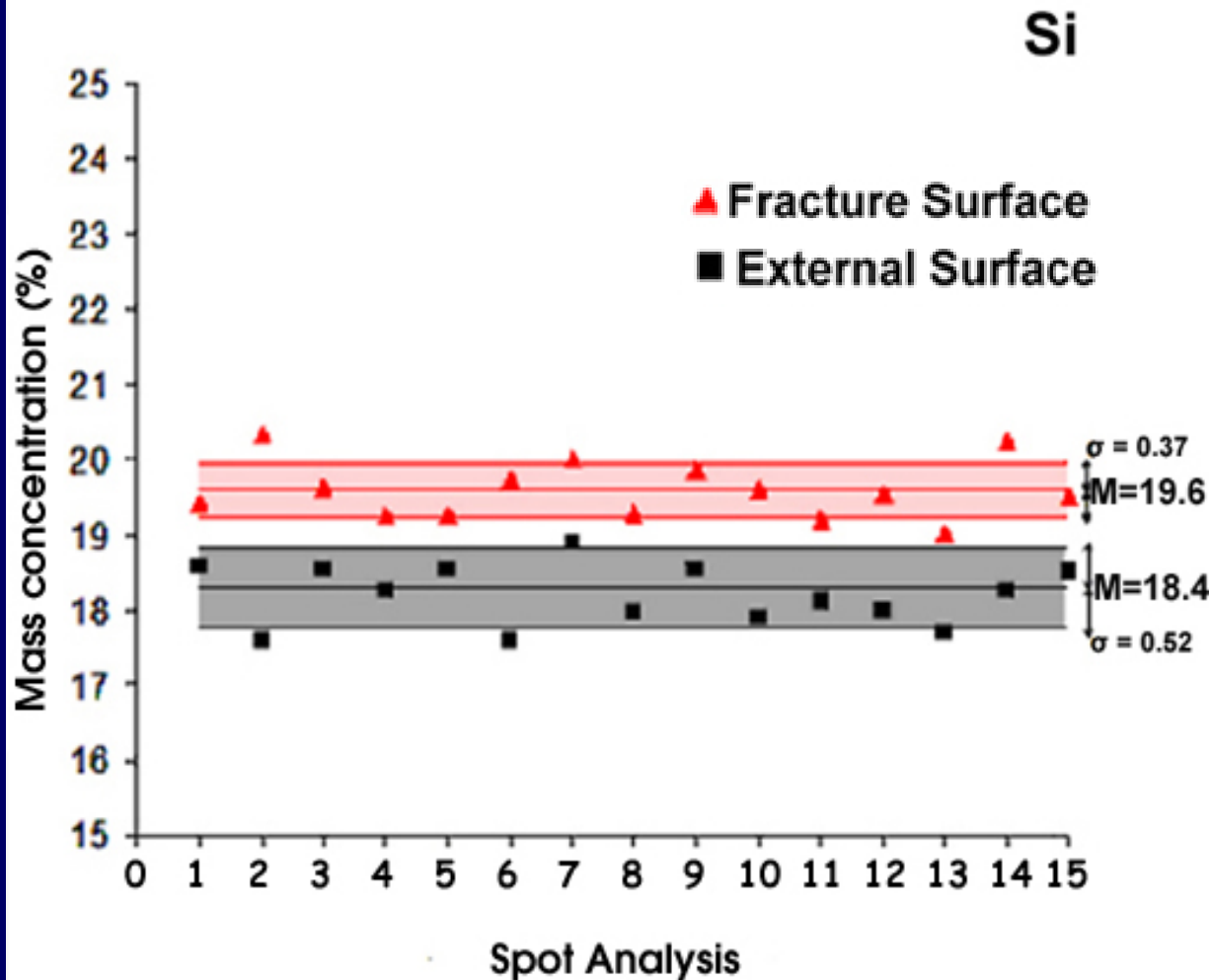
Al content = 8.1%

Al content increase

+1.5%

Biotite: Si concentrations

Si concentration in Biotite



Fracture Surf.:

Si content = 19.6%

External Surf.:

Si content = 18.4%

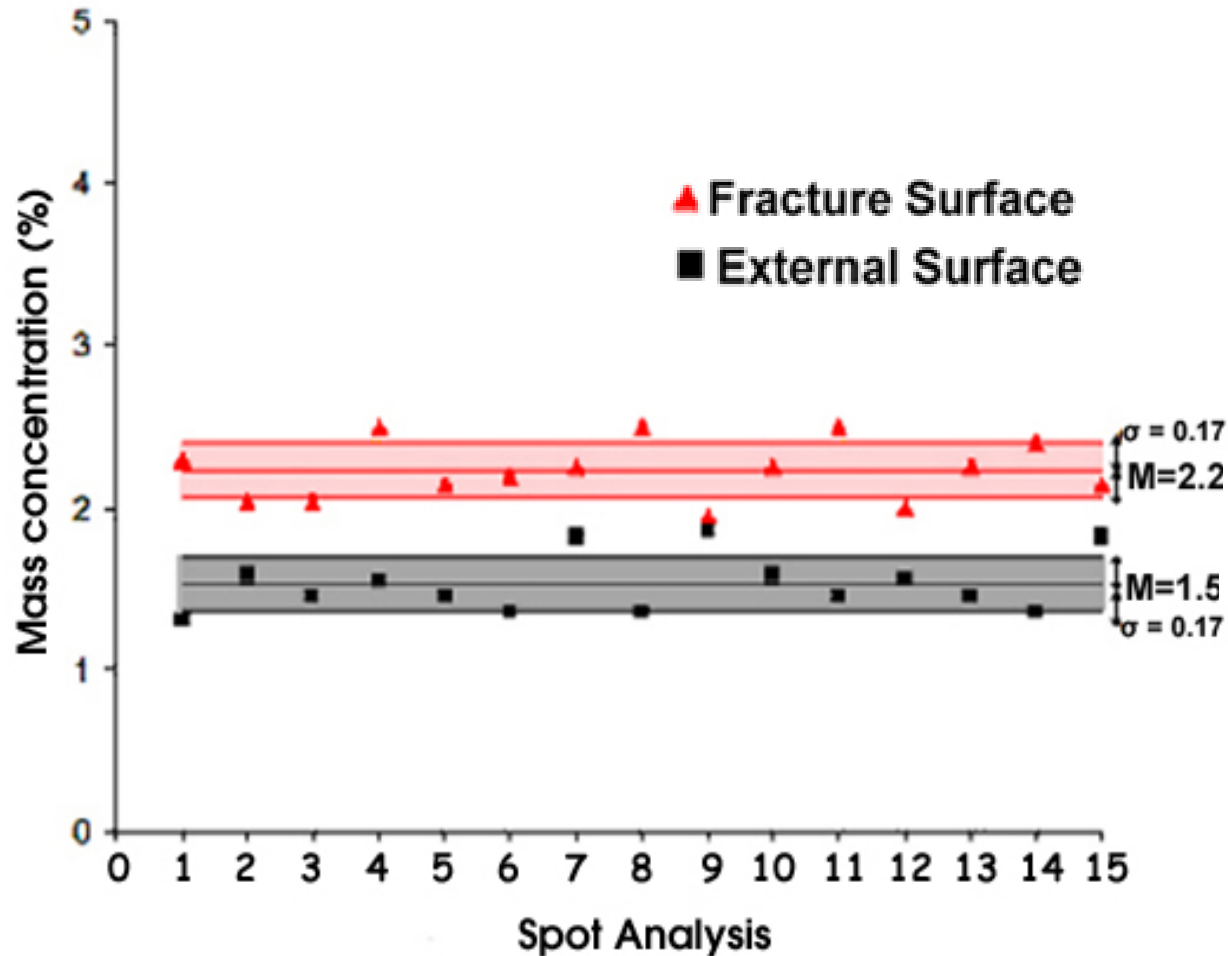
Si content increase

+1.2%

Biotite: Mg concentrations

Mg concentration in Biotite

Mg



Fracture Surf.:

Mg content = 2.2%

External Surf.:

Mg content = 1.5%

Mg content increase

+0.7%

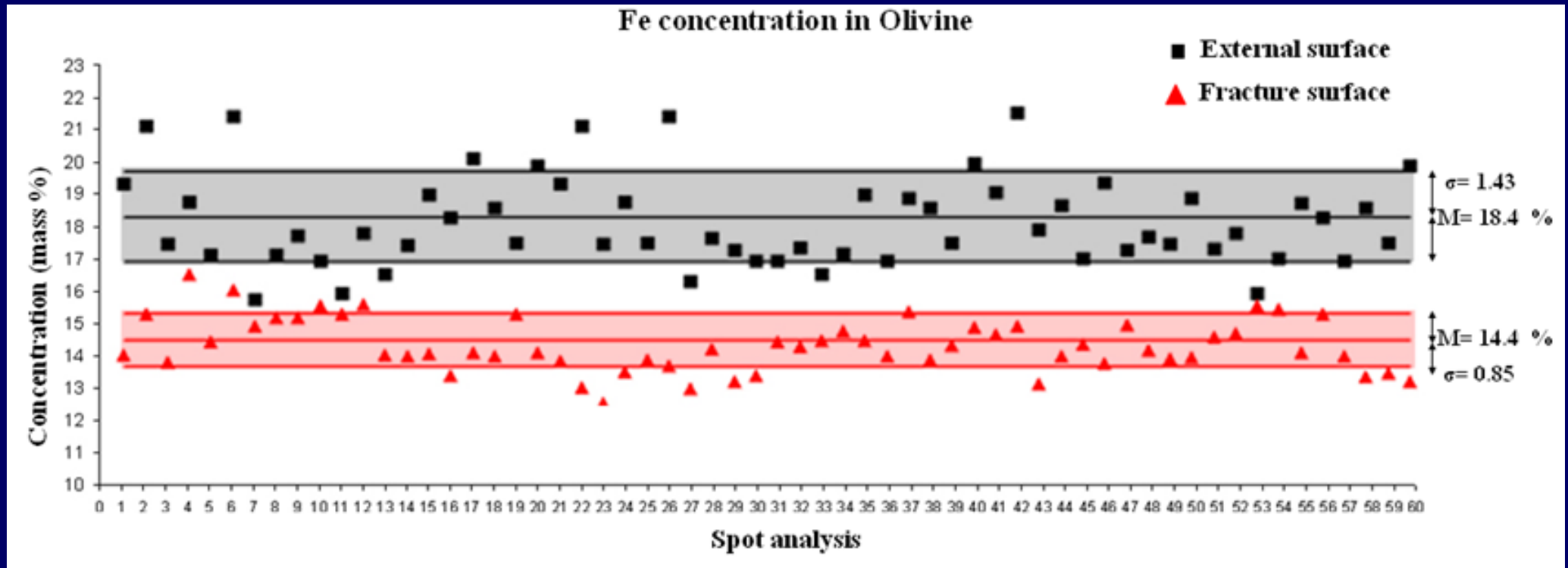
Biotite

	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:



Basalt (Olivine): Fe concentrations



External Surf.: Fe content = 18.4%

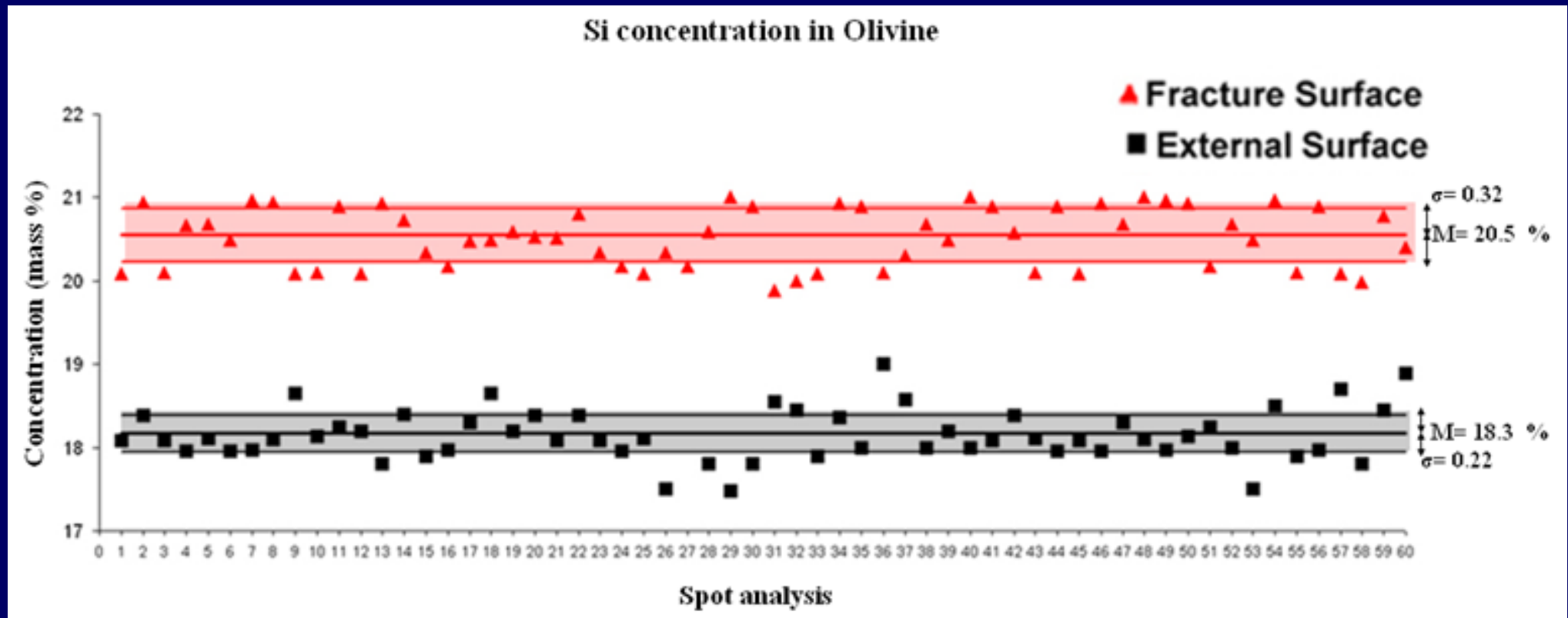


Fracture Surf.: Fe content = 14.4%

Fe content decrease

– 4.0%

Basalt (Olivine): Si concentrations



Fracture Surf.: Fe content = 20.5%

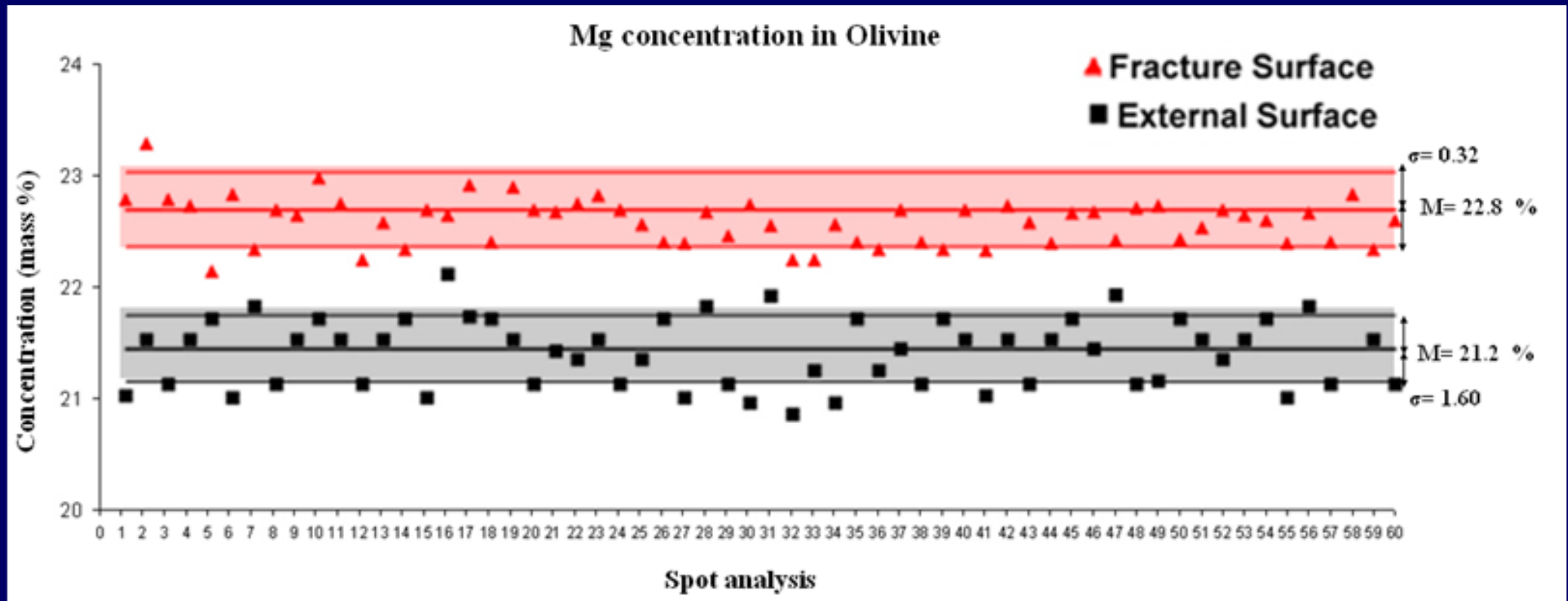


External Surf.: Fe content = 18.3%

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

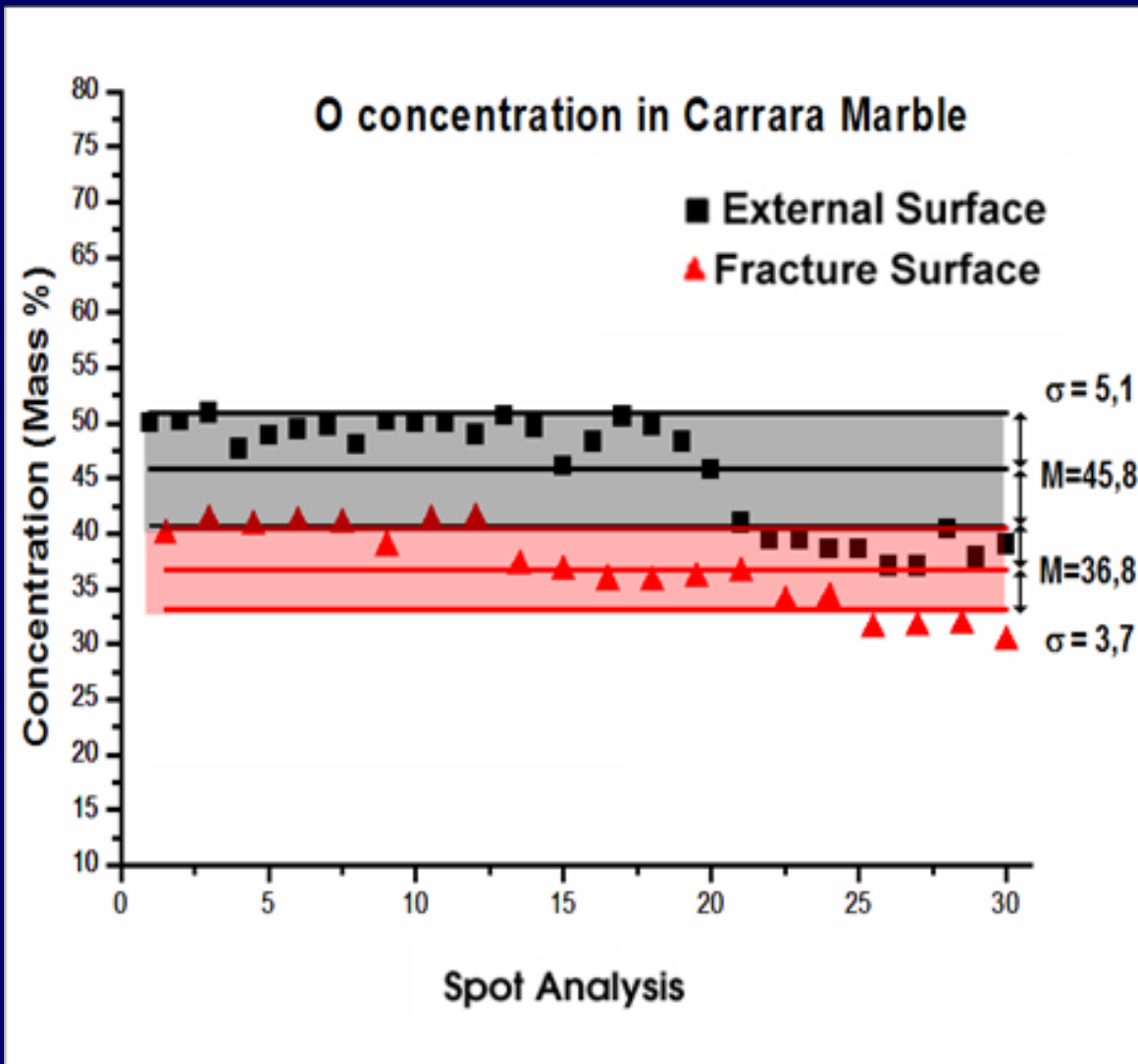
	External surface mean value (wt%)	Fracture surface mean value (wt%)	Increase/ decrease with respect to Olivine	Increase/ decrease with respect to the same element
Fe	18.4	14.4	-4.0 %	-21%
Si	18.3	20.5	+2.2 %	+12%
Mg	21.2	22.8	+1.6 %	+4%
Ca	0.5	0.5	NO VARIATIONS	NO VARIATIONS

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 :



Carrara Marble: O concentrations

X-ray Photoelectron Spectroscopy



External Surf.:

O content = 45.8%

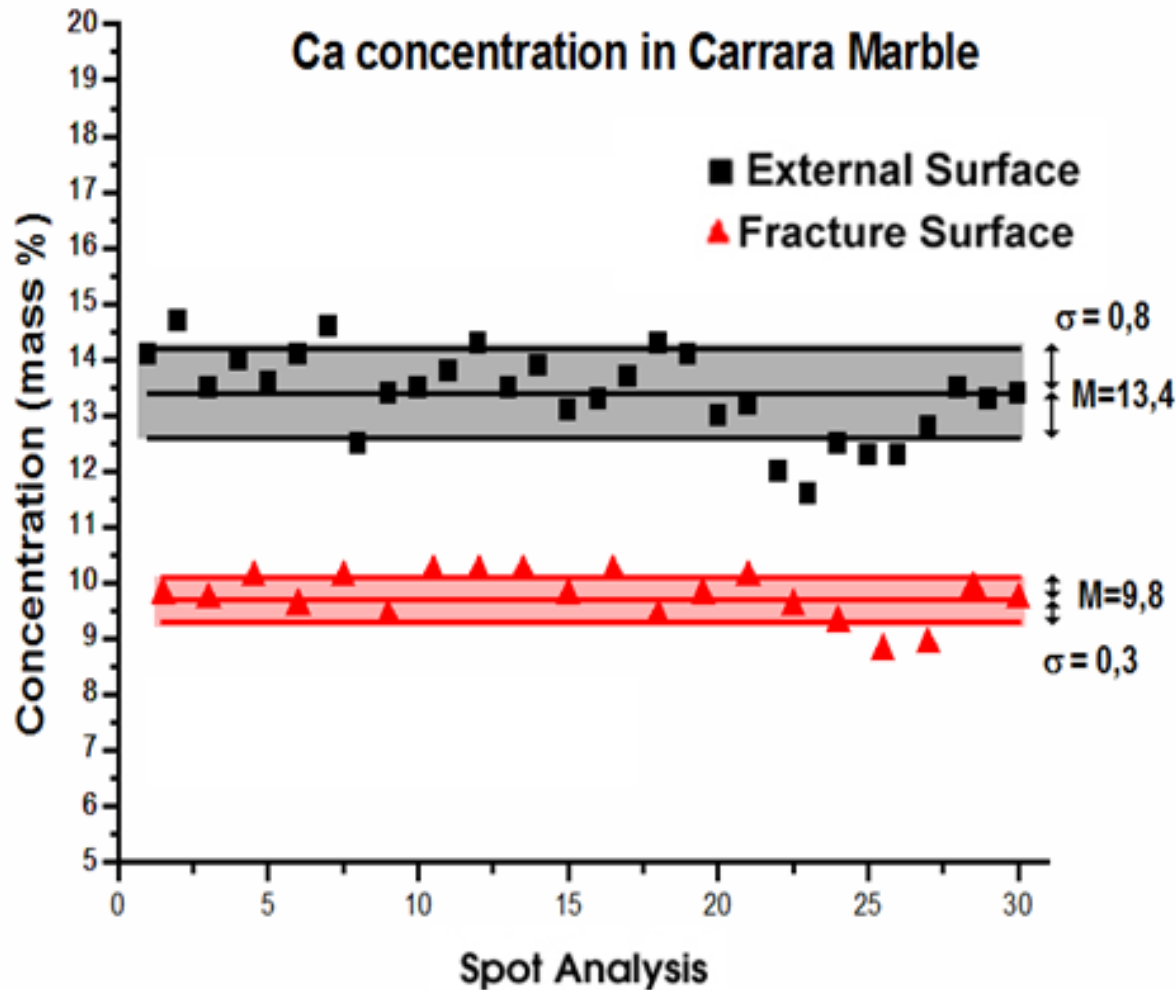
Fracture Surf.:

O content = 36.8%

O content decrease

–9.0%

Carrara Marble: Ca concentrations



External Surf.:

Ca content = 13.4%

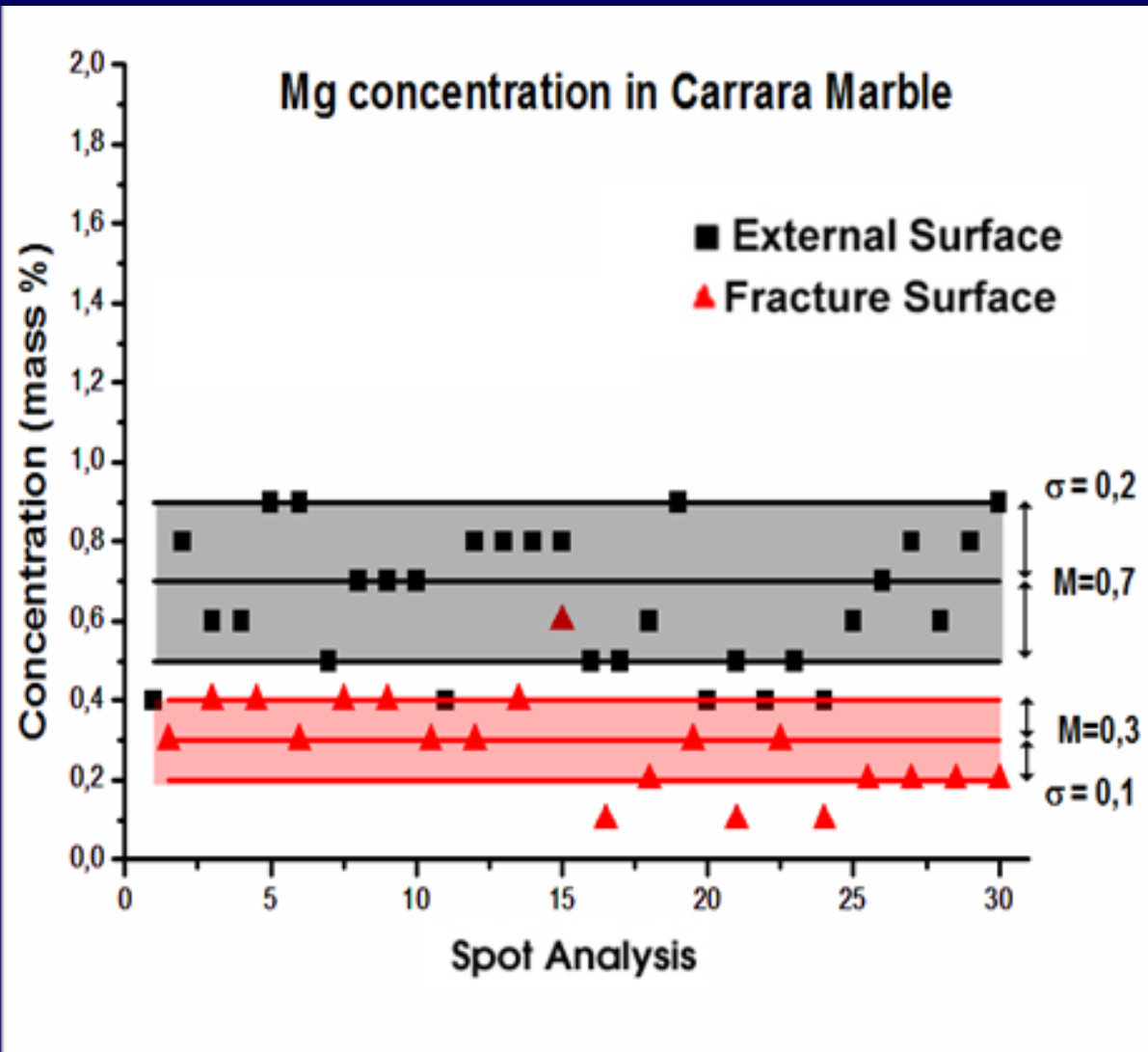
Fracture Surf.:

Ca content = 9.8%

Ca content decrease

–3.6%

Carrara Marble: Mg concentrations



External Surf.:

Mg content = 0.7%



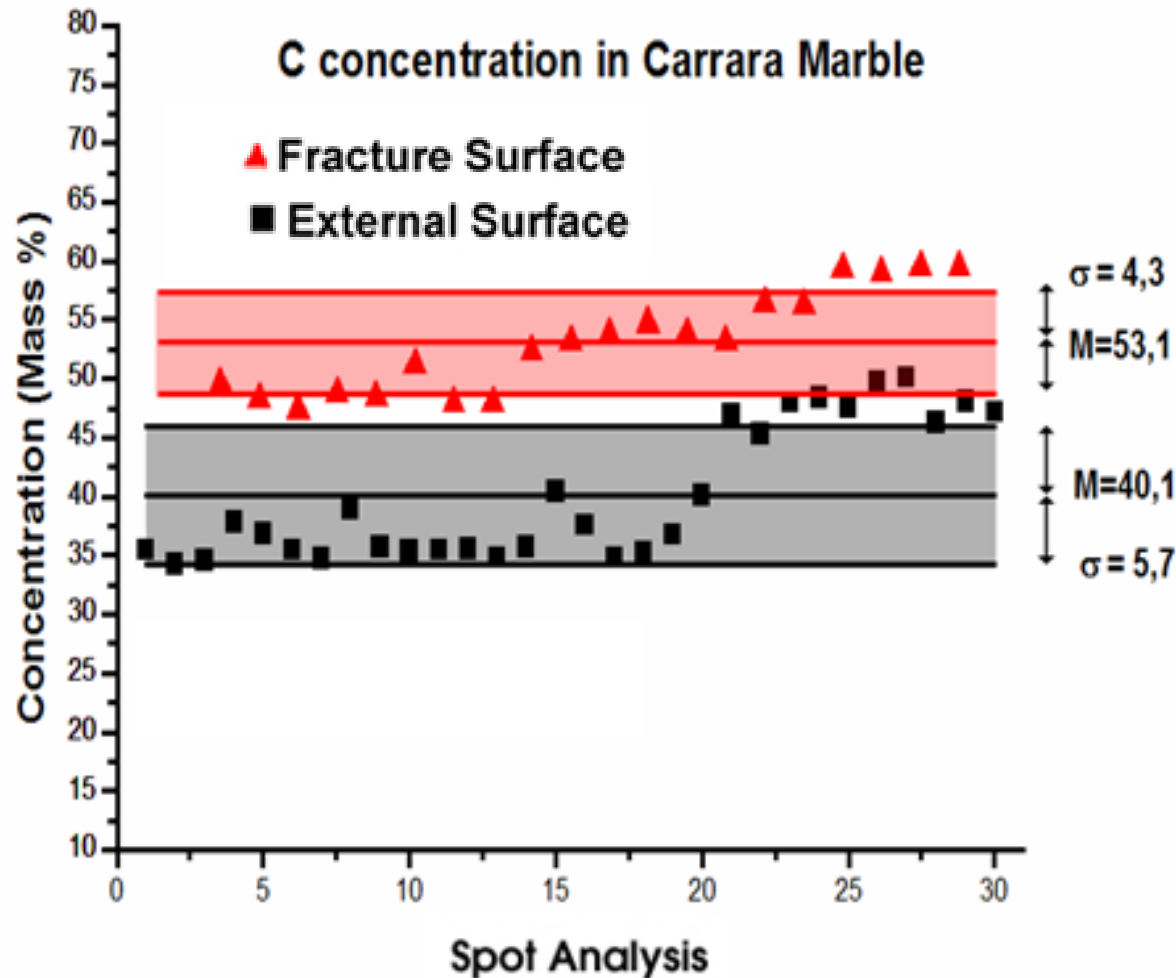
Fracture Surf.:

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%

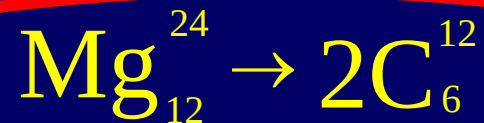
C content increase

+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:



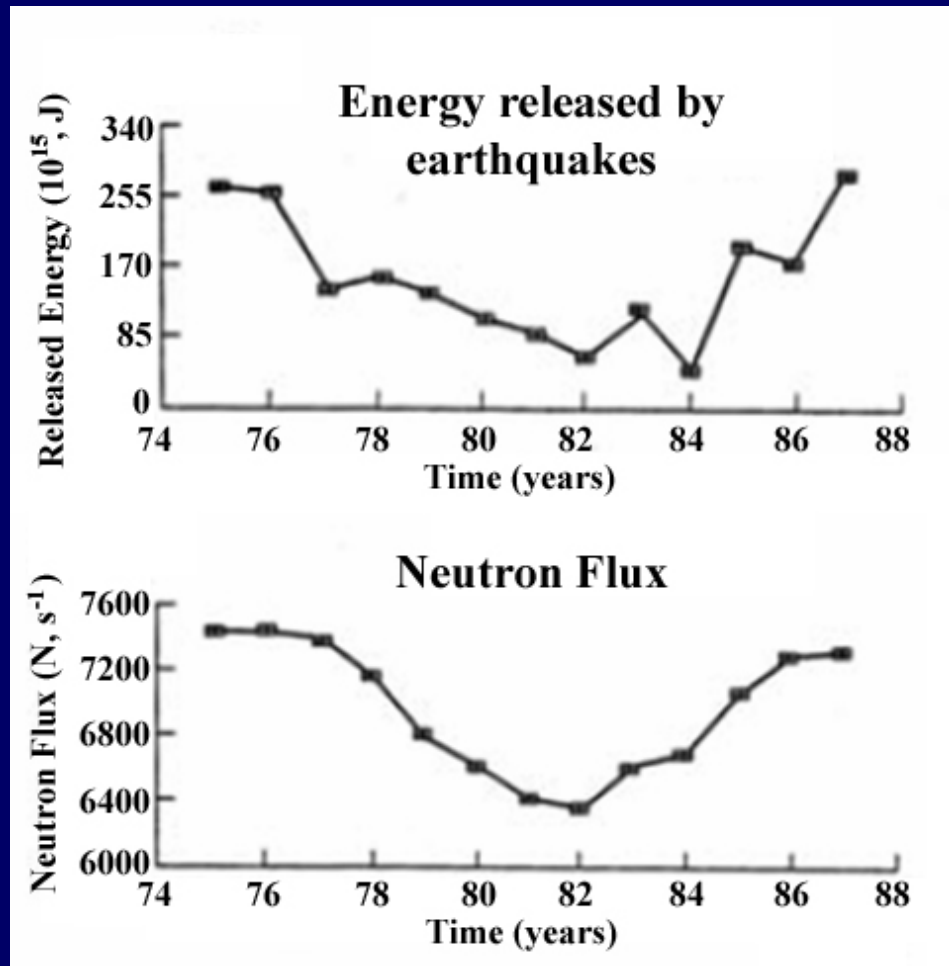
EARTH CRUST EVOLUTION

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).

(Continued)

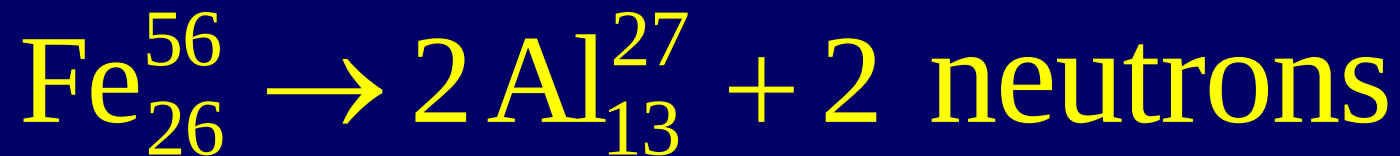
As reported in the literature, an average thermal neutron flux up to $10^0 \text{ cm}^{-2} \text{ s}^{-1}$ (**10^3 times the background level**) was detected in correspondence to earthquakes with a magnitude of the 4th degree in Richter Scale (Volodichev N.N., et al. (1999)).



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).

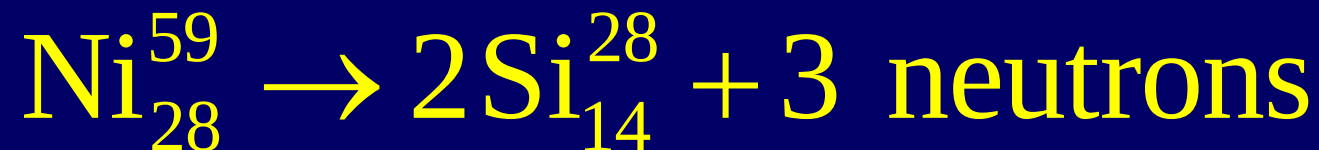
EVOLUTION AND LOCALIZATION OF METAL ABUNDANCES IN THE EARTH CRUST

- 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:



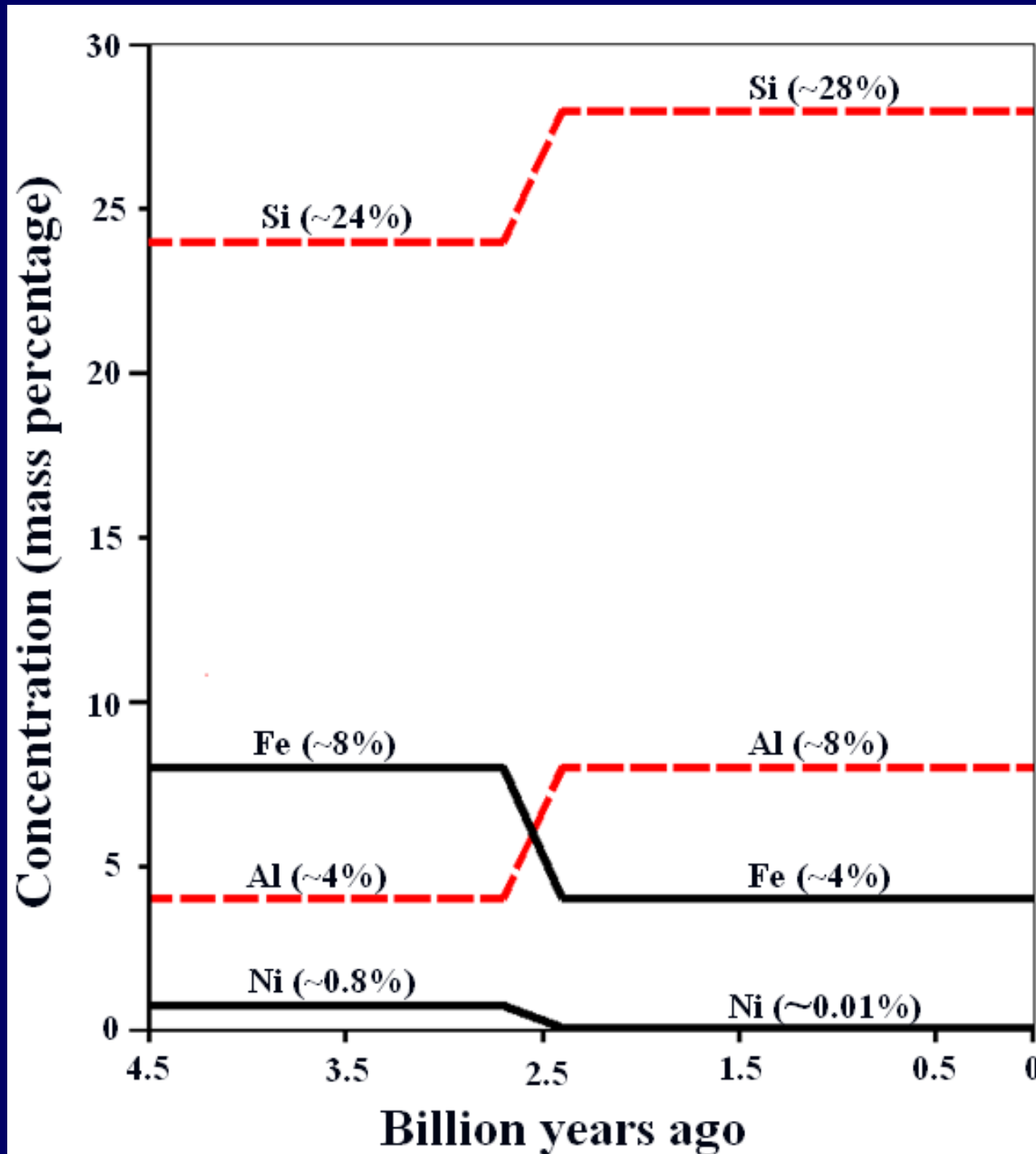
- The present natural abundance in the Earth’s Crust of aluminum (~8%) and iron (~4%) are possibly due to the above piezonuclear fission reaction.
- This reaction would be activated where the environment conditions (pressure and temperature) are particularly severe, and mechanical phenomena of fracture, 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:



- 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 ($\sim 2.5 \times 10^9$ years ago)



Localization of iron mines



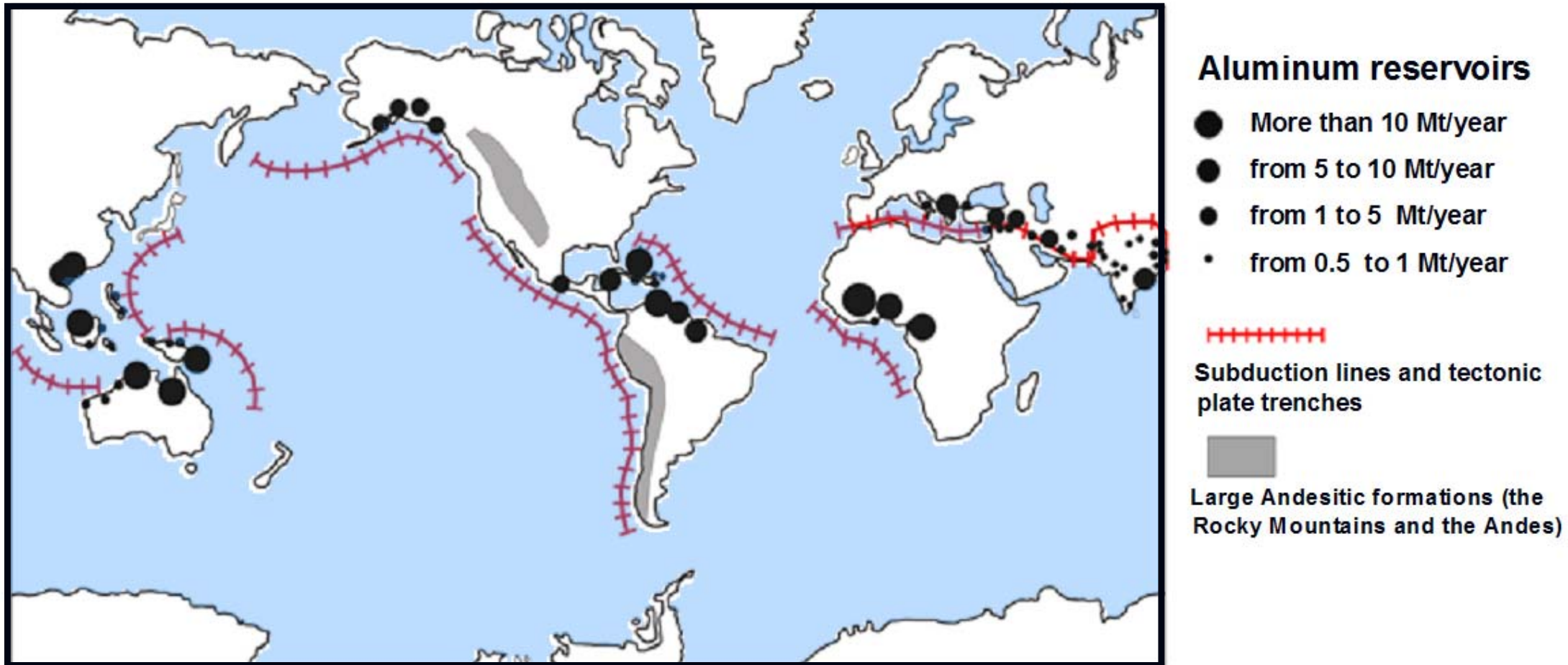
Iron reservoirs

- ▲ More than 40 Mt/year
- ▲ from 10 to 40 Mt/year

(*) 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>.

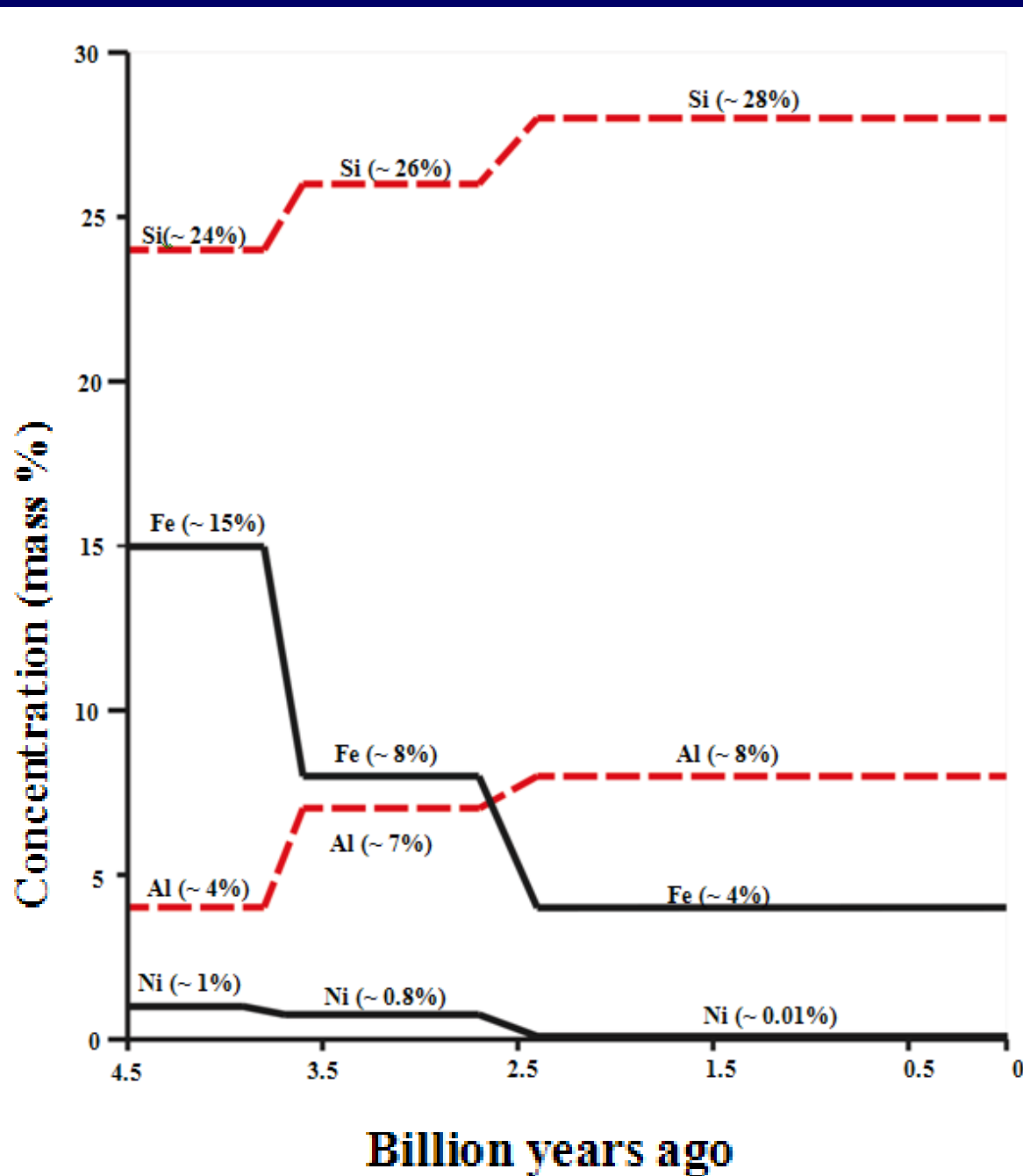
Localization of Aluminum mines



(*) 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 ($\sim 3.8 \times 10^9$ years ago)



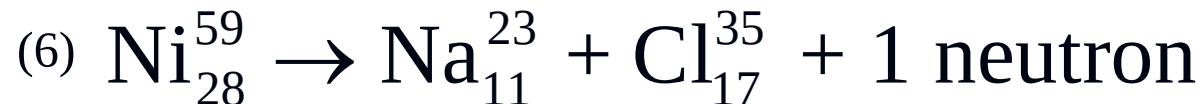
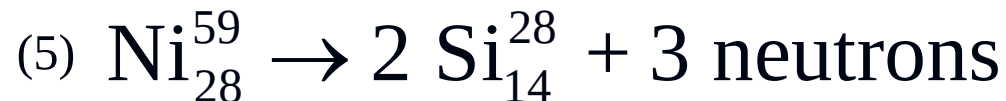
3.8 Billion years ago:

**Fe (−7%) + Ni (−0.2%) =
=Al (+3%) + Si (+2.2%) + Mg (+2%)**

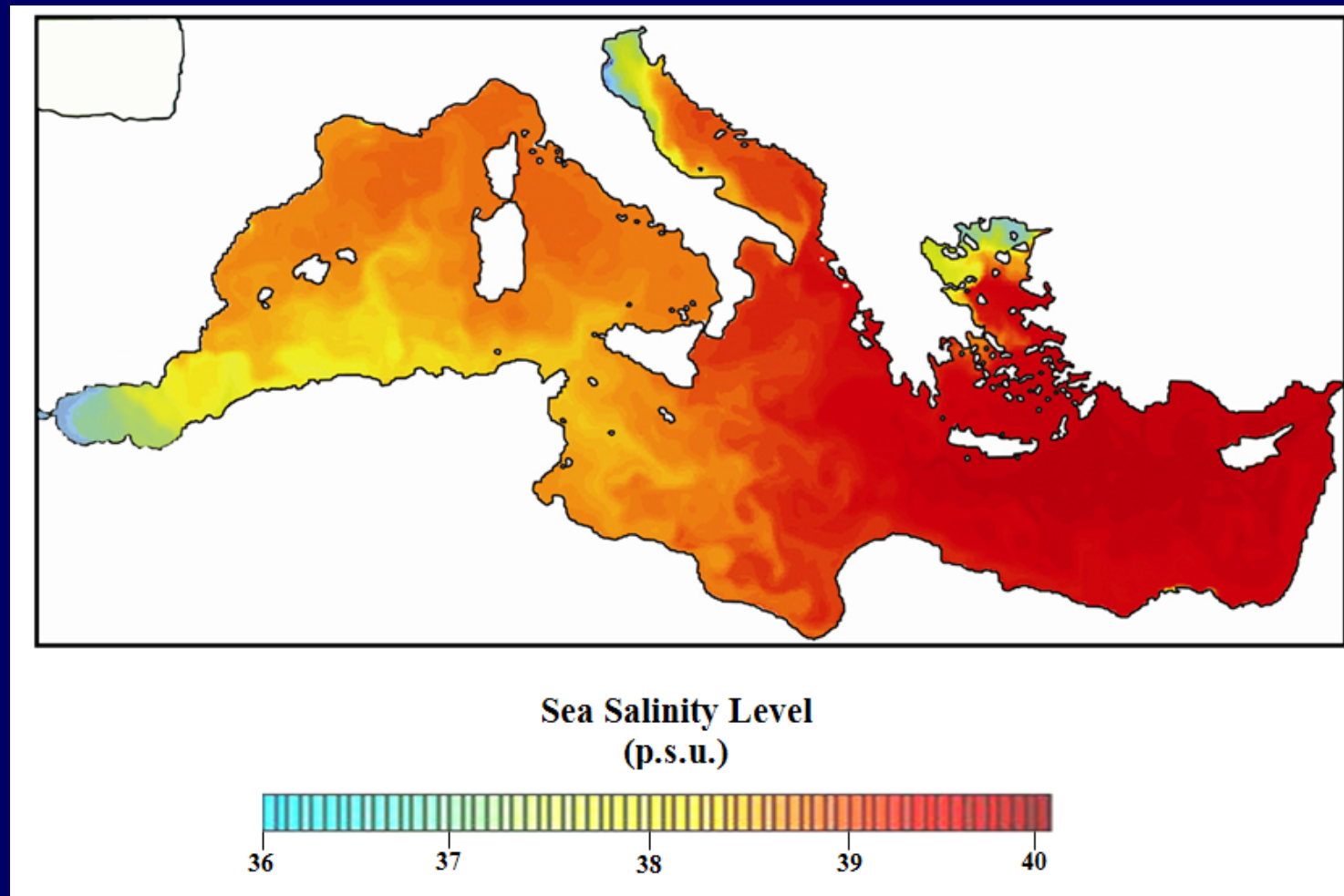
2.5 Billion years ago:

**Fe (−4%) + Ni (−0.8%) =
=Al (+1%) + Si (+2.3%) + Mg (+1.5%)**

Earth's Crust Evolution

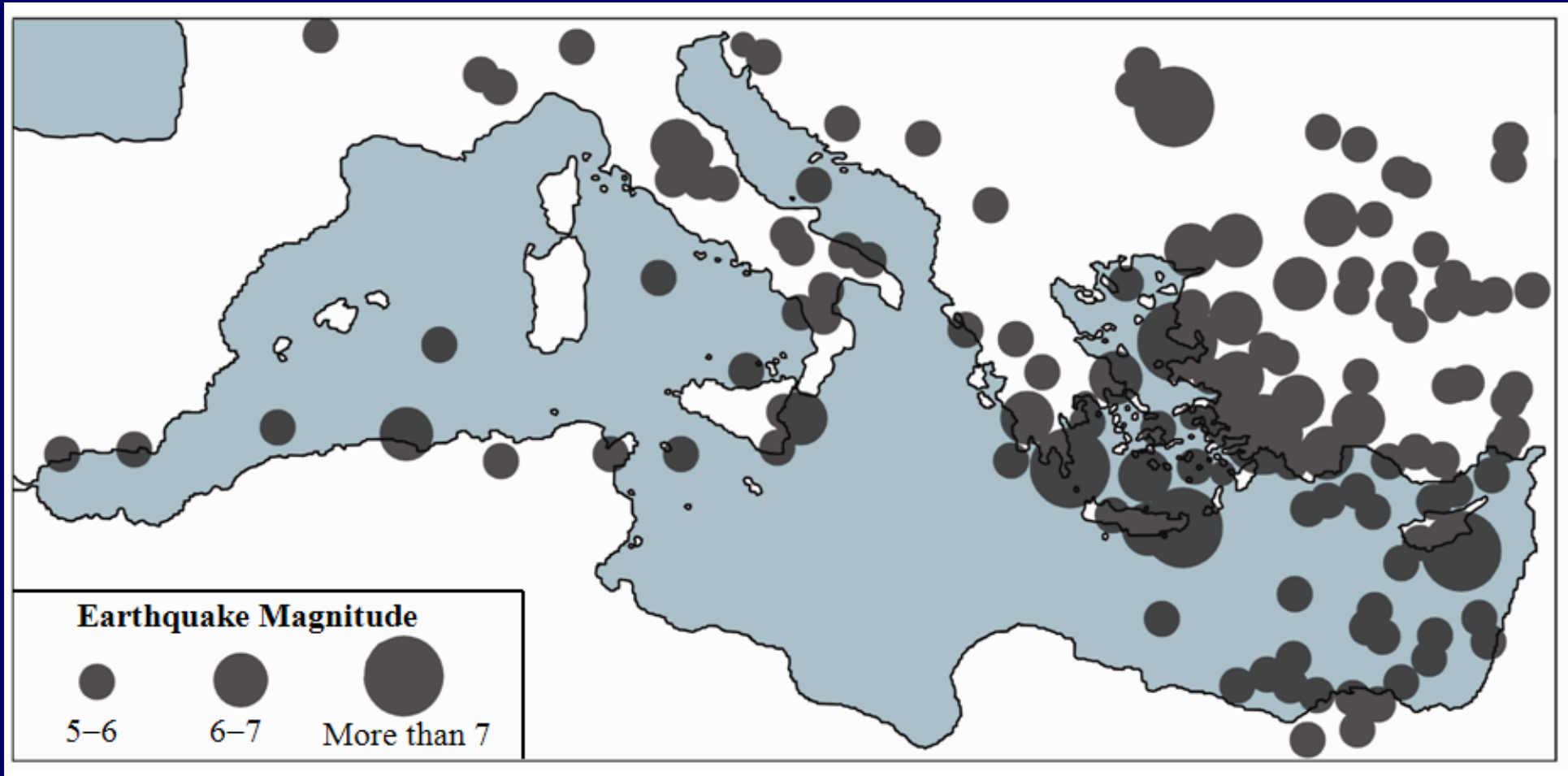


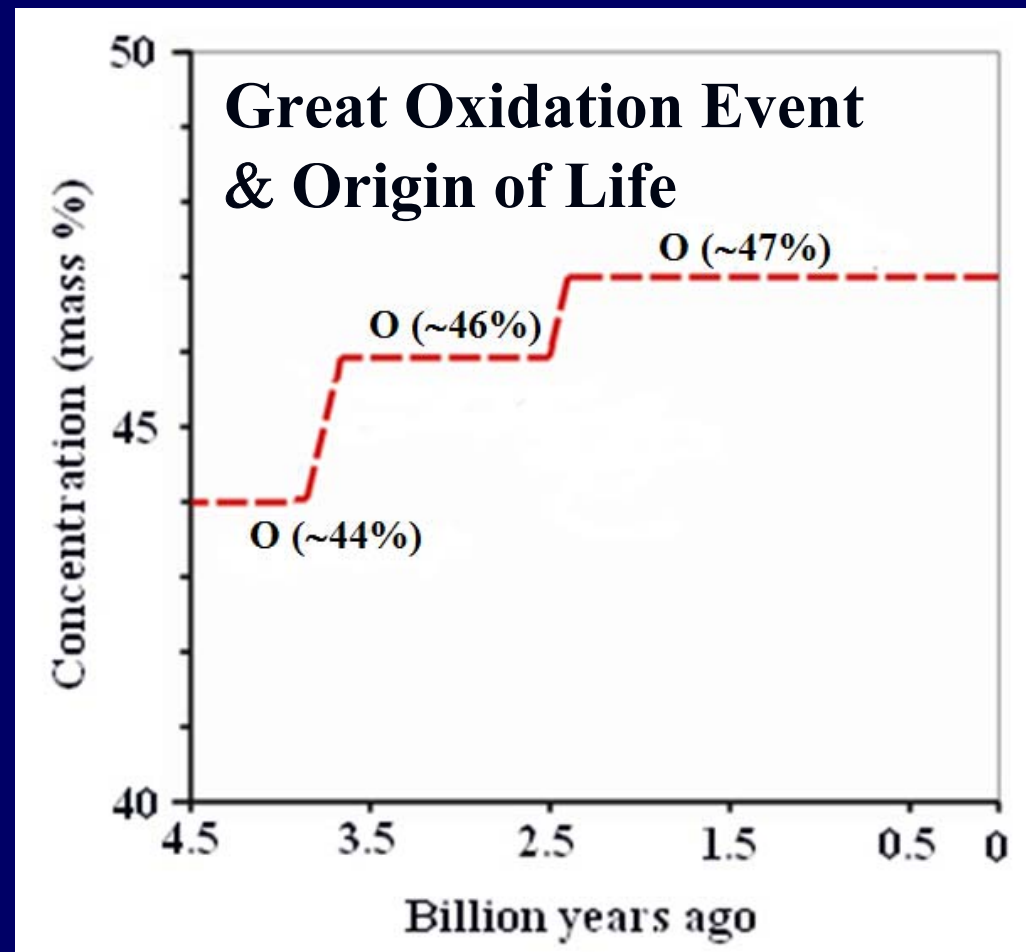
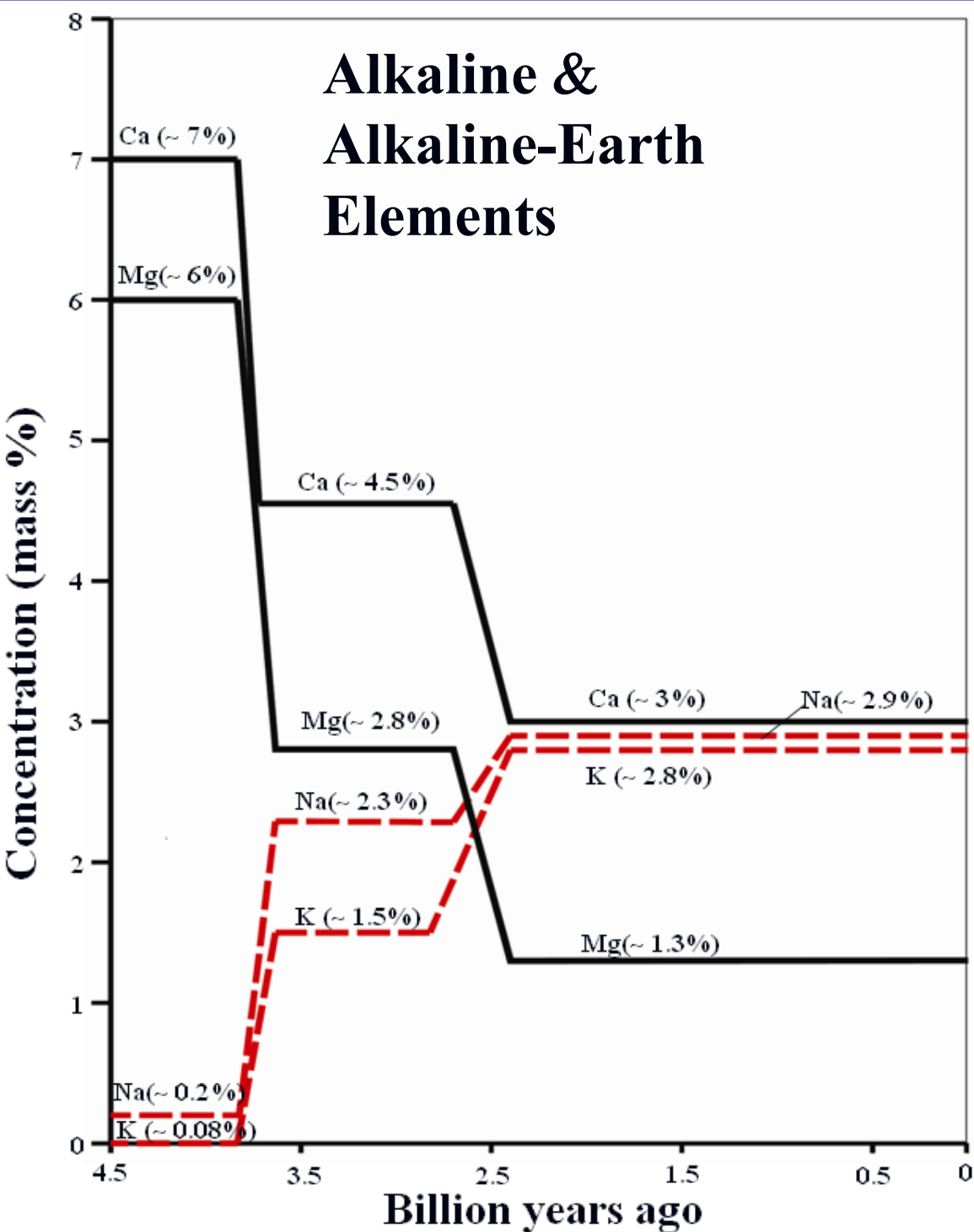
Nickel depletion and salinity level increase in the Mediterranean Sea



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.





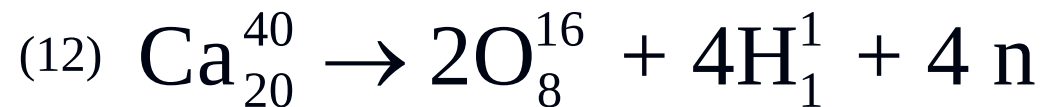
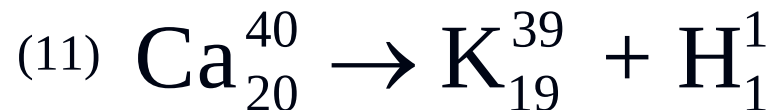
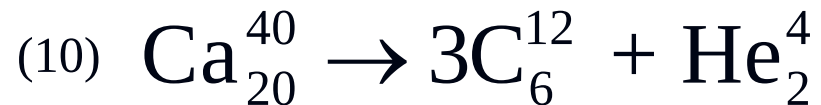
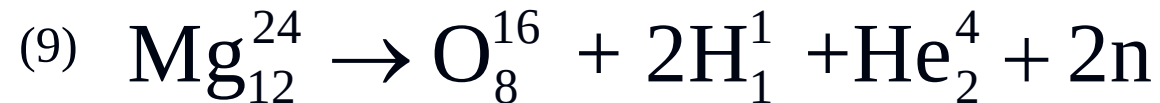
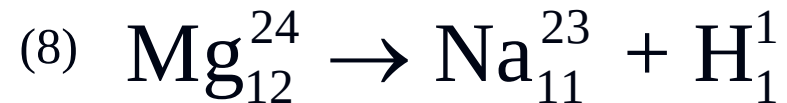
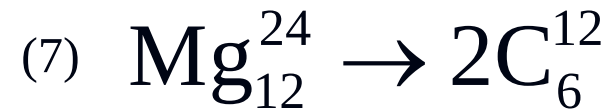
3.8 Billion years ago:

$$\text{Ca } (-2.5\%) + \text{Mg } (-3.2\%) = \text{K } (+1.4\%) + \text{Na } (+2.1\%) + \text{O } (+2.2\%)$$

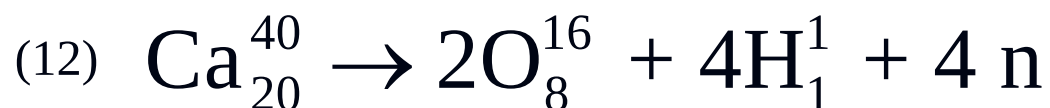
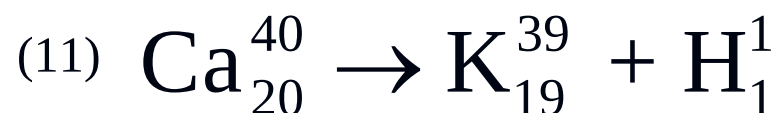
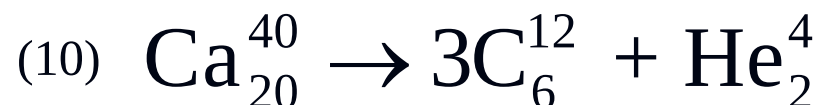
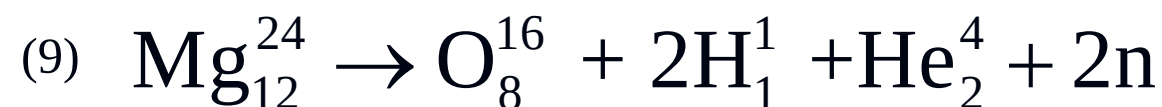
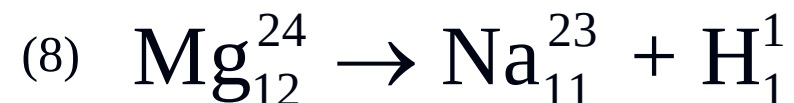
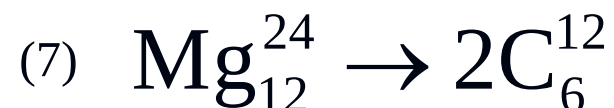
2.5 Billion years ago:

$$\text{Ca } (-1.5\%) + \text{Mg } (-1.5\%) = \text{K } (+1.3\%) + \text{Na } (+0.6\%) + \text{O } (+1.1\%)$$

Atmosphere Evolution, Ocean Formation and Origin of Life



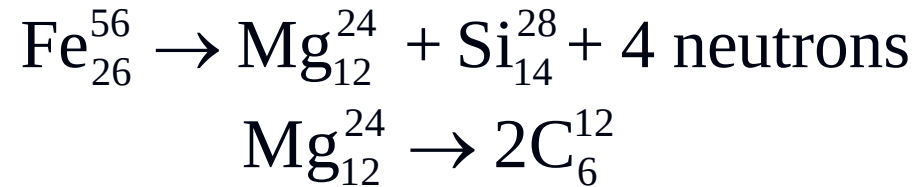
Atmosphere Evolution, Ocean Formation and Origin of Life



**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:



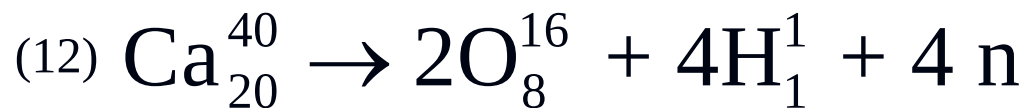
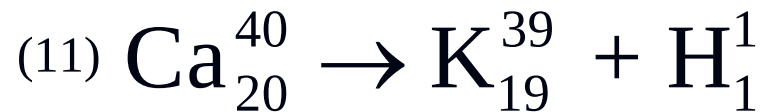
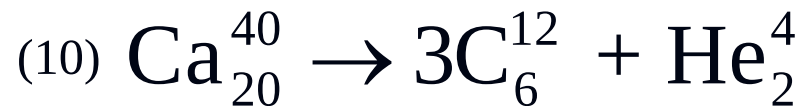
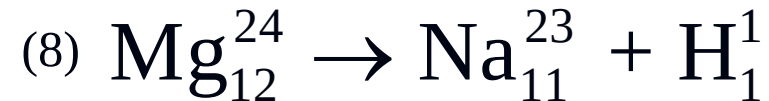
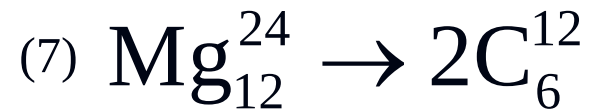
Assuming a mean density of the Earth Crust equal to 3.6 g/cm³ and a thickness of ~60 km, the mass increase in Mg (~3.5×10²¹ kg) implies a very high atmospheric pressure due to the transformed carbon.

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



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

Atmosphere Evolution, Ocean Formation and Origin of Life

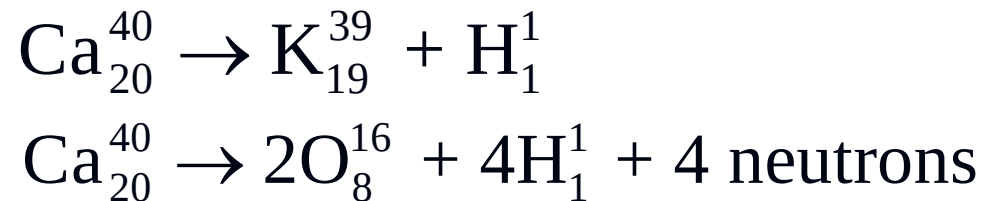


**Ocean
Formation**



Calcium depletion in the Earth Crust and ocean formation

Global decrease in Ca (−4.0%) is counterbalanced by an increase in K (+2.7%) and in H₂O (+1.3%).



Considering a mean density of the Earth Crust equal to 3.6 g/cm³ and an average thickness of ~60 km, the partial mass decrease in Ca is about 1.41×10^{21} kg.

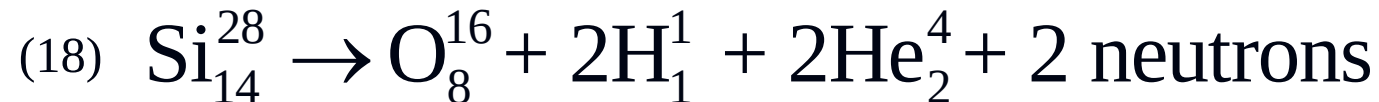
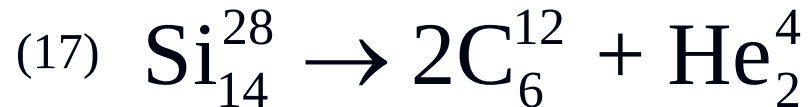
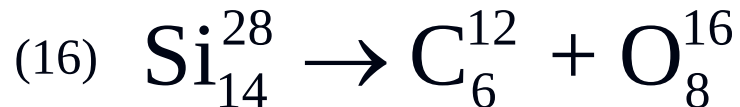
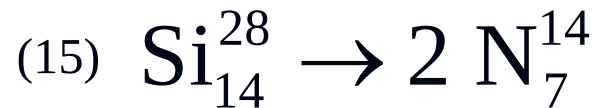
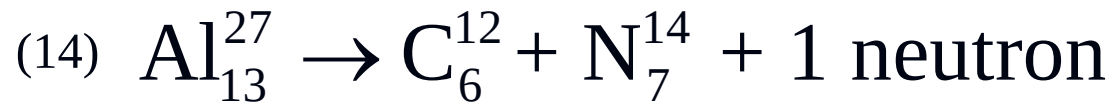
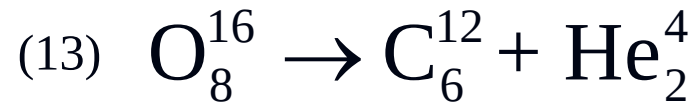
Considering a global ocean surface of 3.607×10^{14} m², and an average depth of 3950 m, we obtain a mass of water of about 1.35×10^{21} kg.

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



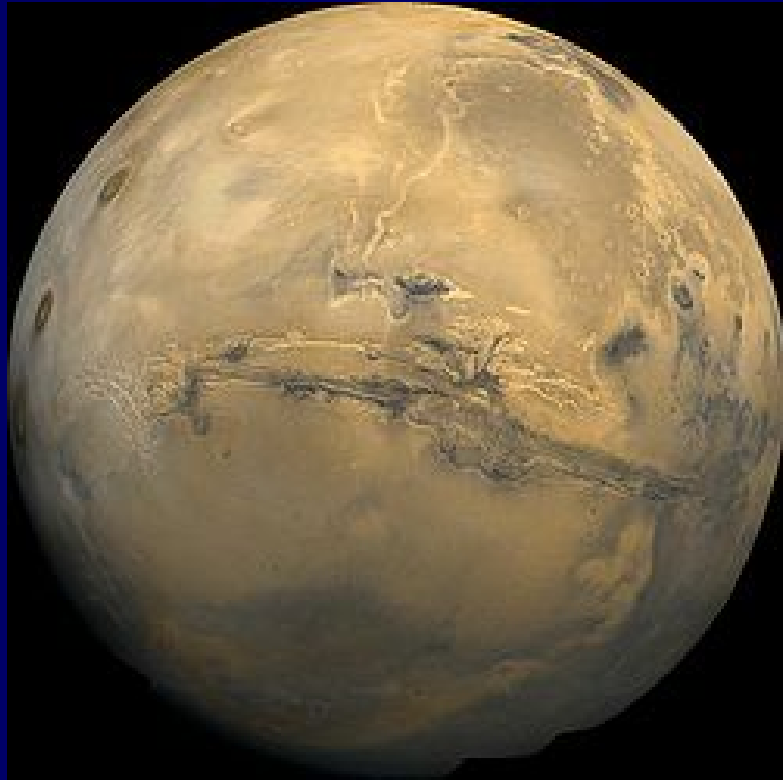
Mass of H₂O in the
oceans today
 1.35×10^{21} kg

Greenhouse Gas Formation



SOLAR SYSTEM EVOLUTION

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



Mars Odyssey, Nasa 2001

Mars Global Surveyor, Nasa 1996

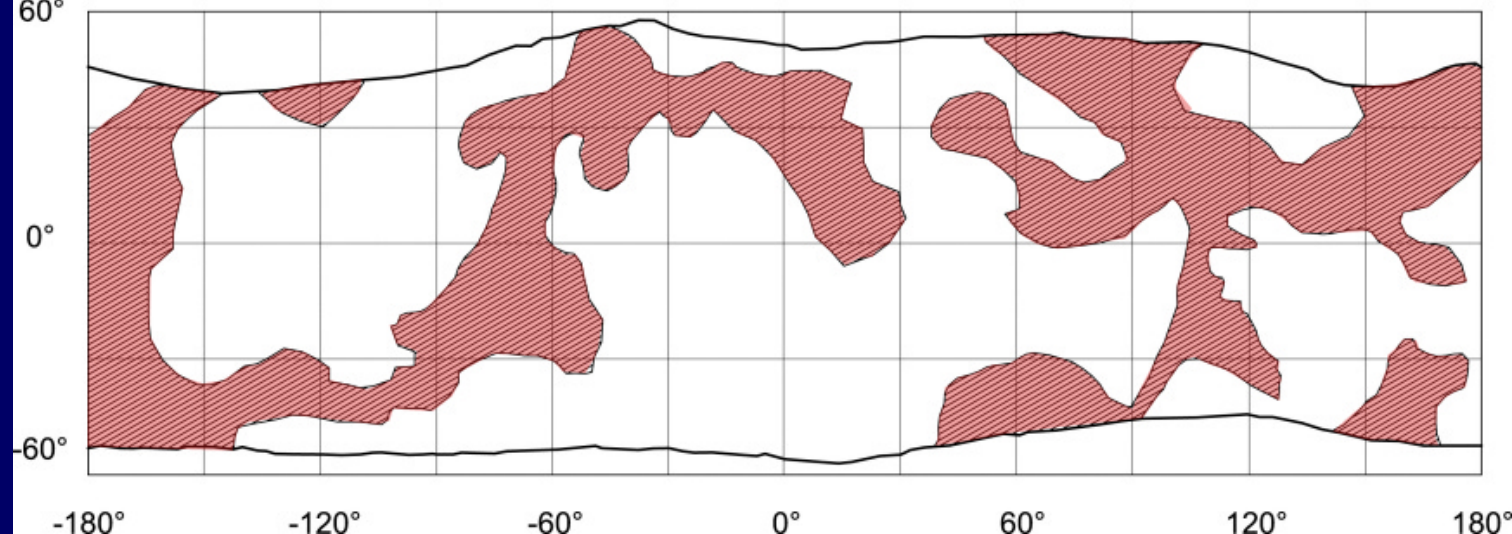
- Seismicity monitoring by the laser altimeter analysis
- Elemental Abundance by the Gamma-Ray Spectrometer
- Neutron Emissions

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

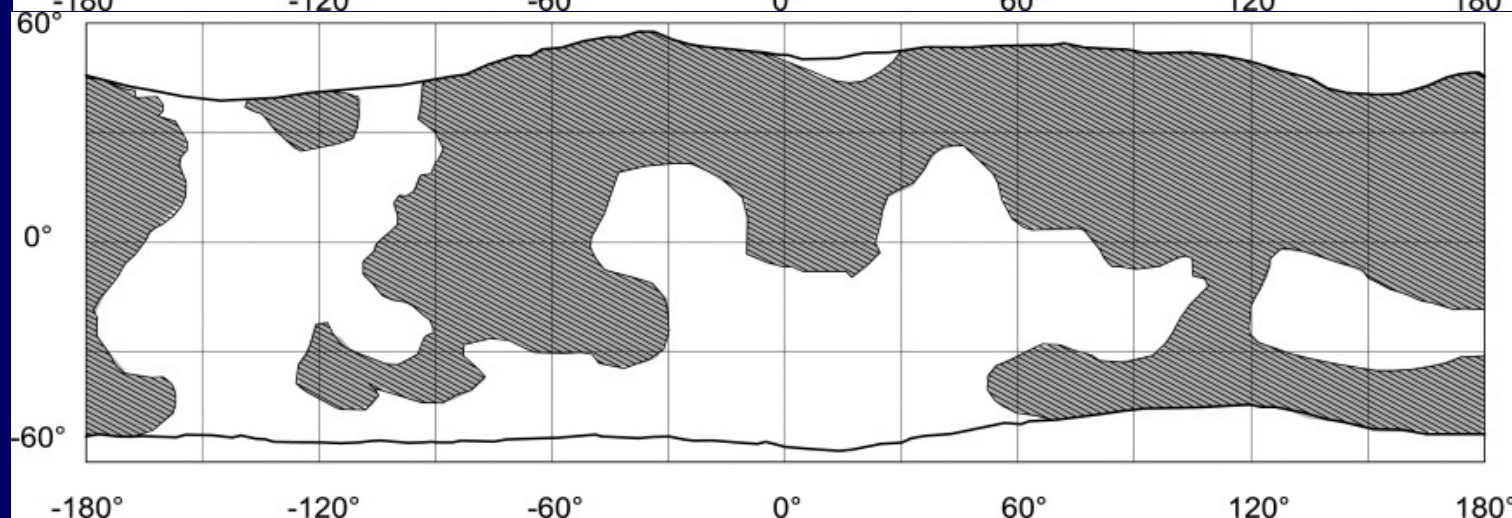
Hahn, B., McLennan, S., "Gamma-Ray Spectrometer Elemental Abundance Correlation with Martian Surface Age: Implication for Martian Crustal Evolution". *Lunar and Planet. Sci.* 37,1904 (2006).

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

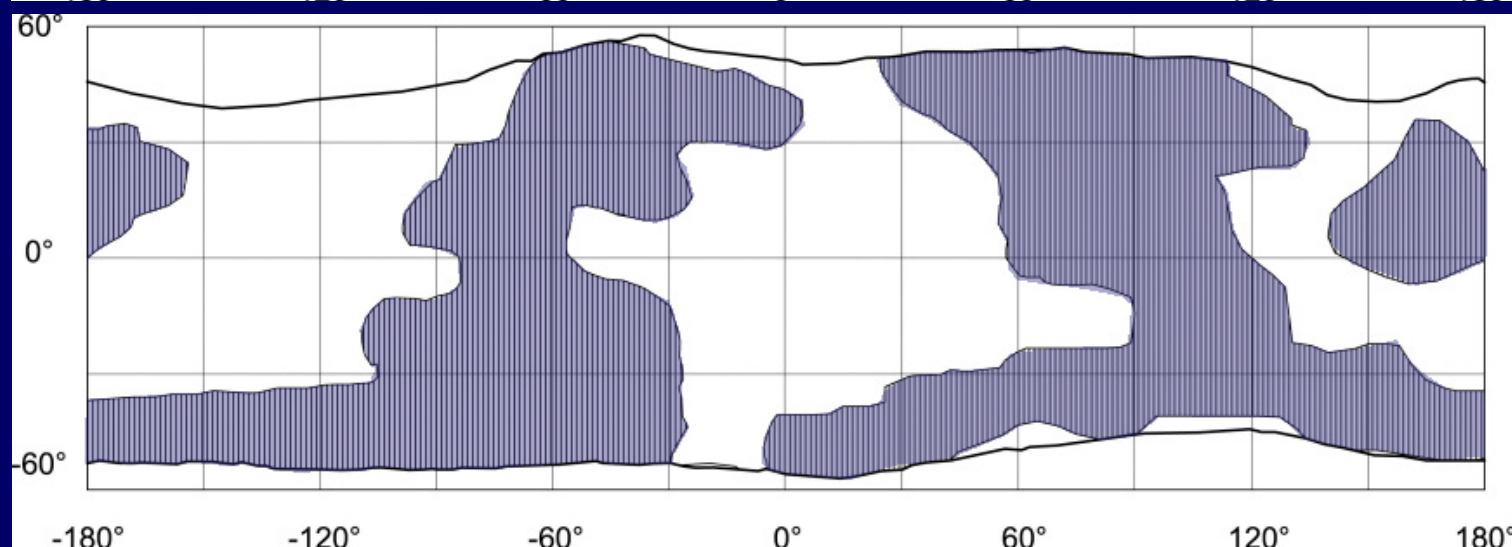
Faults



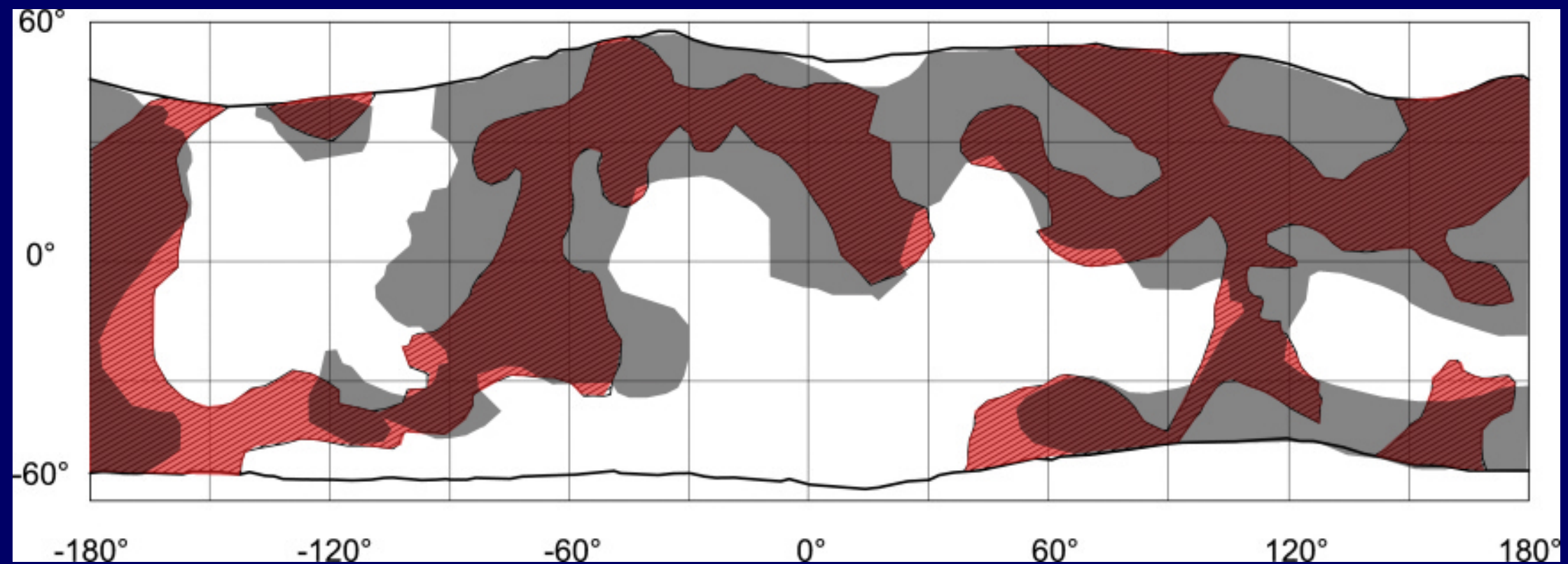
**Iron
($\geq 15\%$)**



**Neutrons
(> 0.18 cps)**



Faults vs Iron

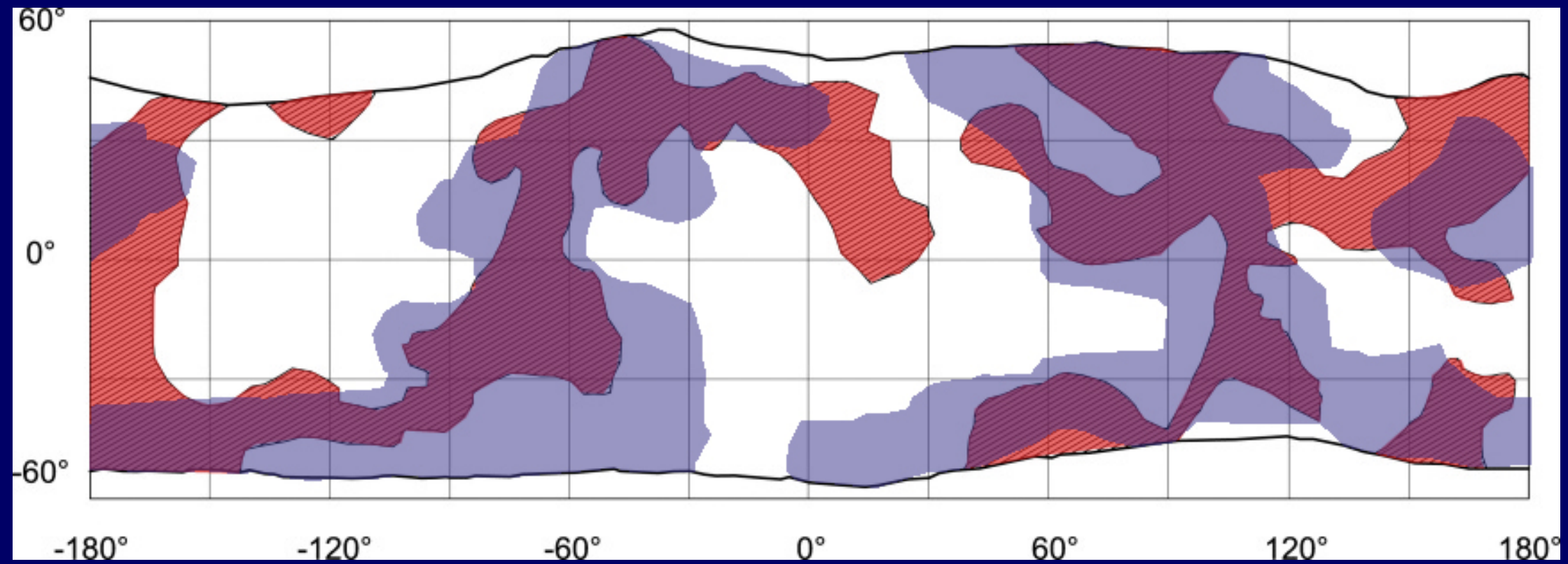


Faults



Iron ($\geq 15\%$)

Faults vs Neutrons

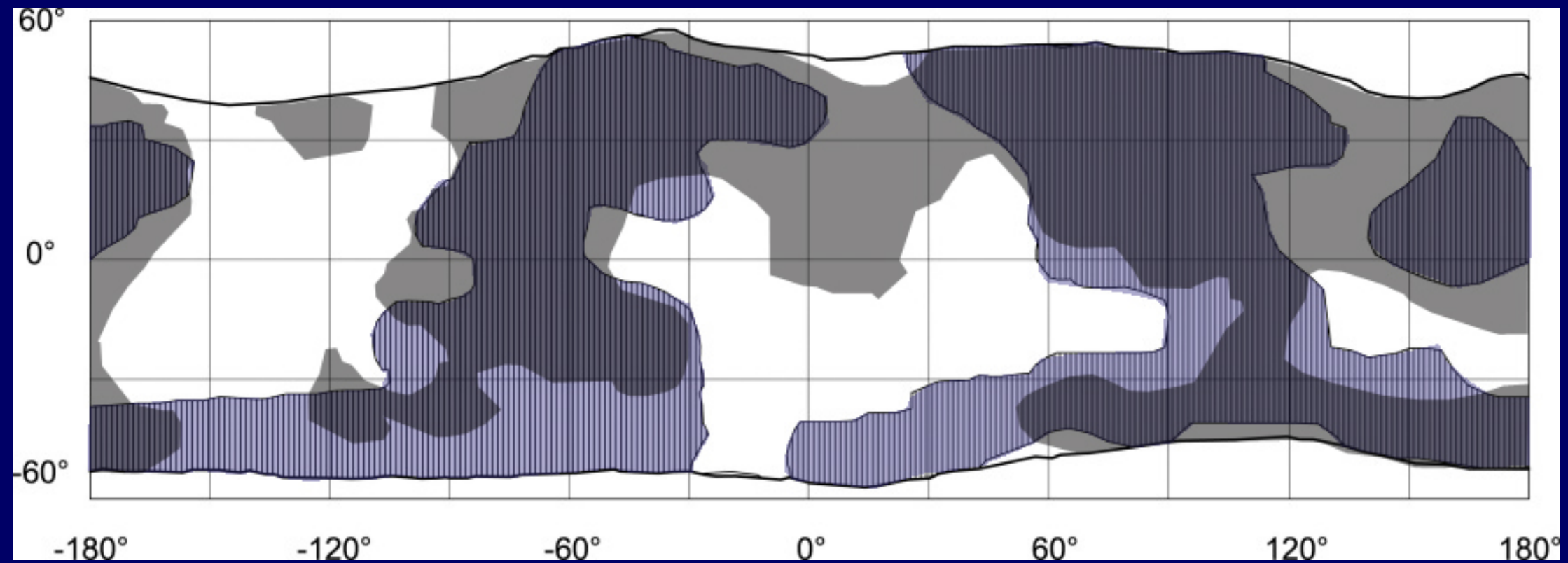


Faults

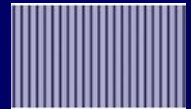


Neutrons (> 0.18 cps)

Iron vs Neutrons

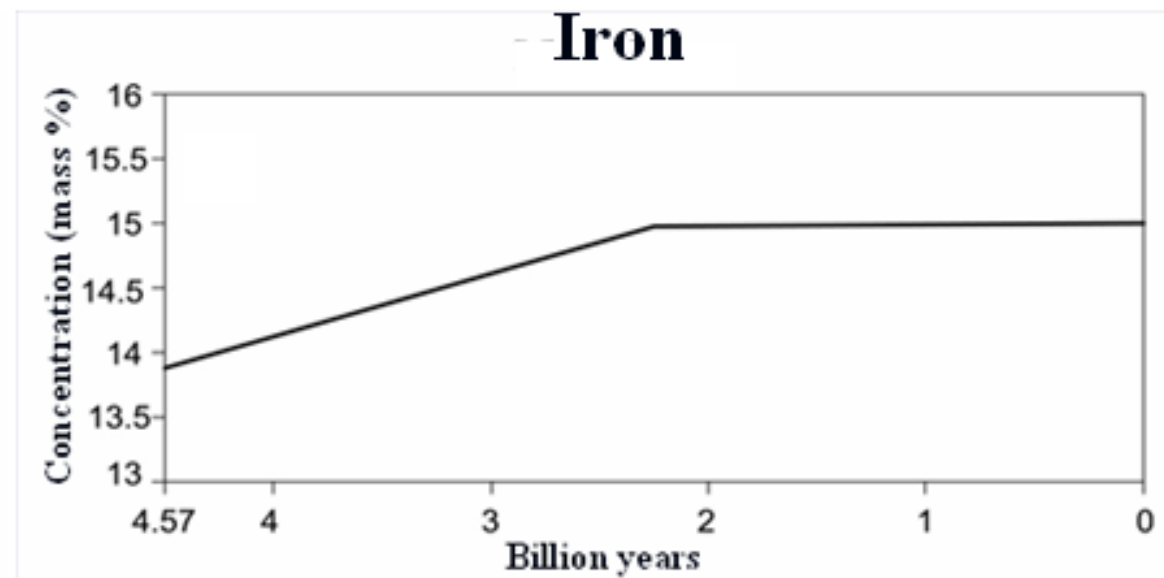
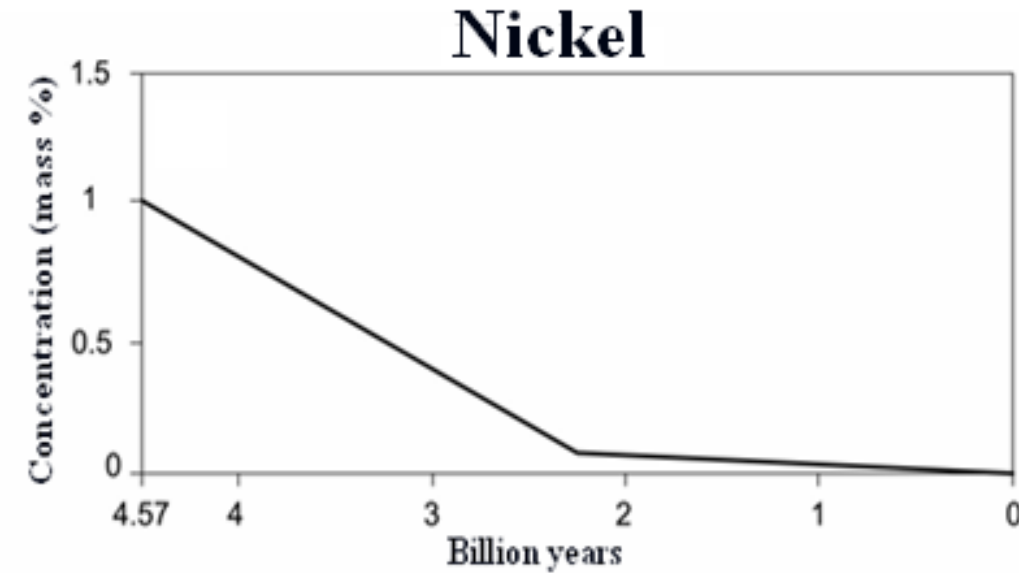


Iron ($\geq 15\%$)

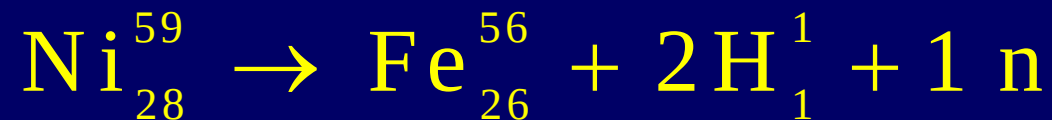


Neutrons (> 0.18 cps)

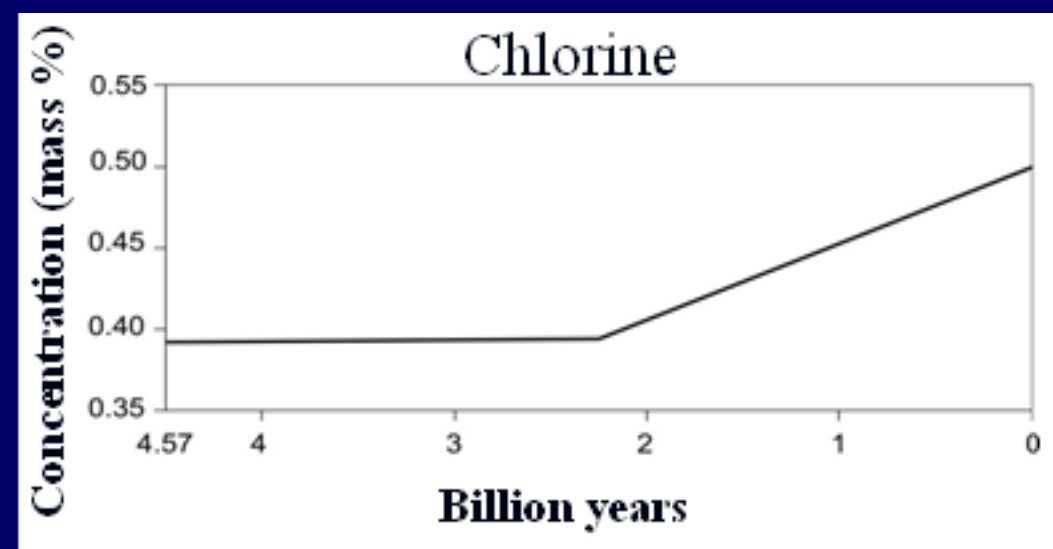
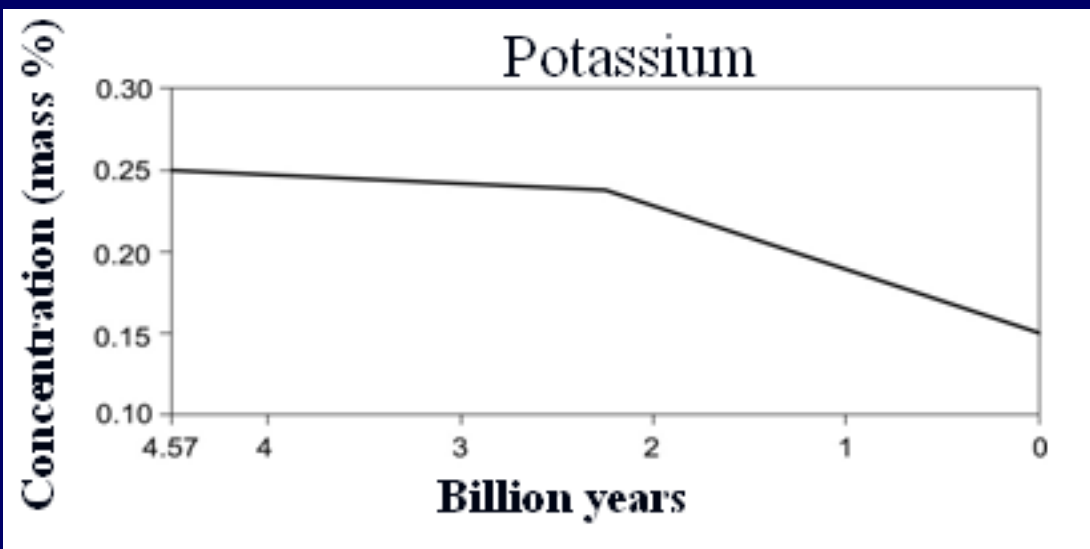
Element evolution on Mars and piezonuclear reactions



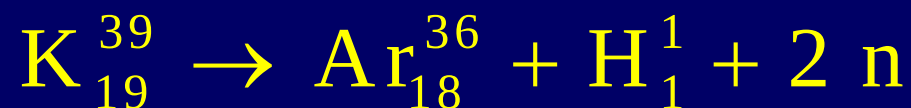
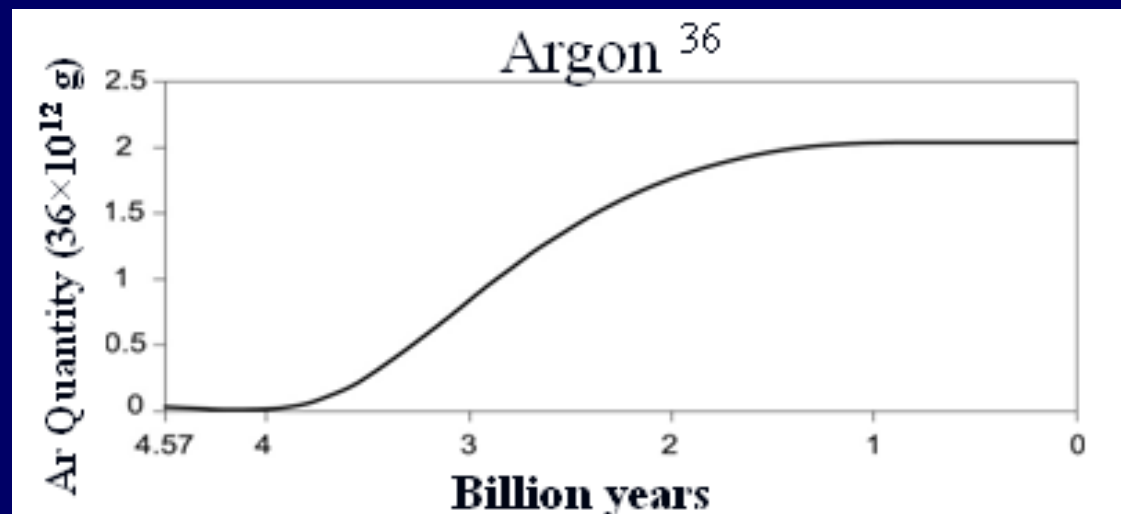
Ni decrease ~ Fe increase ~ 1.0%



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



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



CONCLUSIONS

Two piezonuclear fission reaction jumps typical of the Earth Crust:



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 CO₂ with their effects on global pollution
- Acceleration in the disposal of radioactive wastes
- Clean nuclear energy production (?)