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Reazioni piezonucleari in materiali fragili sottoposti a compressione: Analisi microchimiche ed evidenze alla scala geologica

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PREVIOUS STUDIES

- 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., Cardone, F., Lacidogna, G., “Energy emissions from failure phenomena: Mechanical, electromagnetic, nuclear”. *Experimental Mechanics*, 2009, ISSN: 0014-4851, DOI: 10.1007/s11340-009-9325-7.

- 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).

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Piezonuclear Neutrons From Brittle Fracture: Early Results of Mechanical Compression Tests[1]

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ABSTRACT: Neutron emission measurements by means of helium-3 neutron detectors were performed on solid test specimens during crushing failure. The materials used were marble and granite, selected in that they present a different behaviour in compression failure (i.e. a different brittleness index) and a different iron content. All the test specimens were of the same size and shape. Neutron emissions from the granite test specimens were found to be of about one order of magnitude larger than the natural background level at the time of failure. These neutron emissions were caused by piezonuclear reactions that occurred in the granite, but did not occur in the marble. This is because of the fact that in granite the release rate of accumulated elastic energy ΔE exceeds the power threshold for the generation of piezonuclear reactions, $W_{strong} = 7.69 \times 10^{11}$ W. Moreover, granite contains iron, which has been ascertained to be the most favourable element for the production of piezonuclear reactions when the nuclear interaction energy threshold, $E_{0,strong} = 5.888 \times 10^{-8}$ J, is exceeded in deformed space-time conditions.

KEYWORDS: *catastrophic failure, neutron emission, piezonuclear reactions, rocks crushing failure, size-scale effects in compression*

Introduction

From the studies by Diebner [1], Kaliski [2, 3] and Winterberg [4], it is known that piezonuclear reactions can be obtained in solid radioactive materials in which neutron production is catalysed by pressure. Later on, Arata [5, 6] conducted experiments showing the possibility of piezonuclear reactions taking place in gaseous materials made up of deuterium gas, and Taleyarkhan [7] showed that neutron-emitting piezonuclear reactions may occur in deuterium-containing liquids with radioactive substances dissolved in them. Finally, piezonuclear reactions with neutron emissions were produced in iron-containing inert liquids without deuterium and without radioactive substances [8–10]. Accordingly, tests were conducted to assess neutron production from piezonuclear reactions in solids subjected to compression till failure. These experiments are based on the following phenomenological analogy. In the tests described in [7, 9, 10], the pressure of ultrasonic waves in a liquid was seen to cause the cavitation of the gases dissolved therein, resulting in the speed of energy threshold for nuclear interaction W_{strong} being exceeded, with the ensuing production of piezonuclear reactions [7, 8] and neutron emissions. It was hypothesised that the fracture of solid materials was able to reproduce the cavitation conditions of liquids and hence lead to the production of piezonuclear reactions, provided that the materials were properly selected. The materials selected for the tests were Carrara marble (calcite) and green Luserna granite (gneiss). This choice was prompted by the consideration that, test specimen dimensions being the same, different brittleness numbers [11] would cause catastrophic failure in granite, not in marble. The test specimens were subjected to uniaxial compression to assess scale effects on brittleness [12]. Four test specimens were used, two made of Carrara marble, consisting mostly of calcite, and two made of Luserna granite, all of them measuring $6 \times 6 \times 10$ cm^3 (Figure 1). The same testing machine was used on all the test specimens: a standard servo-hydraulic press with a maximum capacity of 500 kN, equipped with control electronics (Figure 1B). This machine makes it possible to carry out tests in either load control or displacement control. The tests were performed in piston travel displacement control by setting, for all the

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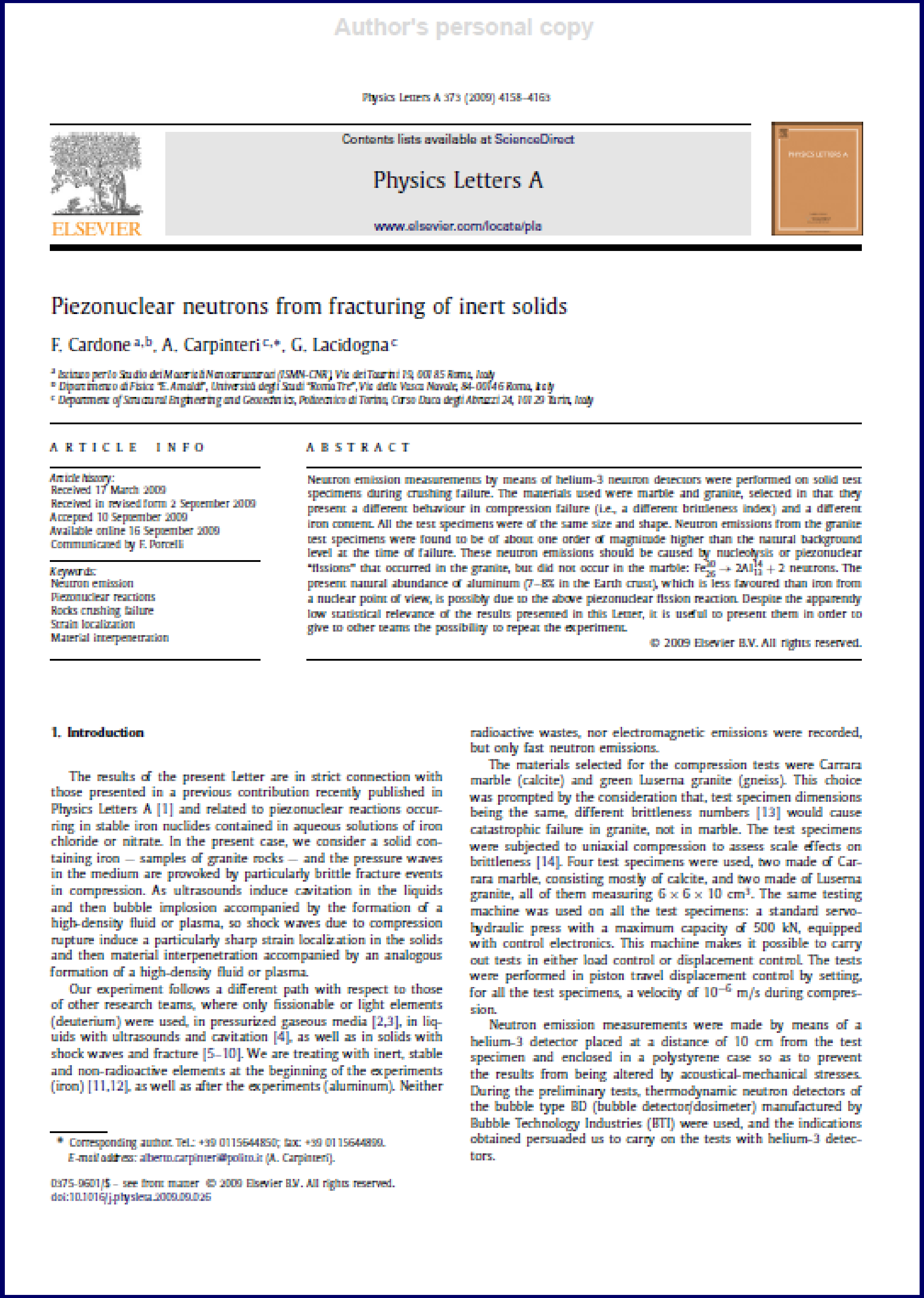
[1] Presented at the Turin Academy of Sciences on December 10, 2008.

Carpinteri, A., Cardone, F., Lacidogna, G., “Piezonuclear neutrons from brittle fracture: Early results of mechanical compression tests”, *Strain*, 45, 332-339 (2009).



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Piezonuclear neutrons from fracturing of inert solids

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ABSTRACT

Neutron emission measurements by means of helium-3 neutron detectors were performed on solid test specimens during crushing failure. The materials used were marble and granite, selected in that they present a different behaviour in compression failure (i.e., a different brittleness index) and a different iron content. All the test specimens were of the same size and shape. Neutron emissions from the granite test specimens were found to be of about one order of magnitude higher than the natural background level at the time of failure. These neutron emissions should be caused by nucleolysis or piezonuclear "fissions" that occurred in the granite, but did not occur in the marble: $\mathrm{Fe}^{30}_{26} \to 2\mathrm{Al}^{14}_{13} + 2$ neutrons. The present natural abundance of aluminum (7–8% in the Earth crust), which is less favoured than iron from a nuclear point of view, is possibly due to the above piezonuclear fission reaction. Despite the apparently low statistical relevance of the results presented in this Letter, it is useful to present them in order to give to other teams the possibility to repeat the experiment.

1. Introduction

The results of the present Letter are in strict connection with those presented in a previous contribution recently published in Physics Letters A [1] and related to piezonuclear reactions occurring in stable iron nuclides contained in aqueous solutions of iron chloride or nitrate. In the present case, we consider a solid containing iron – samples of granite rocks – and the pressure waves in the medium are provoked by particularly brittle fracture events in compression. As ultrasounds induce cavitation in the liquids and then bubble implosion accompanied by the formation of a high-density fluid or plasma, so shock waves due to compression rupture induce a particularly sharp strain localization in the solids and then material interpenetration accompanied by an analogous formation of a high-density fluid or plasma.

Our experiment follows a different path with respect to those of other research teams, where only fissionable or light elements (deuterium) were used, in pressurized gaseous media [2,3], in liquids with ultrasounds and cavitation [4], as well as in solids with shock waves and fracture [5–10]. We are treating with inert, stable and non-radioactive elements at the beginning of the experiments (iron) [11,12], as well as after the experiments (aluminum). Neither radioactive wastes, nor electromagnetic emissions were recorded, but only fast neutron emissions.

The materials selected for the compression tests were Carrara marble (calcite) and green Luserna granite (gneiss). This choice was prompted by the consideration that, test specimen dimensions being the same, different brittleness numbers [13] would cause catastrophic failure in granite, not in marble. The test specimens were subjected to uniaxial compression to assess scale effects on brittleness [14]. Four test specimens were used, two made of Carrara marble, consisting mostly of calcite, and two made of Luserna granite, all of them measuring 6 × 6 × 10 cm^3. The same testing machine was used on all the test specimens: a standard servo-hydraulic press with a maximum capacity of 500 kN, equipped with control electronics. This machine makes it possible to carry out tests in either load control or displacement control. The tests were performed in piston travel displacement control by setting, for all the test specimens, a velocity of 10^{-6} m/s during compression.

Neutron emission measurements were made by means of a helium-3 detector placed at a distance of 10 cm from the test specimen and enclosed in a polystyrene case so as to prevent the results from being altered by acoustical-mechanical stresses. During the preliminary tests, thermodynamic neutron detectors of the bubble type BD (bubble detector/dosimeter) manufactured by Bubble Technology Industries (BTI) were used, and the indications obtained persuaded us to carry on the tests with helium-3 detectors.

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Cardone, F., Carpinteri, A., Lacidogna, G.,"Piezonuclear neutrons from fracturing of inert solids", *Physics Letters A*, 373, 4158-4163 (2009).

EXPERIMENTAL SETUP

The materials used were marble and granite, selected in that they present a different behaviour in compression failure (i.e., a different brittleness index) and a different iron content. All the test specimens were of the same size and shape.

Neutron emission measurements by means of helium-3 neutron detectors and neutron bubble detector were performed on solid test specimens during crushing failure.

Neutron emissions from the granite test specimens were found to be about one order of magnitude larger than the natural background level at the time of failure.

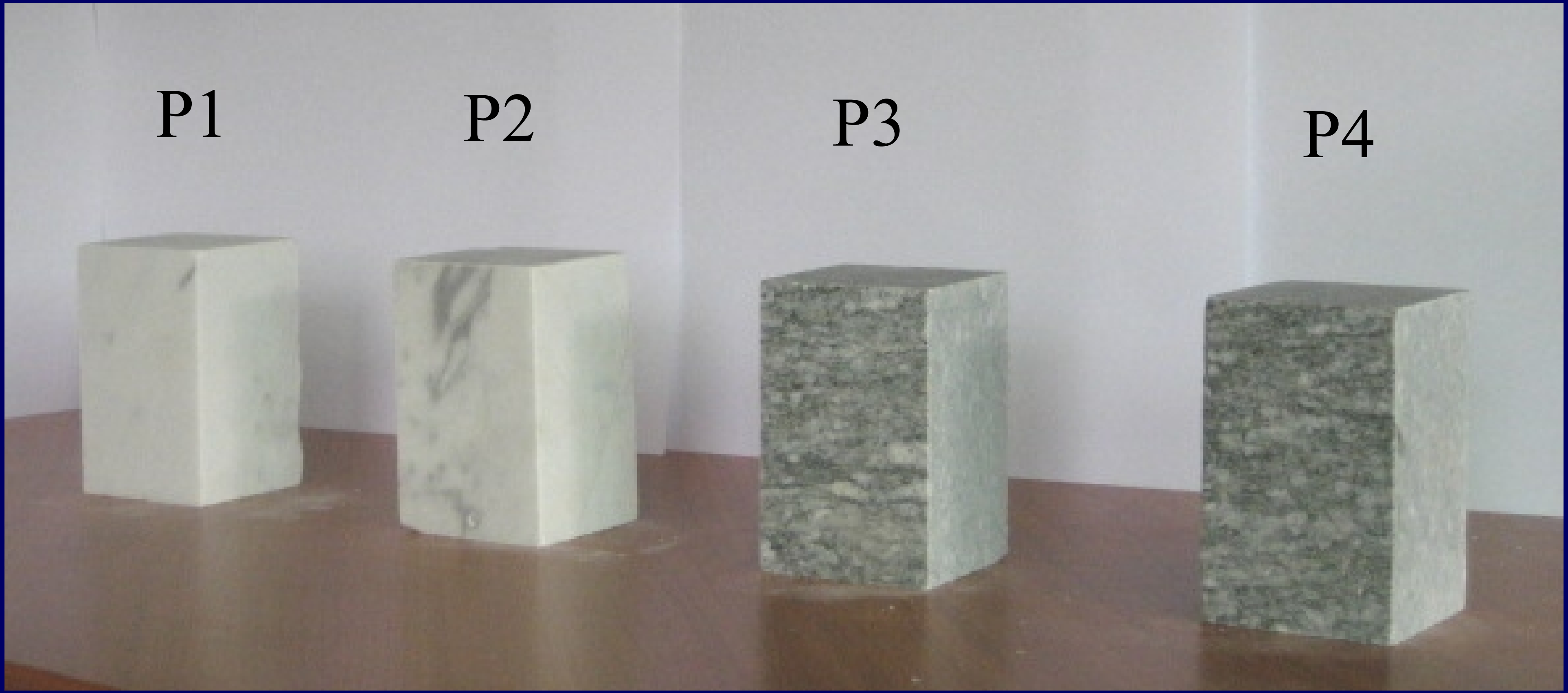
These neutron emissions were caused by piezonuclear reactions that occurred in the granite, but did not occur in the marble.

Specimens

During the experimental analysis four test specimens were used:

- two made of Carrara marble, calcite, specimens P1 and P2;
- two made of Luserna granite, gneiss, specimens P3 and P4;
- all of them measuring 6x6x10 cm3.

This choice was prompted by the consideration that, test specimen dimensions being the same, different brittleness numbers would cause catastrophic failure in granite, not in marble.

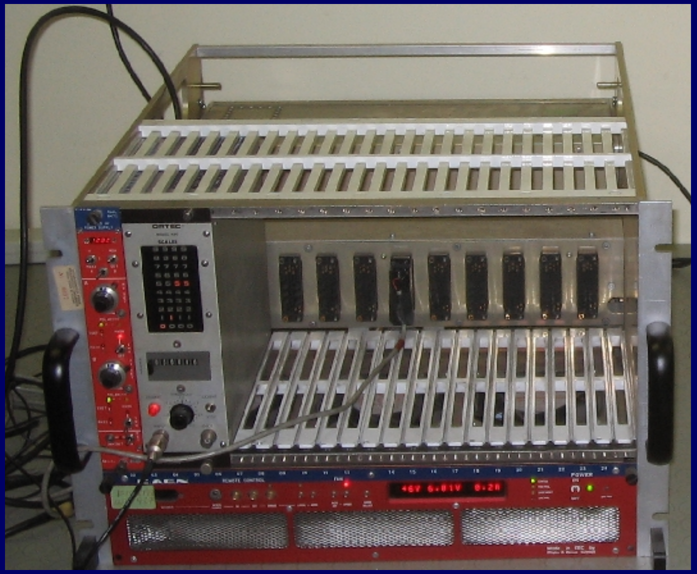


Testing Machine

The same testing machine was used on all the test specimens: a standard servo-hydraulic press Baldwin with a maximum capacity of 500 kN, equipped with control electronics.

The tests were performed in piston travel displacement control by setting, for all the test specimens, a velocity of 10^{-6} m/s during compression.

Neutron Detectors – $_{3}$He detector

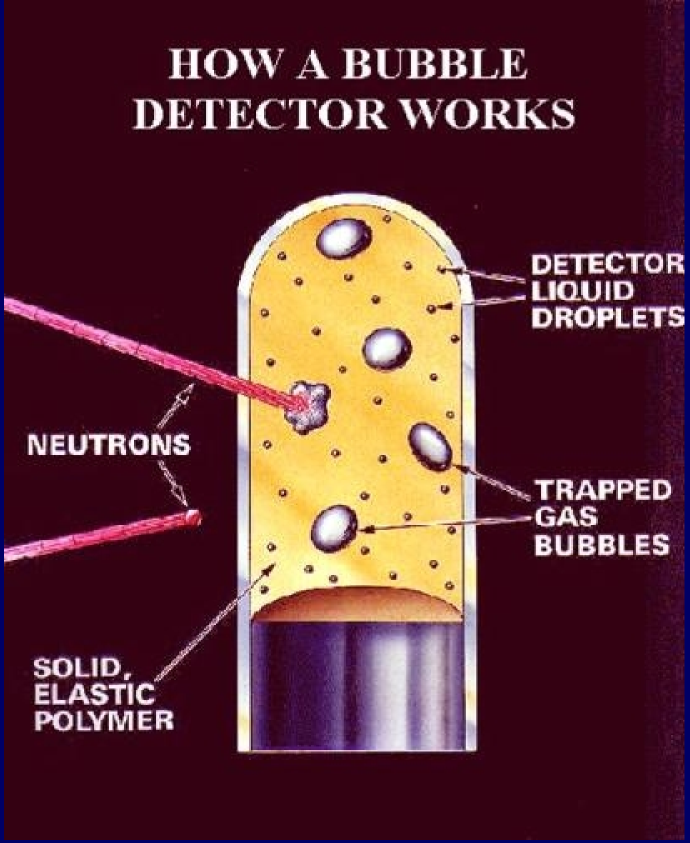


Natural radionuclide in rocks composition, mainly due to:

Ra-226 (125 Bq/Kg, decay gamma energy 186.1 keV),
Th-232 (114 Bq/Kg, decay gamma energy 63.81 keV and 140.88 keV),
K-40 (1276 Bq/Kg, decay gamma energy 1460.83 keV).

The logic output discrimination threshold on the $_{3}$He proportional counter is fixed to 300 mV. This value was determined by measuring the analog signal of the detector by means of a Co-60 gamma source type decay: beta-, beta maximum energy: 317.8 keV, gammas: 1173.2 keV and 1332.5 keV.

The neutron detectors used are designed and manufactured under a quality system, in compliance with the standard requirements provided by the International Electrotechnical Commission for EMI (Electro-Magnetic Interference). In particular, the instruments used are insensitive to electromagnetic noise in the frequency range from 150 kHz to 230 MHz,



The deposition of energy of the charged particles produced by interactions of incident neutrons, generates local regions of high energy density that cause local vaporization

$$\boxed{G = 4\pi r^2 \gamma(T) - 4/3\pi r^3 (p_v - p_0)\ ,}$$

$\gamma(T)$ = liquid-vapour interfacial tension,
p_v = vapour pressure of the superheated liquid, p_0 = ambient pressure.

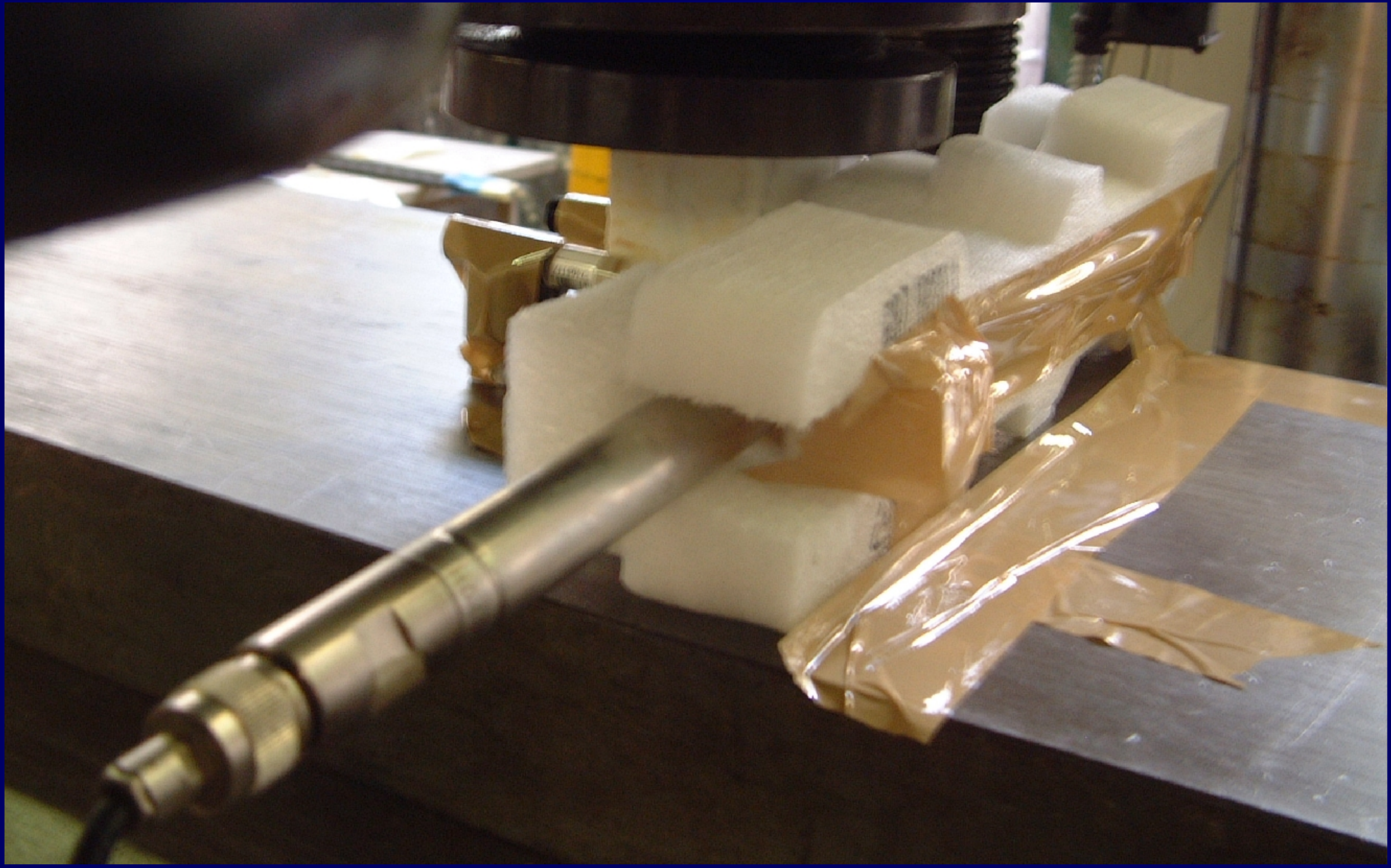
G is maximum for: $r = 2\gamma(T)/\,(p_v - p_0) = r_c$,

The energy deposition path is linked to the critical radius by a factor ranging from 2 to 12.96.

Neutron Detectors

Neutron emission measurements were made by means of a helium-3 detector placed at a distance of 10 cm from the test specimen.

The detector was enclosed in a polystyrene case to prevent the results from being altered by impacts and vibrations.



NEUTRON EMISSION MEASUREMENTS

Before the loading tests

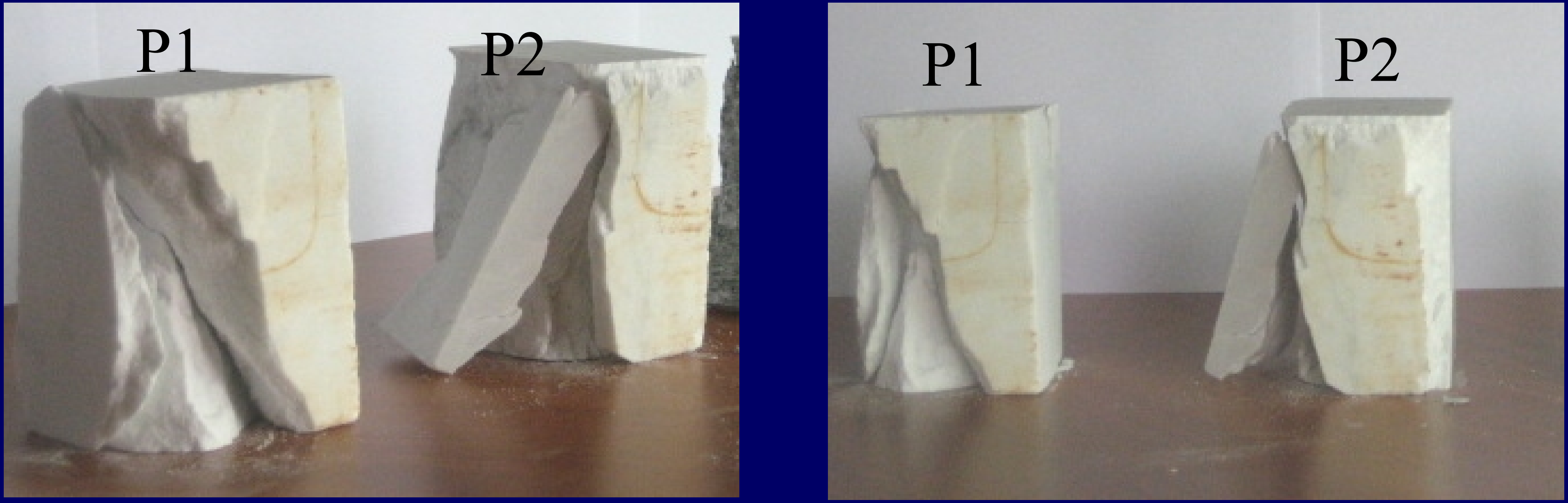
The neutron background was measured at 600 s time intervals to obtain sufficient statistical data with the detector in the position shown in the previous figure.

The average background count rate was:

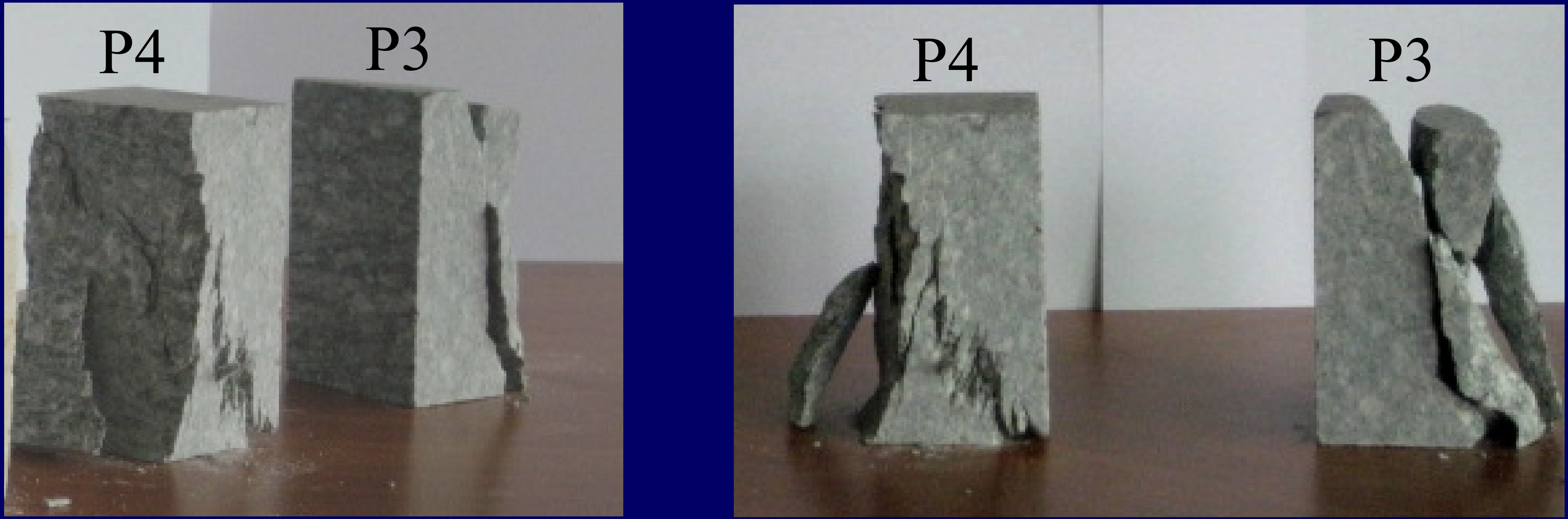
$$3.8\times10^{-2} \pm 0.2\times10^{-2} \text{ cps.}$$

During the loading tests

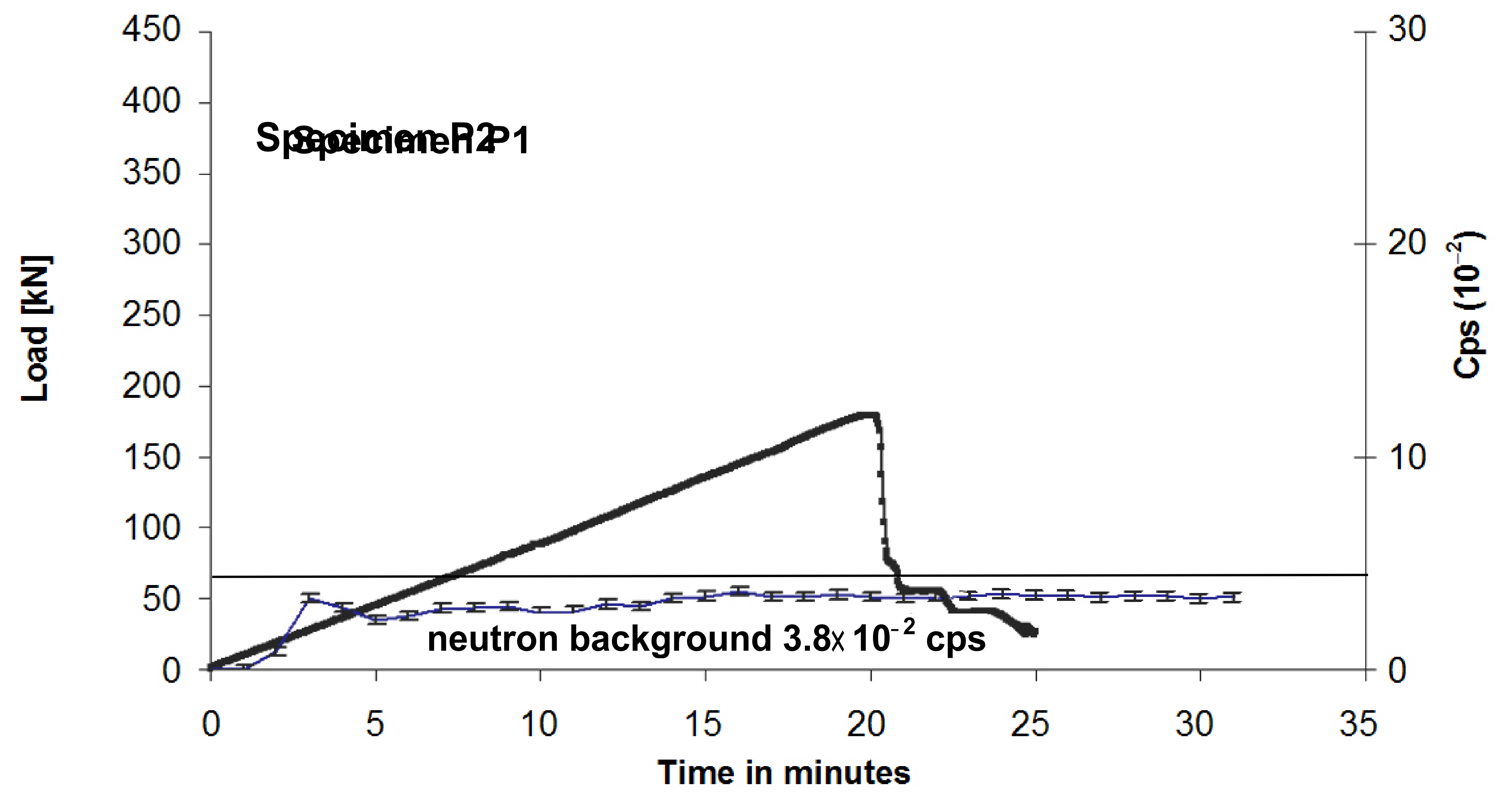
- The neutron measurements obtained on the two Carrara marble specimens yielded values comparable with the background, even at the time of test specimen failure.
- The neutron measurements obtained on the two Luserna granite specimens, instead, exceeded the background value by about one order of magnitude at the test specimen failure.



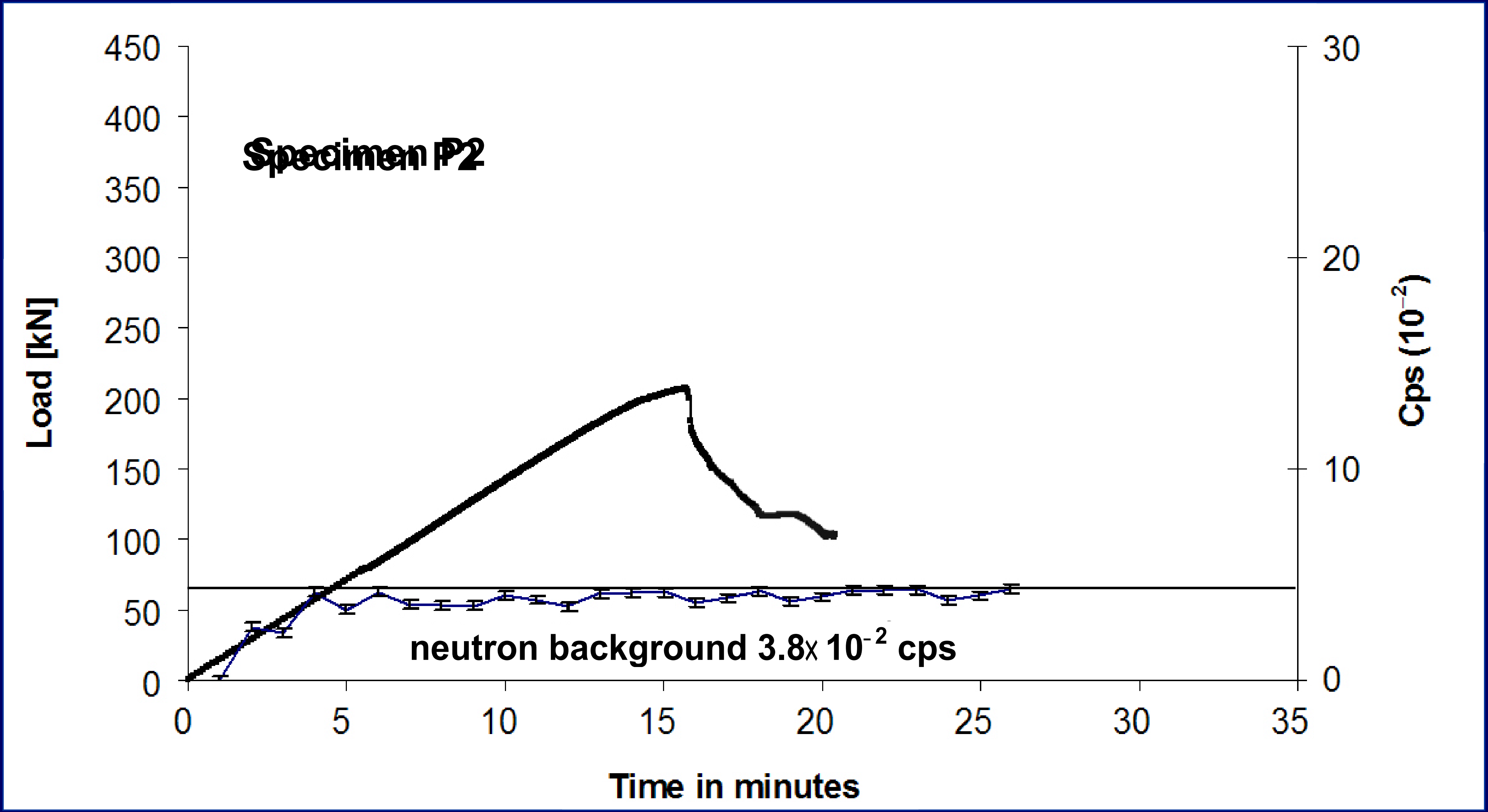
Specimens P1 and P2 in Carrara marble following compression failure.



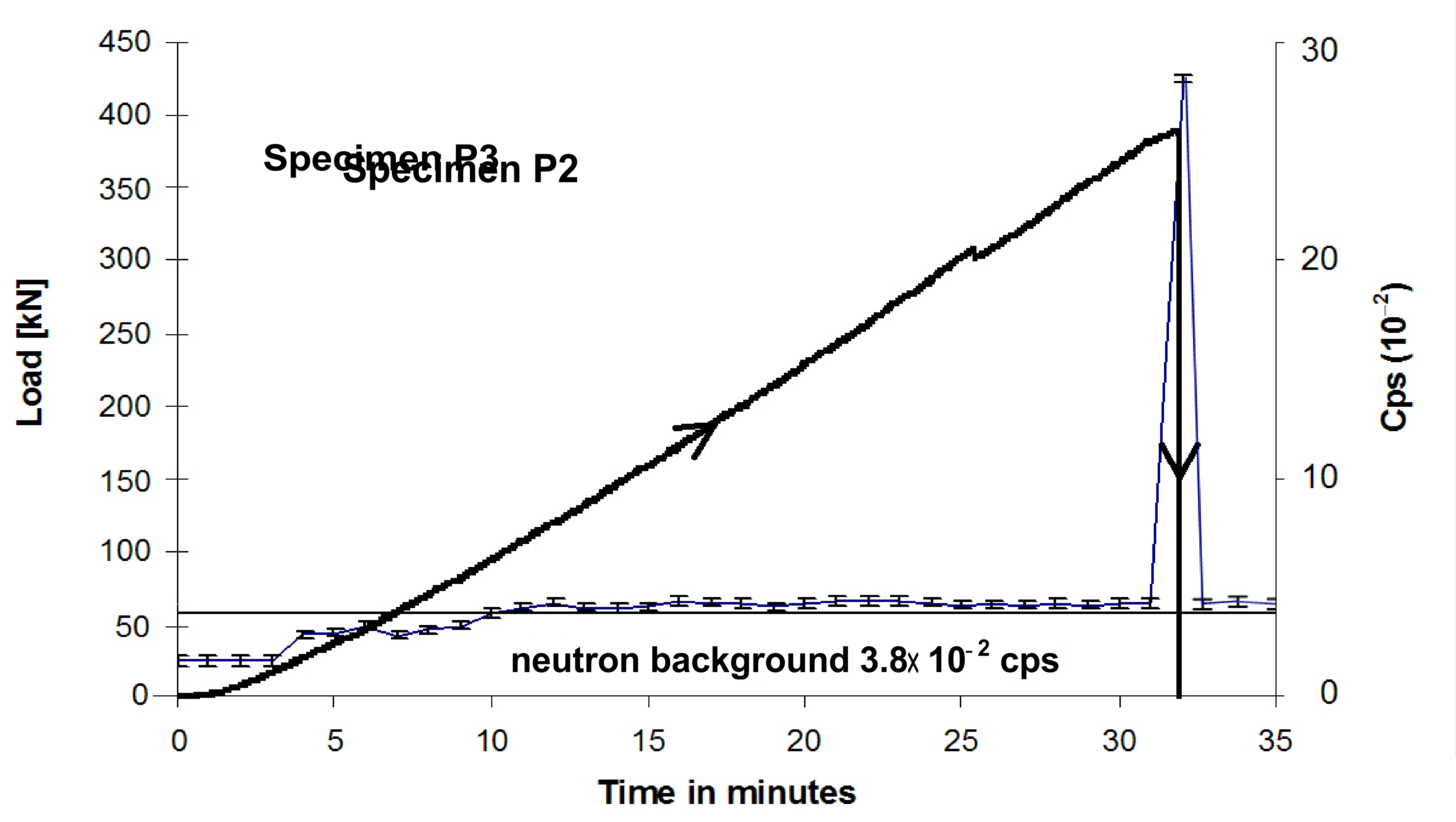
Specimens P3 e P4 in Luserna granite following compression failure.



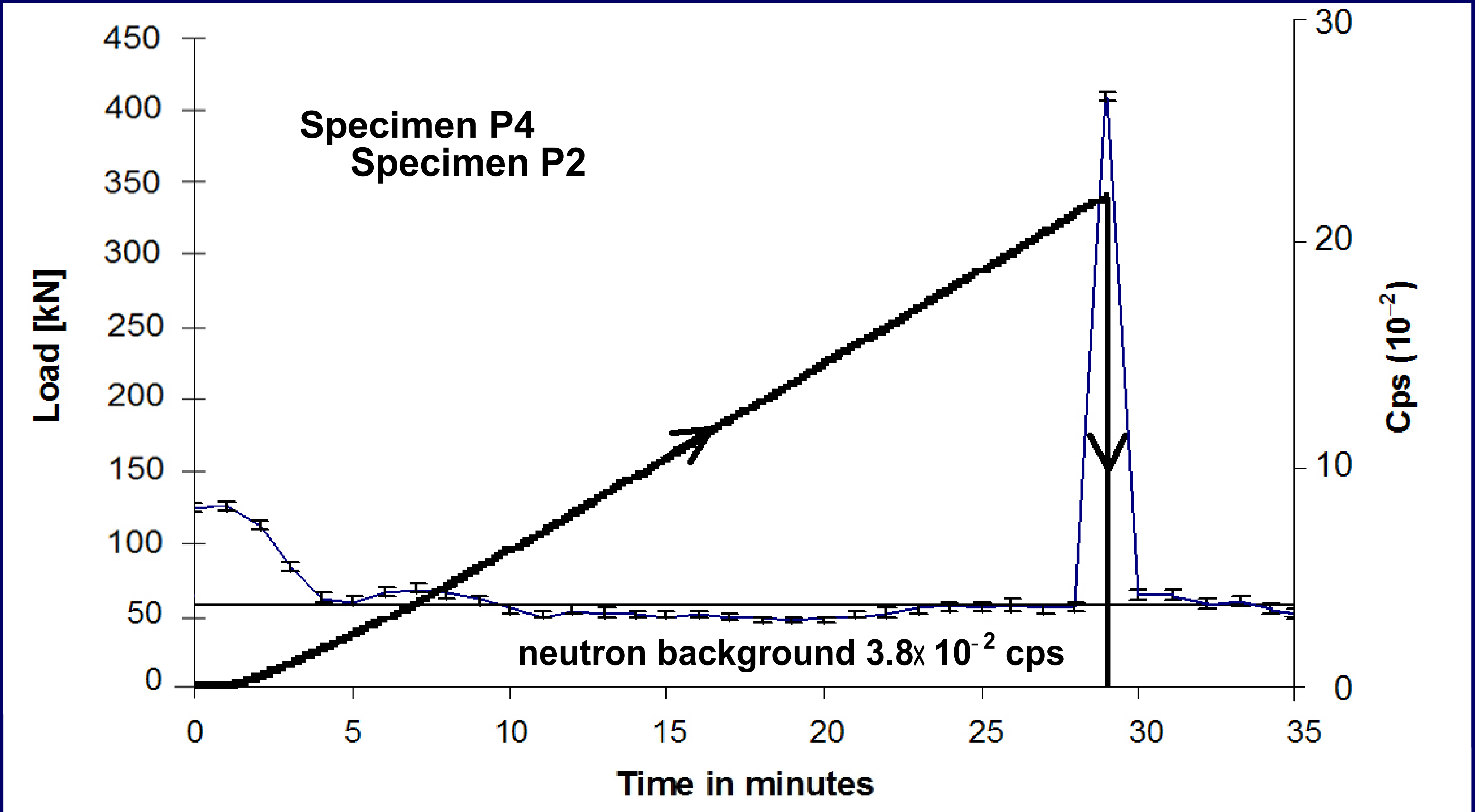
Load vs. time and cps curve for P1 test specimen in Carrara marble.



Load vs. time and cps curve for P2 test specimen in Carrara marble.



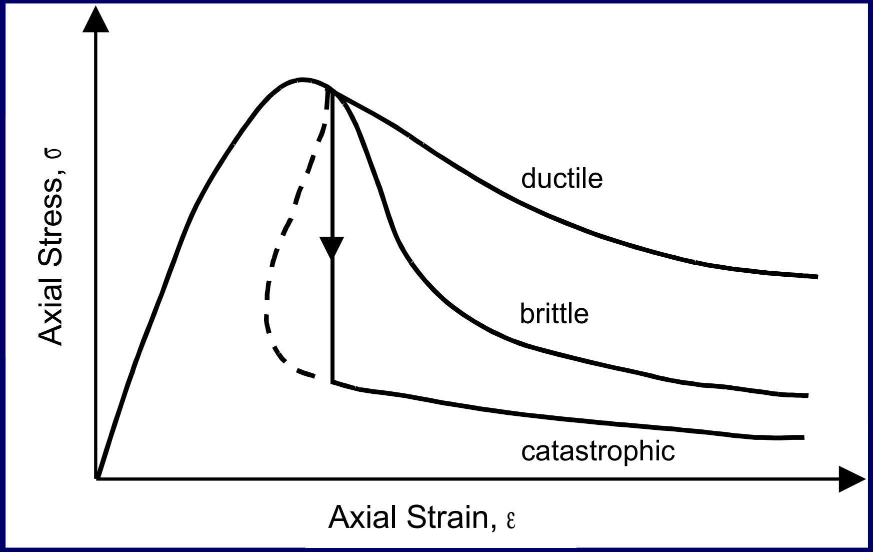
Load vs. time and cps curve for P3 test specimen in Luserna granite.

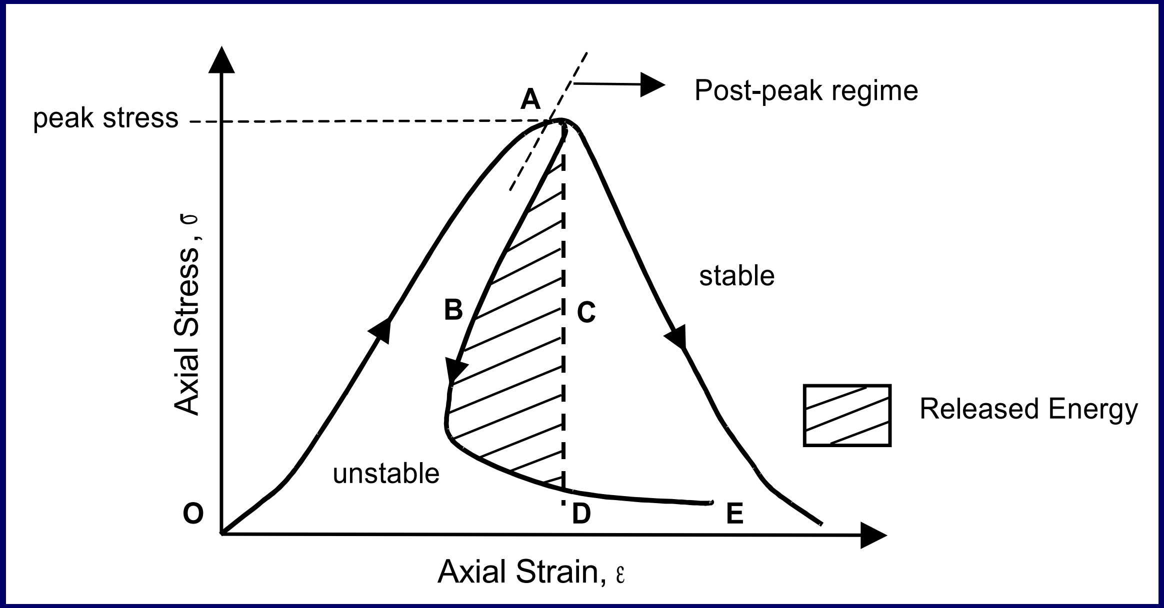


Load vs. time and cps curve for P4 test specimen in Luserna granite.

Two views of neutron detection by thermodynamic detectors
type BD (bubble detector/dosimeter)
manufactured by Bubble Technology Industries (BTI)

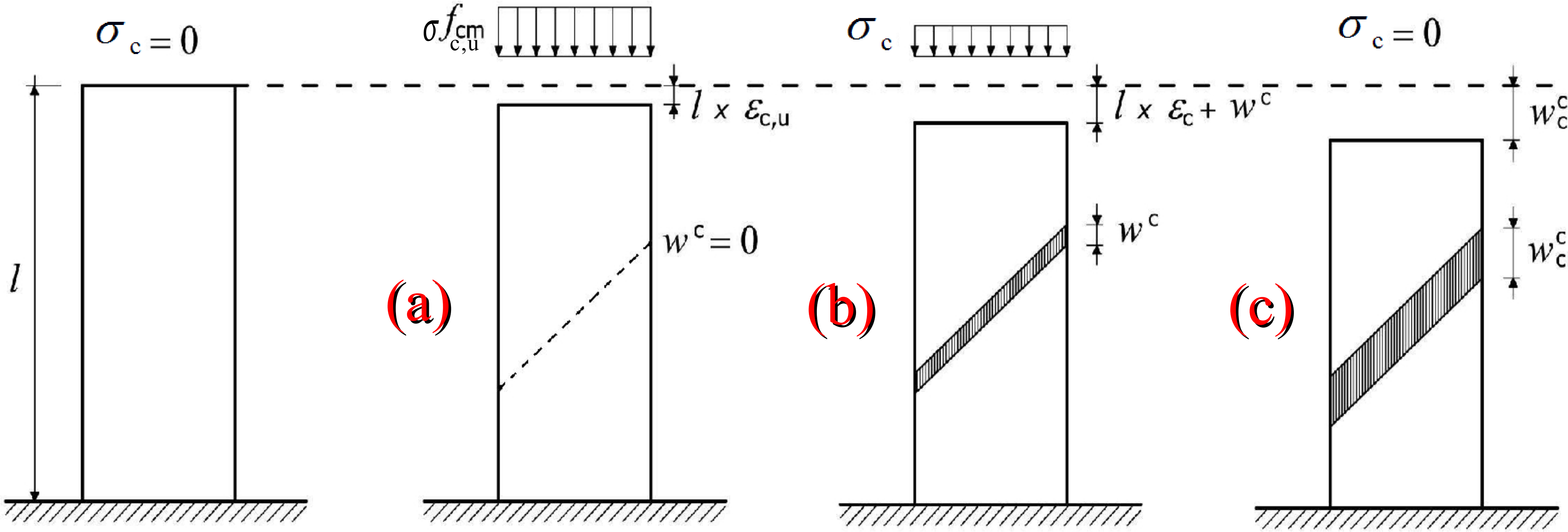
DUCTILE, BRITTLE AND CATASTROPHIC BEHAVIOUR





Energy release and stable vs. unstable stress-strain behaviour

Subsequent stages in the deformation history of a specimen in compression(I) (II)

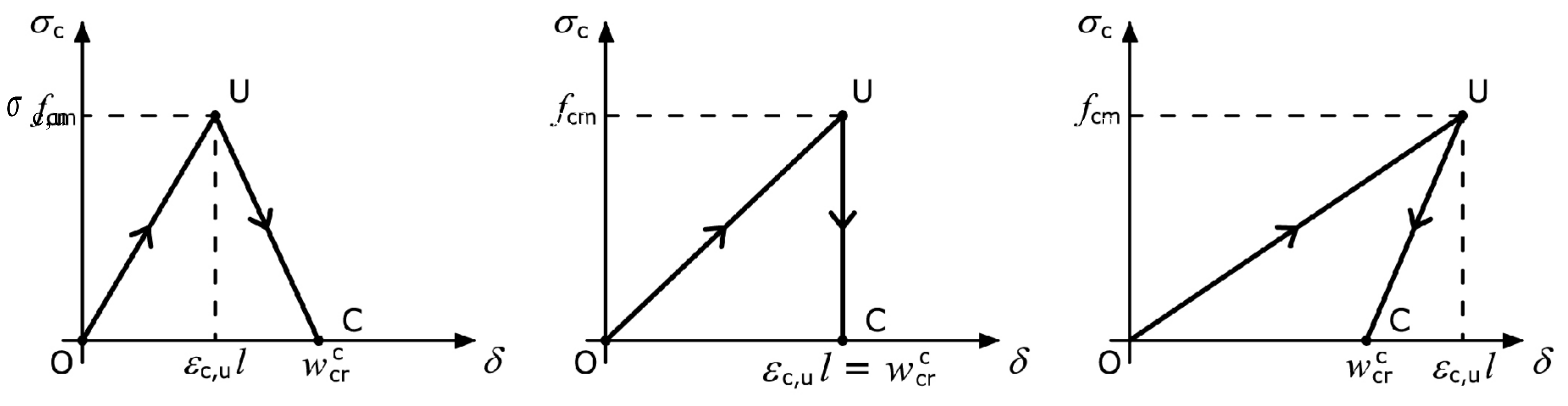


$$\delta = \varepsilon_{c} l = \frac{\sigma_{c}}{E} l; \qquad \delta = \frac{\sigma_{c}}{E} l + w^{c}; \qquad \delta \geq w^{c}_{cr}.$$

(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, 2530-2540 (2009).

Stress vs. displacement response of a specimen in compression



Normal softening

Vertical drop

Catastrophic behaviour

Elastic strain energy at the peak load, ΔE

Test specimen	Material	ΔE [J]
P1	Carrara marble	124
P2	Carrara marble	128
P3	Luserna granite	384
P4	Luserna granite	296

Threshold of energy rate for piezonuclear reactions (III) (IV):

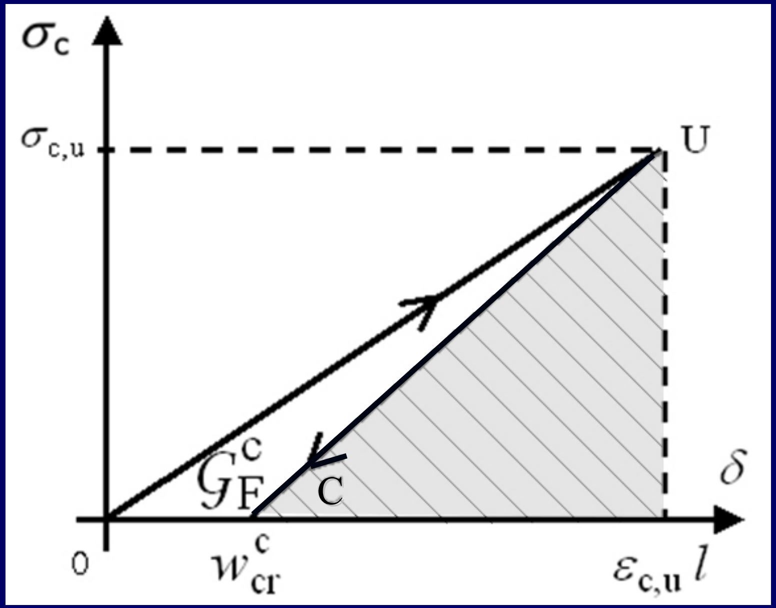
$$\frac{\Delta E}{\Delta t} \sim 7.69 \times 10^{11}\,\mathrm{W} \quad \rightarrow \quad \Delta t \sim 0.5\,\mathrm{ns}$$

Extension of the energy release zone:

$$\Delta x = v \Delta t \sim 4000\,\mathrm{m/s} \times 0.5\,\mathrm{ns} \sim 2\,\mu\mathrm{m}$$

Comparison with the critical value of the interpenetration length:

$$\Delta x \sim w_{\mathrm{cr}}^{\mathrm{c}} \; ?$$

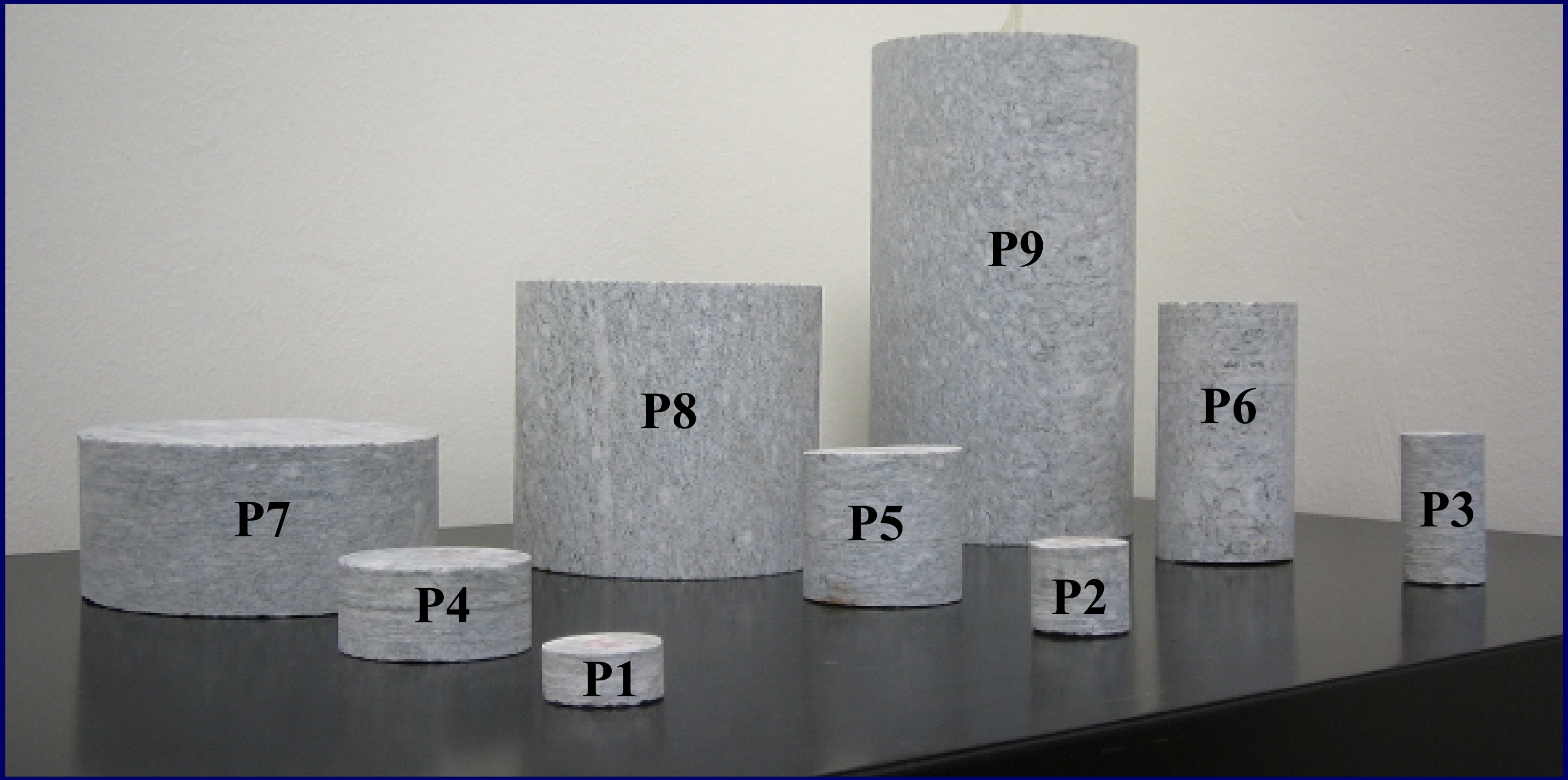


(III) Cardone, F., Mignani, R., “Piezonuclear reactions and Lorenz invariance breakdown”, *Int. J. of Modern Physics E, Nuclear Physics*, 15 (901), 911-924 (2006).

(IV) Cardone, F., Mignani, R., Deformed Spacetime, Springer, Dordrecht, 2007, chaps 16 -17.

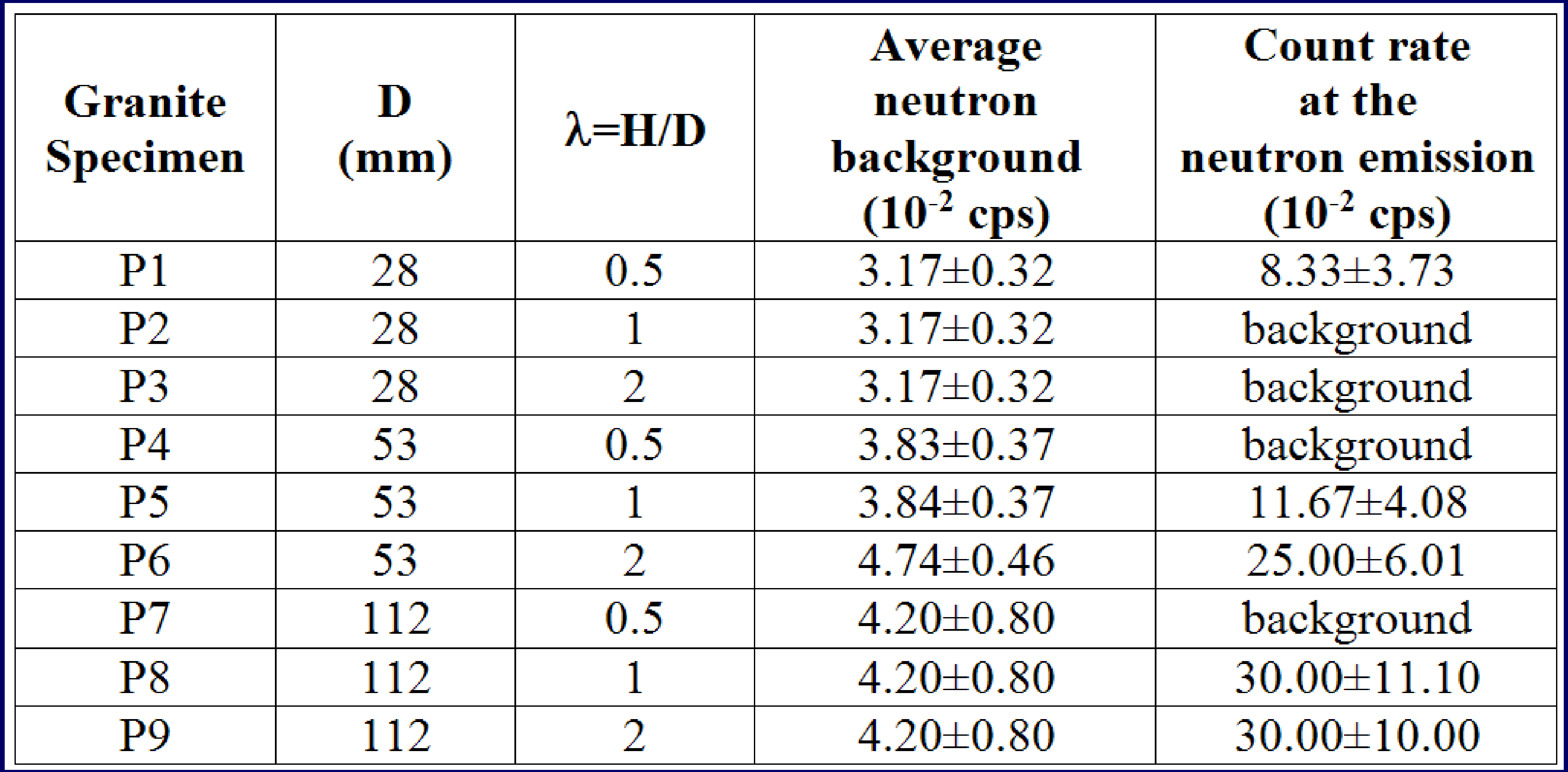
MONOTONIC, CYCLIC, AND VIBRATIONAL LOADING

Monotonic Load



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

Monotonic Load: Experimental Results

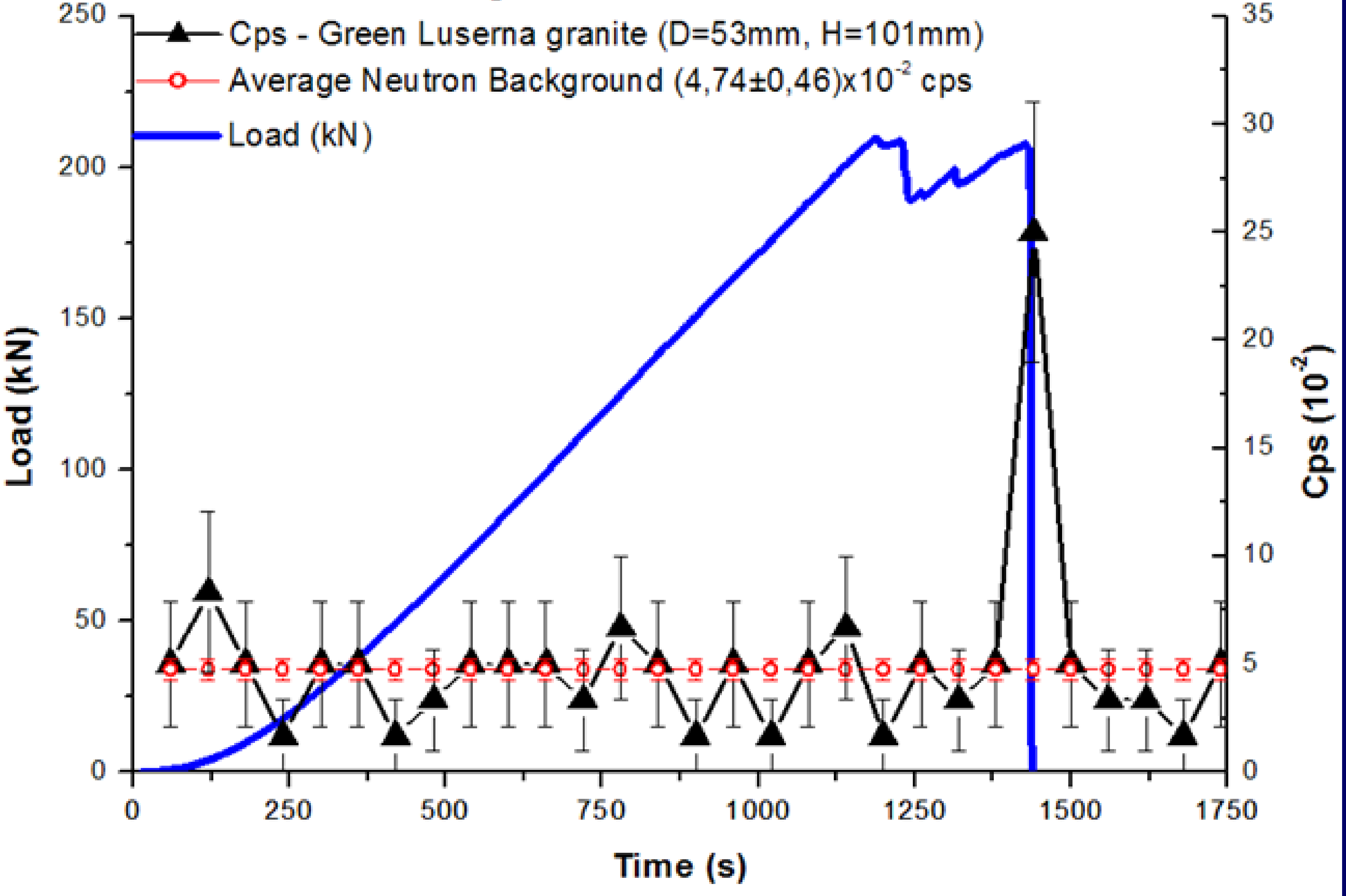


Granite Specimen	D (mm)	λ=H/D	Average neutron background (10^{-2} cps)	Count rate at the neutron emission (10^{-2} cps)
P1	28	0.5	3.17±0.32	8.33±3.73
P2	28	1	3.17±0.32	background
P3	28	2	3.17±0.32	background
P4	53	0.5	3.83±0.37	background
P5	53	1	3.84±0.37	11.67±4.08
P6	53	2	4.74±0.46	25.00±6.01
P7	112	0.5	4.20±0.80	background
P8	112	1	4.20±0.80	30.00±11.10
P9	112	2	4.20±0.80	30.00±10.00

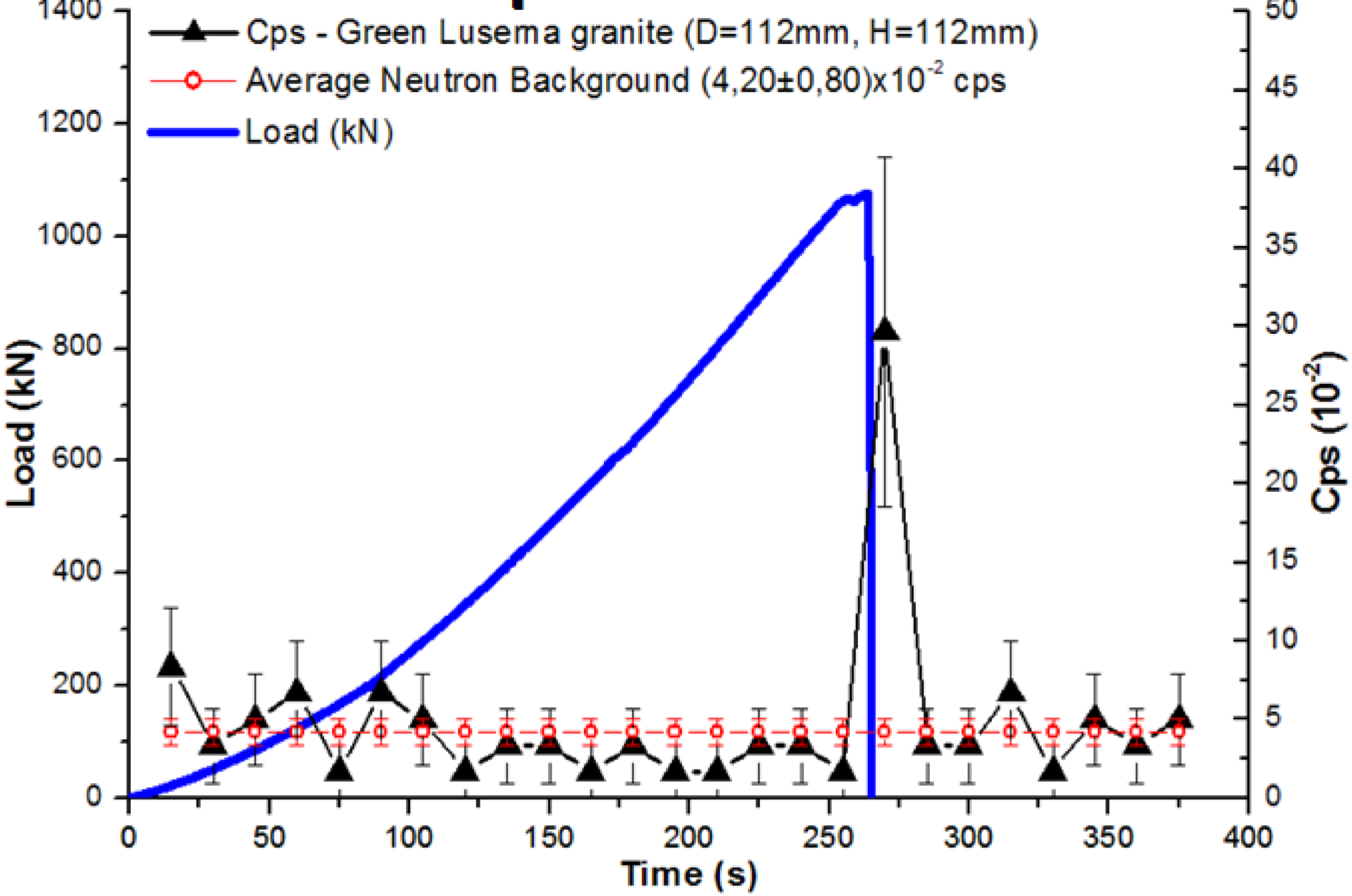
Neutron measurements of specimen P2, P3, P4, P7 yielded values comparable with the ordinary natural background.

For specimens P1 and P5, the experimental data exceeded the background value approximately by four times, whereas for specimen P6, P8, P9, the neutron emissions achieved values by one order of magnitude higher than the ordinary background.

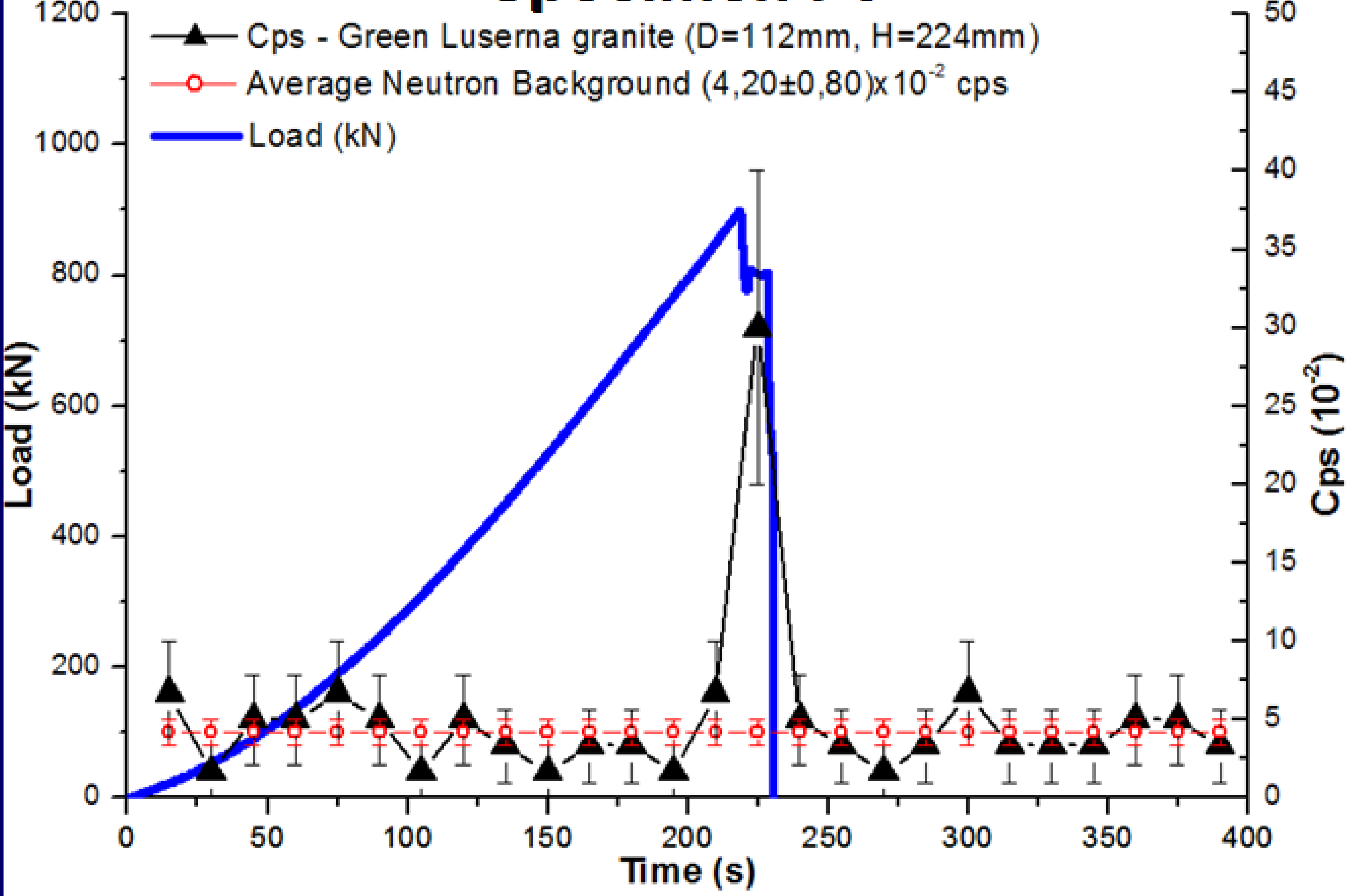
Specimen P6


Cps - Green Luserna granite (D=53mm, H=101mm)
Average Neutron Background $(4,74 \pm 0,46) \times 10^{-2}$ cps
Load (kN)
Load (kN)
Cps (10^{-2})
Time (s)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
0
250
500
750
1000
1250
1500
1750

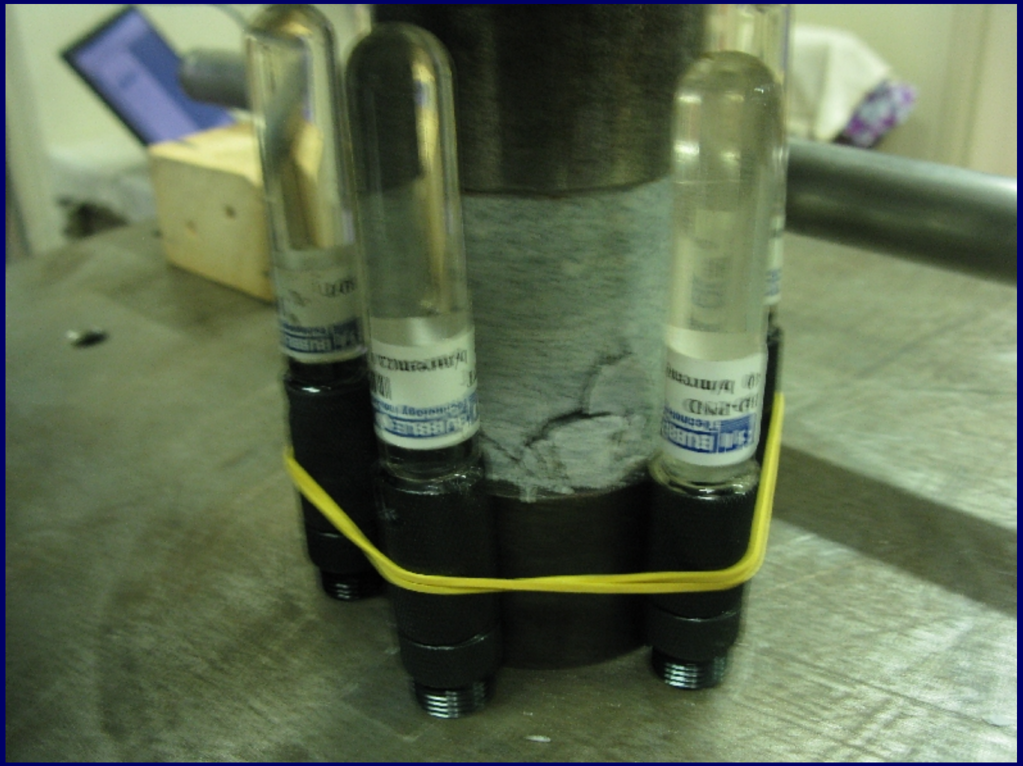
Specimen P8


Cps - Green Lusema granite (D=112mm, H=112mm)
Average Neutron Background (4,20±0,80)x10^{-2} cps
Load (kN)
Load (kN)
Cps (10^{-2})
Time (s)
0
200
400
600
800
1000
1200
1400
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
300
350
400

Specimen P9

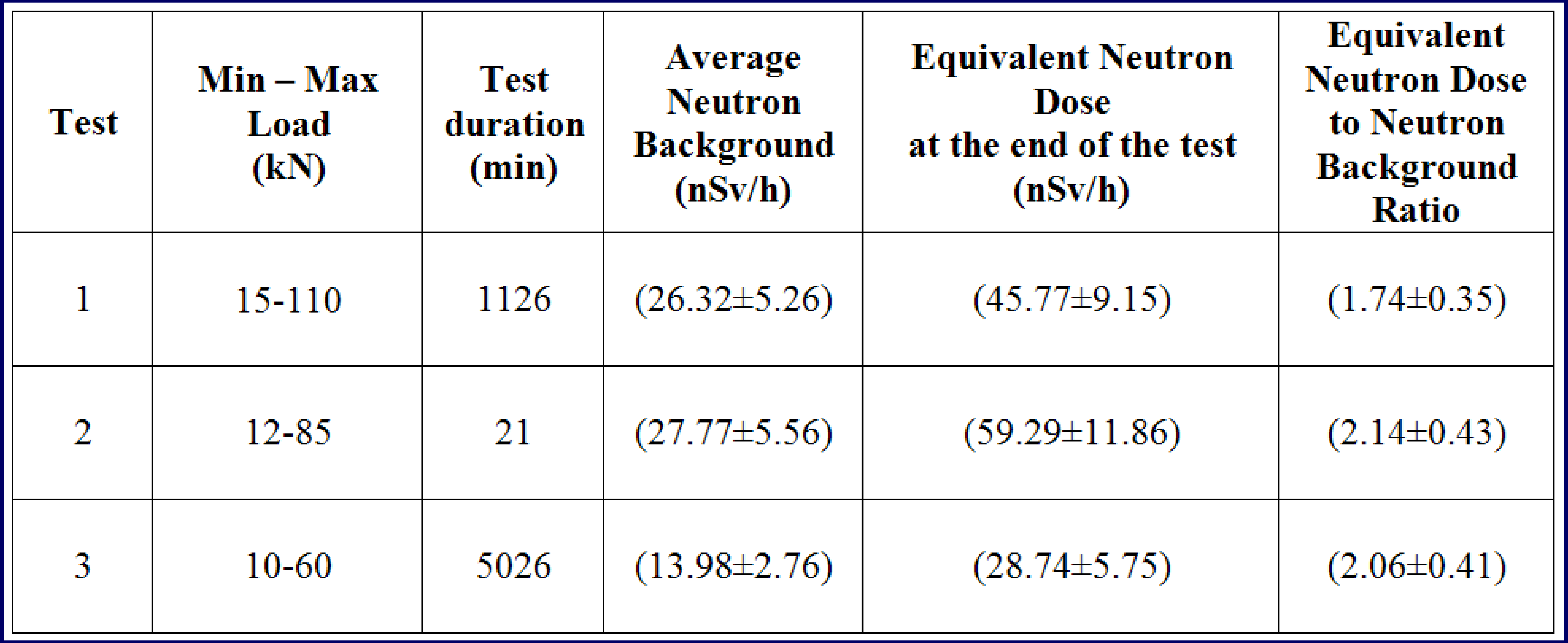

Cps - Green Luserna granite (D=112mm, H=224mm)
Average Neutron Background (4,20±0,80)x10⁻² cps
Load (kN)
Load (kN)
Cps (10⁻²)
Time (s)
0
200
400
600
800
1000
1200
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
300
350
400

Cyclic Loading

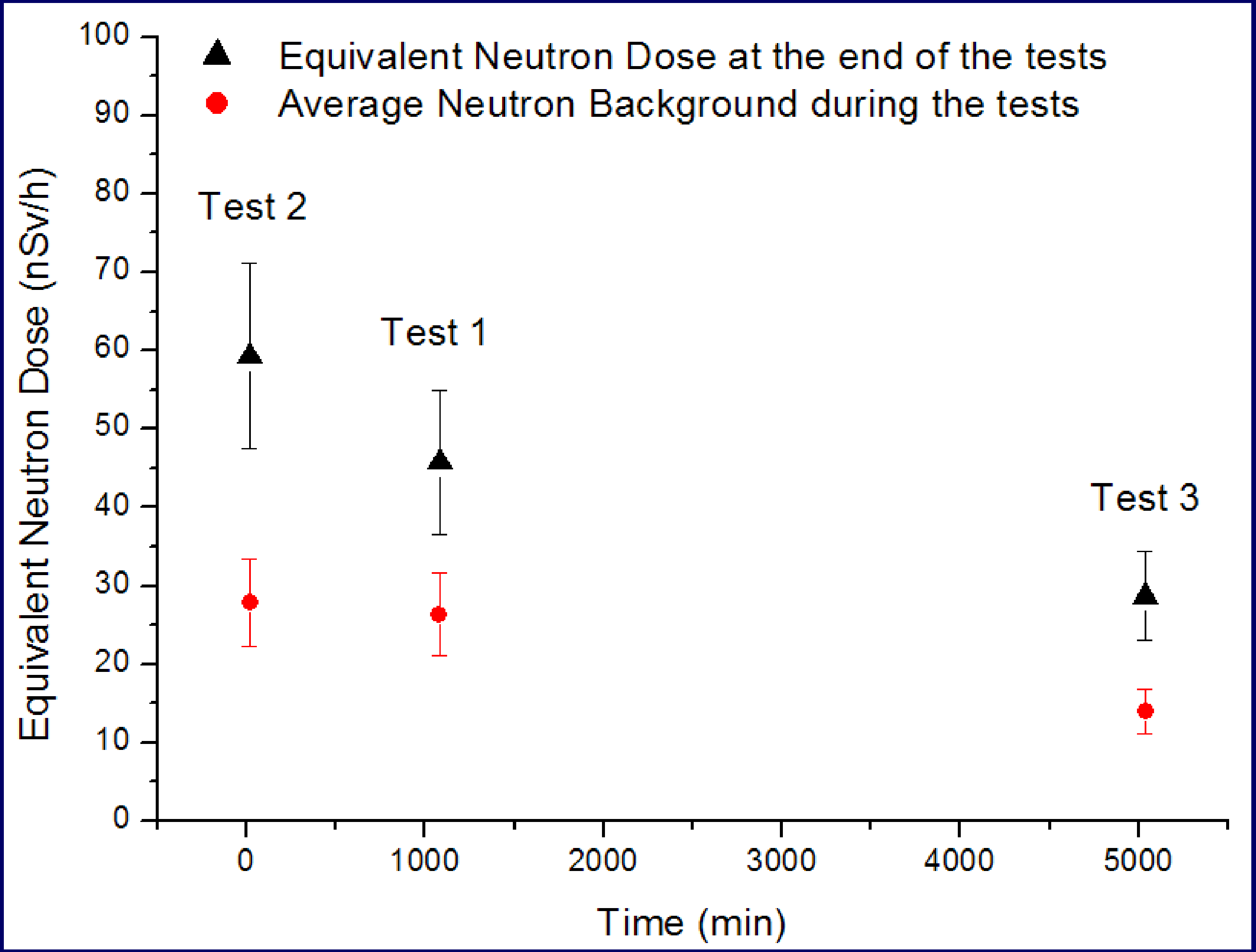


Neutron emissions from compression tests under cyclic loading were detected by using neutron bubble detectors. Due to anisotropic neutron emission, three BDT and three BD-PND detectors were positioned at a distance of about 5 cm, all around the specimen.

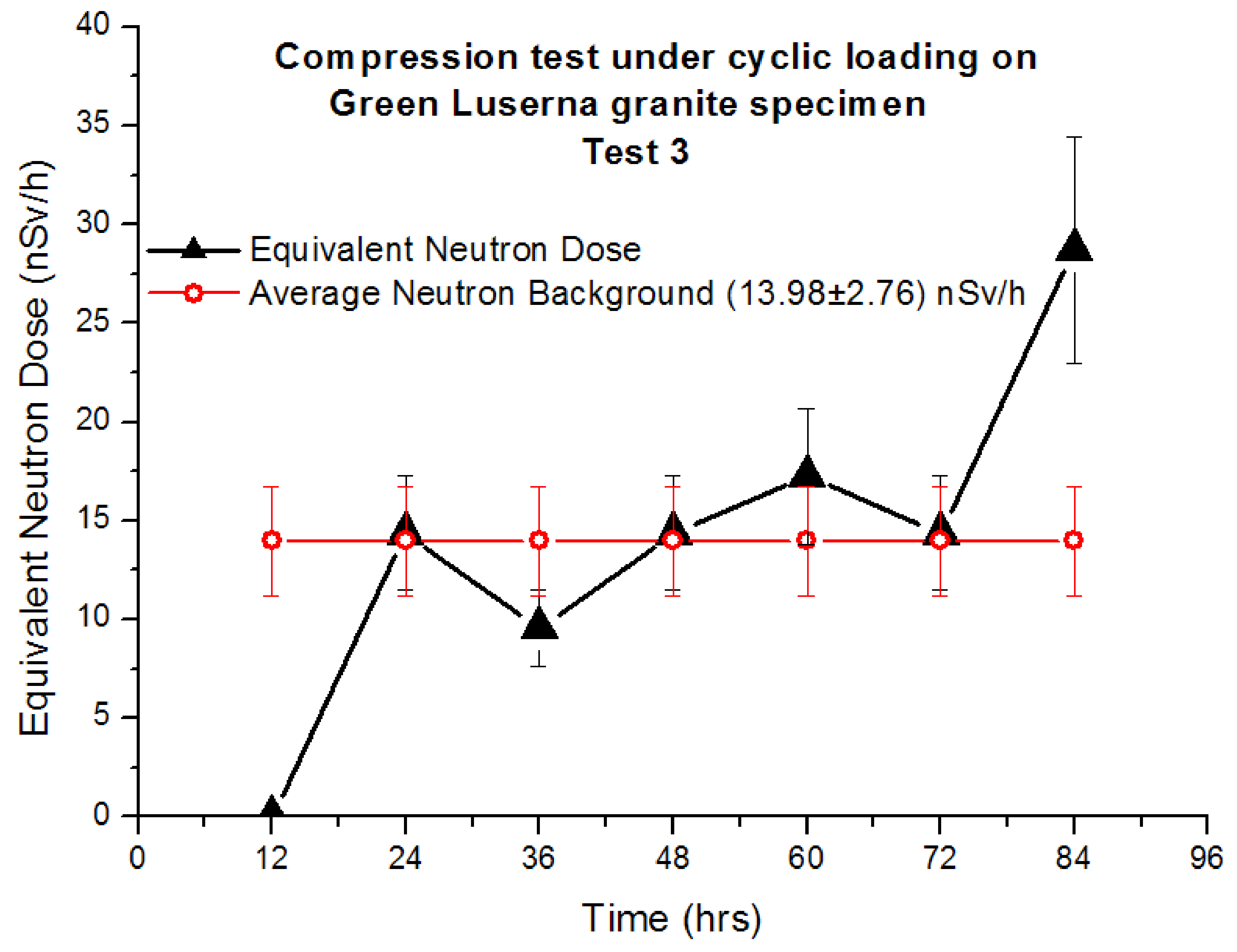
The cyclic loading was fixed at a frequency of 2 Hz for three specimens with the same shape and size (D=53mm, H=53mm, λ=1).



Test	**Min – Max Load (kN)**	**Test duration (min)**	**Average Neutron Background (nSv/h)**	**Equivalent Neutron Dose at the end of the test (nSv/h)**	**Equivalent Neutron Dose to Neutron Background Ratio**
1	15-110	1126	(26.32±5.26)	(45.77±9.15)	(1.74±0.35)
2	12-85	21	(27.77±5.56)	(59.29±11.86)	(2.14±0.43)
3	10-60	5026	(13.98±2.76)	(28.74±5.75)	(2.06±0.41)



The comparison between the equivalent background neutron dose and the equivalent neutron dose at the end of the cyclic loading tests, are reported. Considering the sensitivity of bubble detectors (20%), it is possible to observe that in each test the average increment of equivalent neutron dose at failure is about twice higher than natural neutron background.

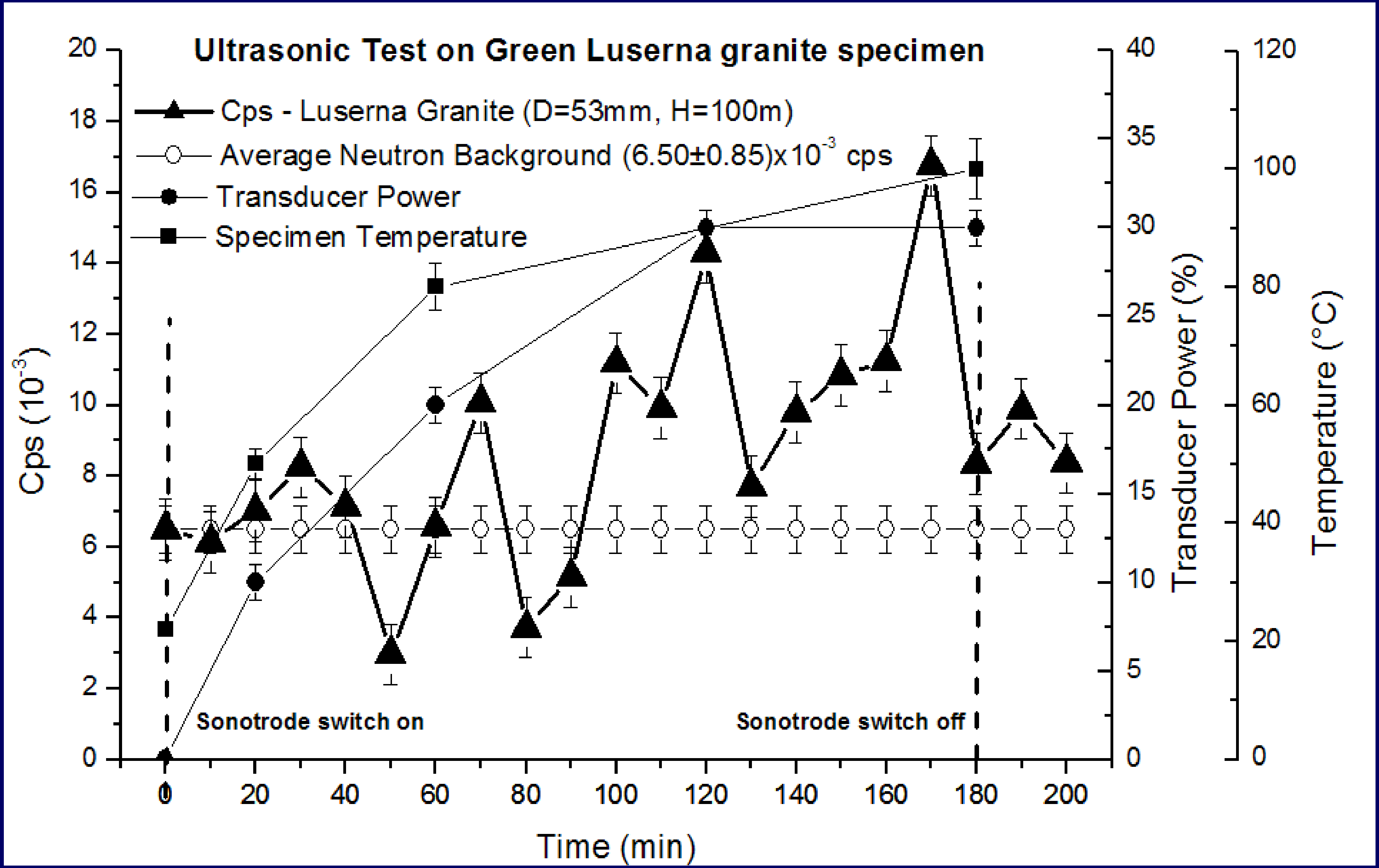


The equivalent neutron dose variation, evaluated during the third cyclic loading test, is shown. An increment of more than twice with respect to the background level was detected at specimen failure.

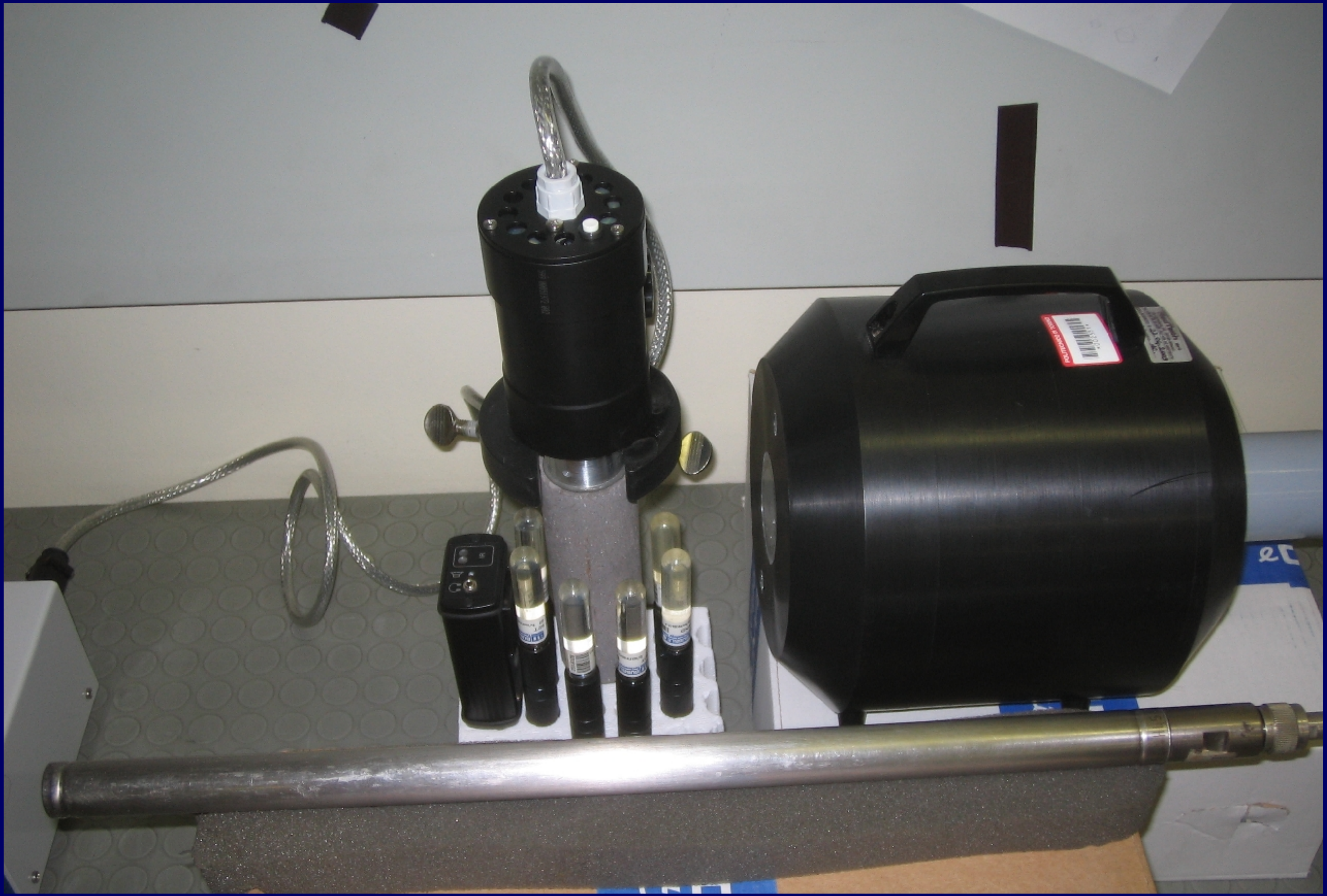
Vibrational Loading – Green Luserna Granite

Ultrasonic vibration was generated by an high intensity ultrasonic horn working at 20 kHz. The device guarantees a constant amplitude (ranging from 10% to 100%) independently of changing conditions within the sample. The apparatus consists of a generator that converts electrical energy to 20 kHz ultrasound, and of a transducer that switches this energy into mechanical longitudinal vibration of the same frequency.

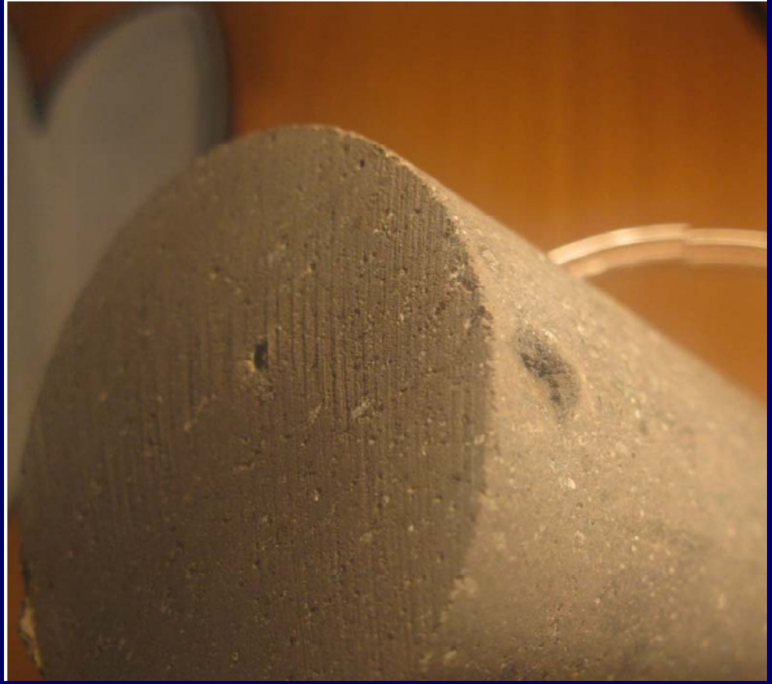
Experimental Results

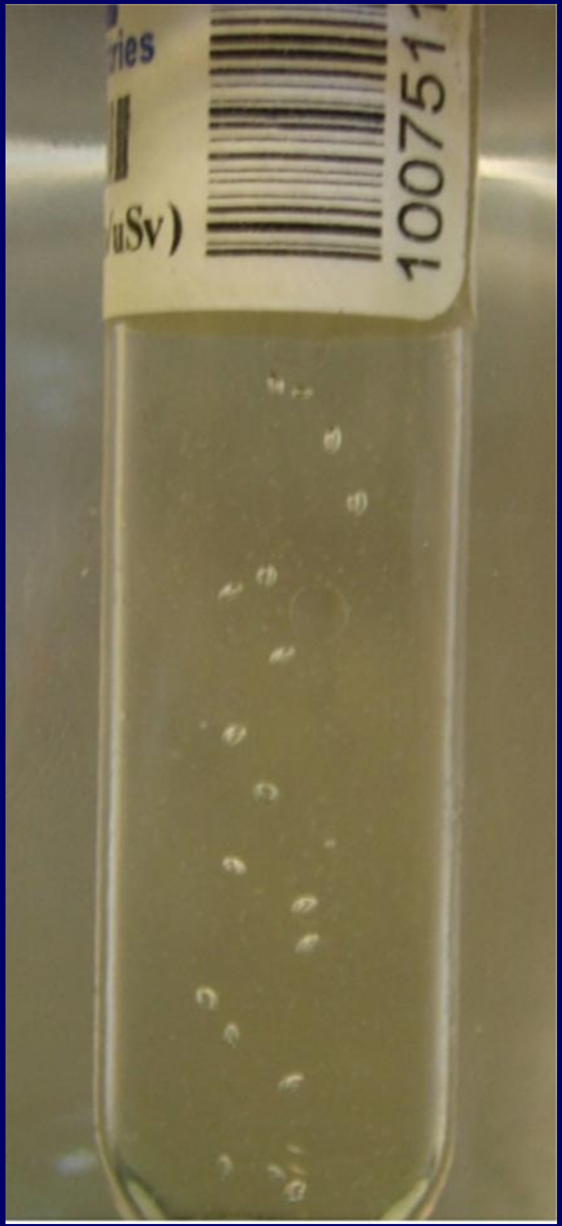


Vibrational Loading – Basalto



Neutron emissions from vibrational loading test were detected by using neutron bubble detectors and ^{3}He devices.

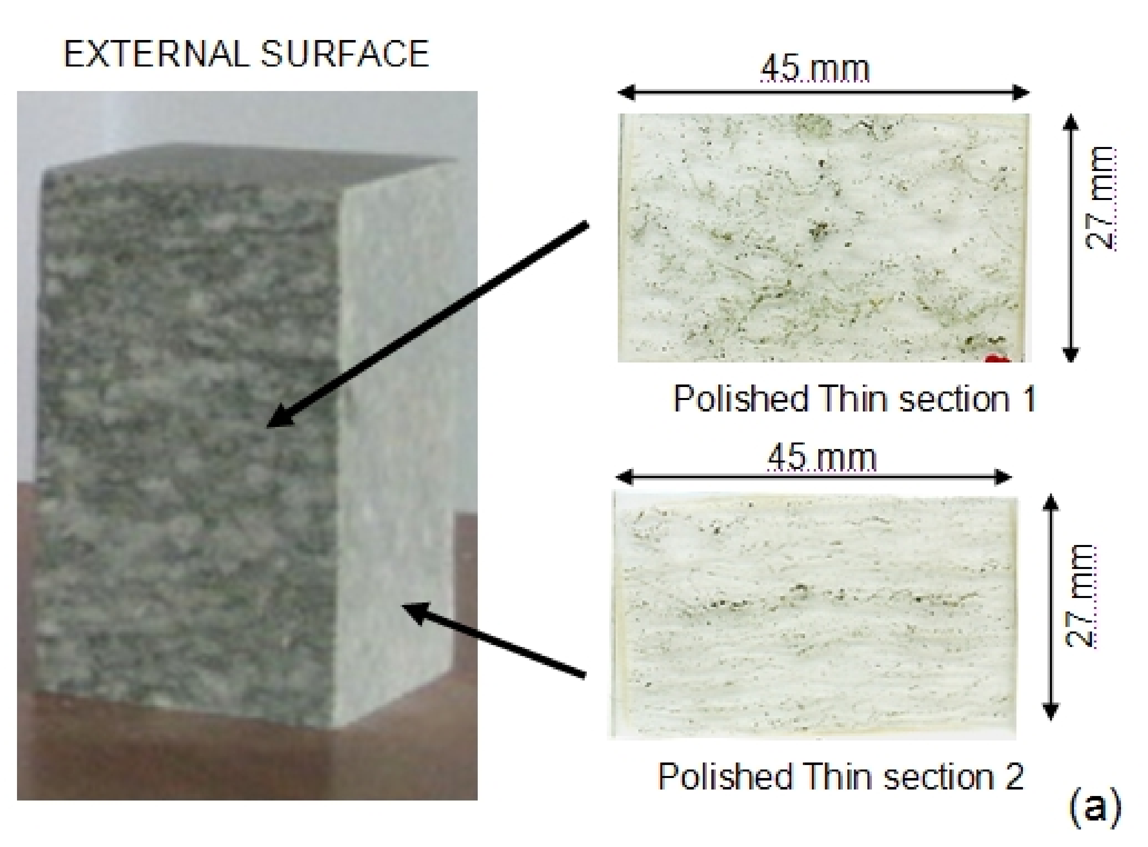


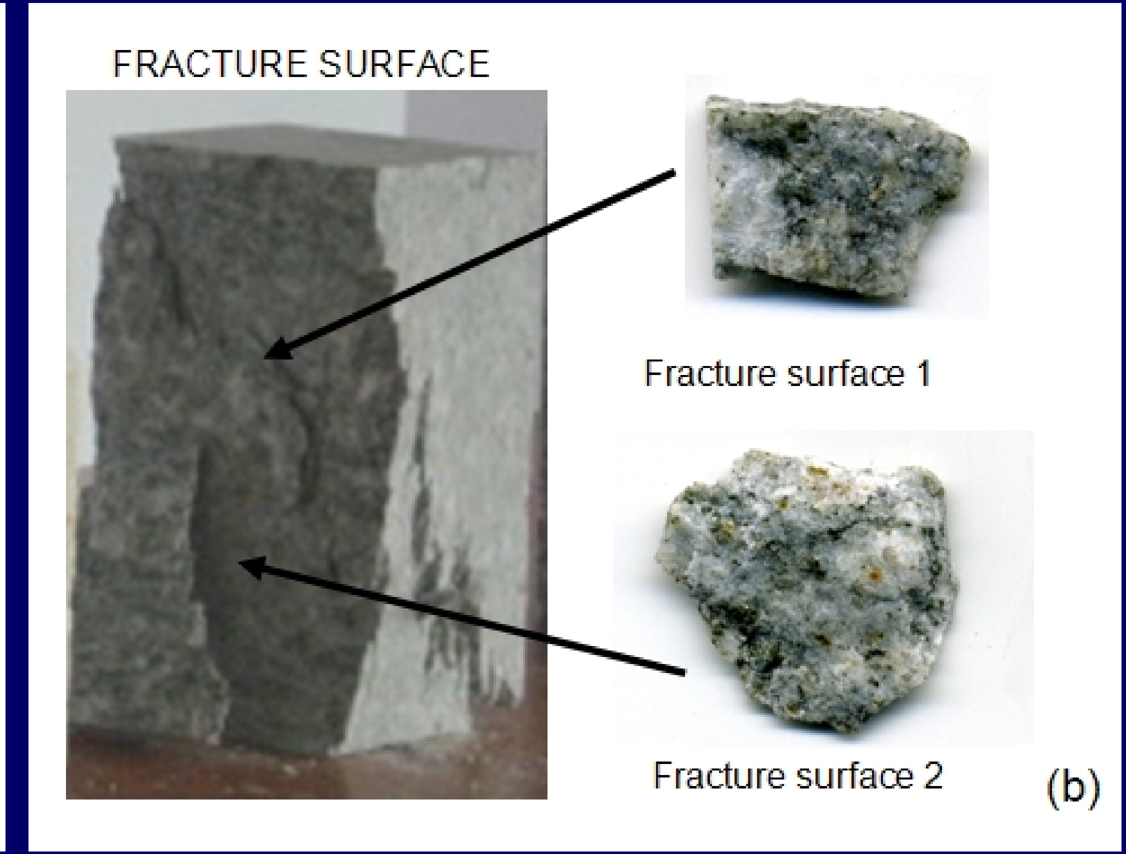


The experimental data exceeded the background value approximately by one order of magnitude

EDS ANALYSIS: COMPOSITIONAL CHANGES

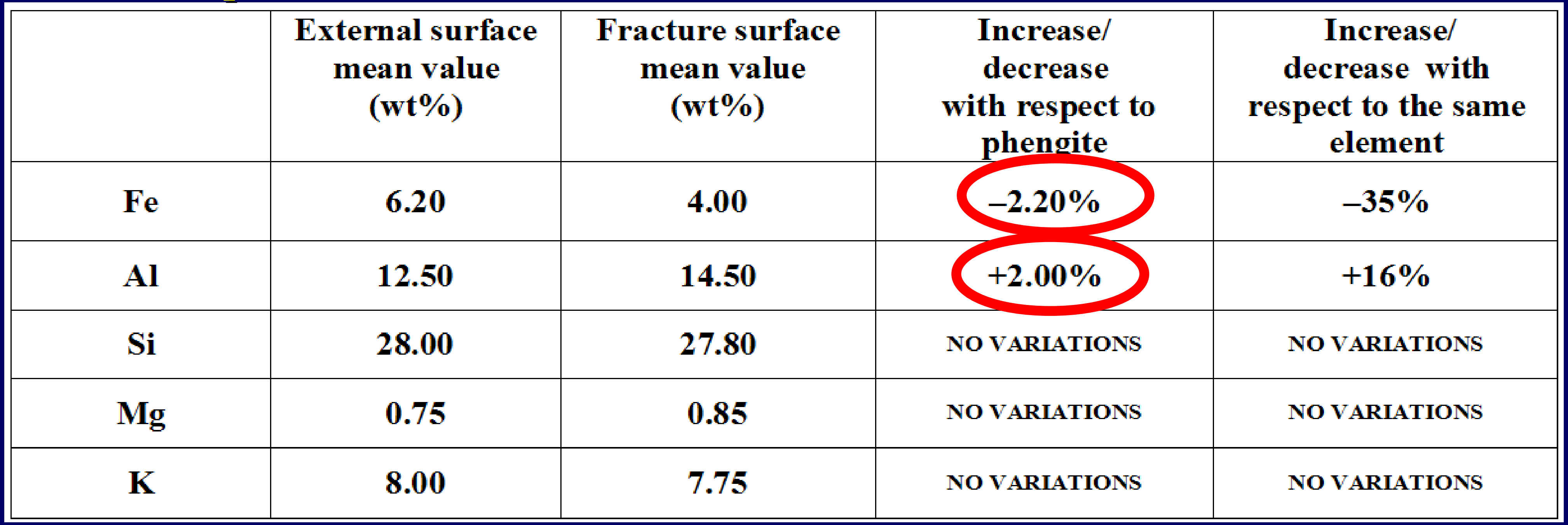
Two different kinds of samples were examined: (i) polished thin sections, finished with a standard petrographic sample procedure for what concerns the external surface; (ii) small portions of fracture surfaces without any kind of preparation for the fracture surface.





Quantitative analysis was performed on the collected spectra in order to correlate the oxides content with the specific crystalline phase and recognized specific variations of each element between external and fracture surfaces.

The evidence emerging from the EDS analyses, that the two values for the iron decrease (–2.20%) and for the Al increase (+2.0%) are approximately equal, is really impressive. This iron content reduction corresponds to a relative decrease of 35% with respect to the previous Fe content, The relative increase in Al content is equal to 16%.



	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	**6.20**	**4.00**	**–2.20%**	**–35%**
Al	**12.50**	**14.50**	**+2.00%**	**+16%**
Si	**28.00**	**27.80**	**NO VARIATIONS**	**NO VARIATIONS**
Mg	**0.75**	**0.85**	**NO VARIATIONS**	**NO VARIATIONS**
K	**8.00**	**7.75**	**NO VARIATIONS**	**NO VARIATIONS**

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

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

has occurred in the rock specimens.

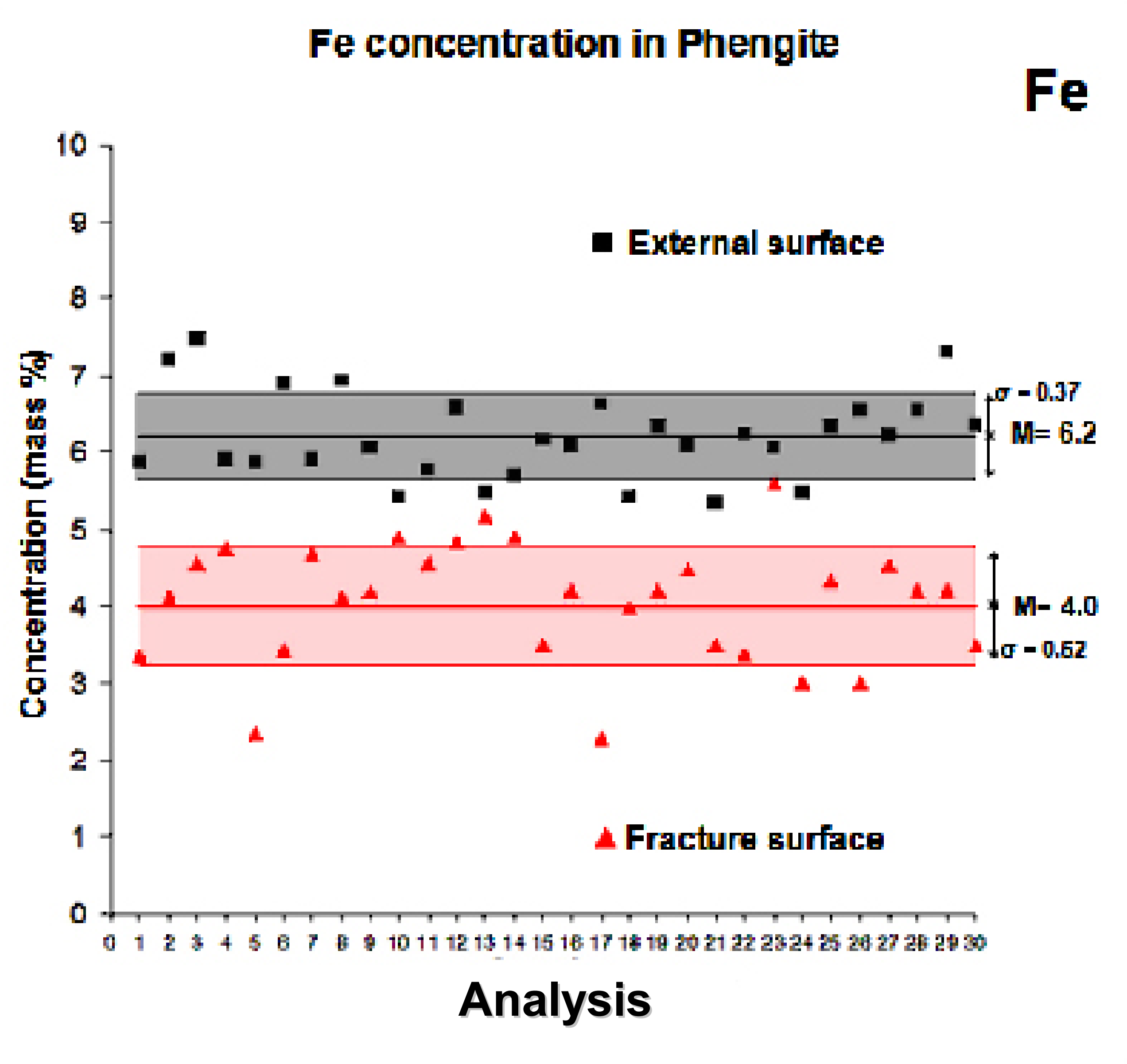
Biotite: Fe, Al, Si, Mg, and K weight percentage mean values on external and fracture surfaces. Variations with respect to the mineral (biotite) and to the same element

	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	**21.20**	**18.20**	**–3.00%**	**–14%**
Al	**8.10**	**9.60**	**+1.50%**	**+18%**
Si	**18.40**	**19.60**	**+1.20%**	**+6%**
Mg	**1.50**	**2.20**	**+0.70%**	**+46%**
K	**6.90**	**7.10**	**NO VARIATIONS**	**NO VARIATIONS**

Therefore, the Fe decrease (–3.00%) in biotite is counterbalanced by an increase in Al (+1.50%), Si (+1.20%), and Mg (+0.70%). Considering these evidences, in analogy to the previous results, it is possible to assess that another piezonuclear reaction has been occurred in biotite crystalline phase during the piezonuclear tests:

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

Phengite: Fe concentrations



External Surf.:

Fe content M= <u>6.20%</u>

Fracture Surf.:

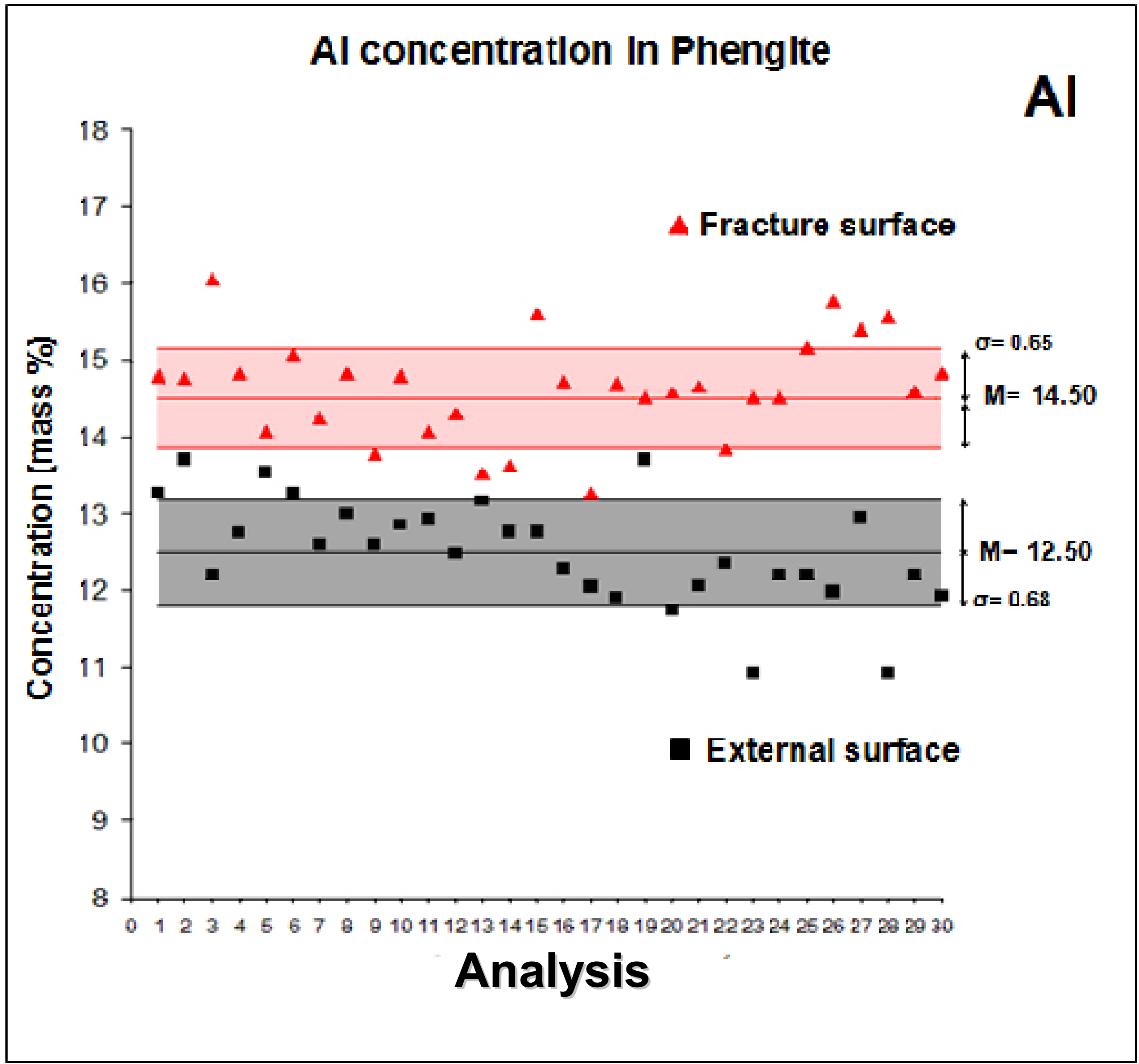
Fe content M= <u>4.00%</u>

Fe content decrease

–2.20%

The distribution of Fe concentrations for the external surfaces show an average value equal to 6.20%. The distribution of Fe concentrations on the fracture samples shows a mean value equal to 4.0%. The iron decrease is 2.20%.

Phengite: Al concentration



Fracture Surf.:

Al content M= 14.50%

External Surf.:

Al content M= 12.50%

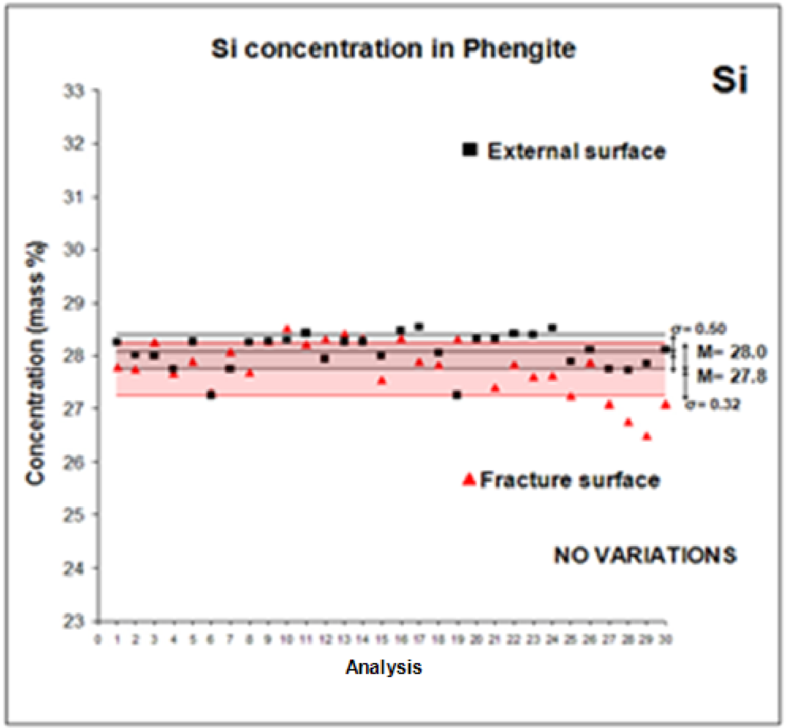
Al content increase

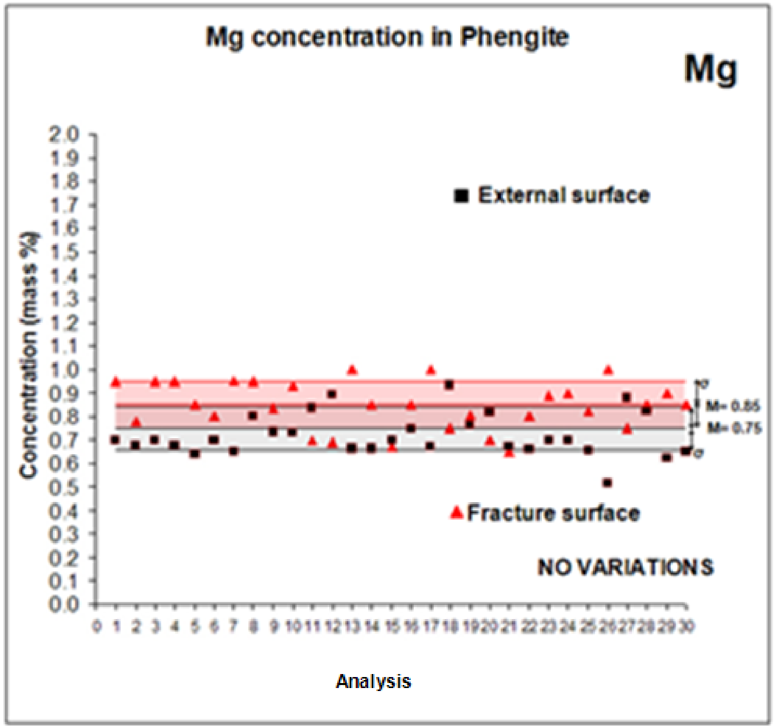
+2.00%

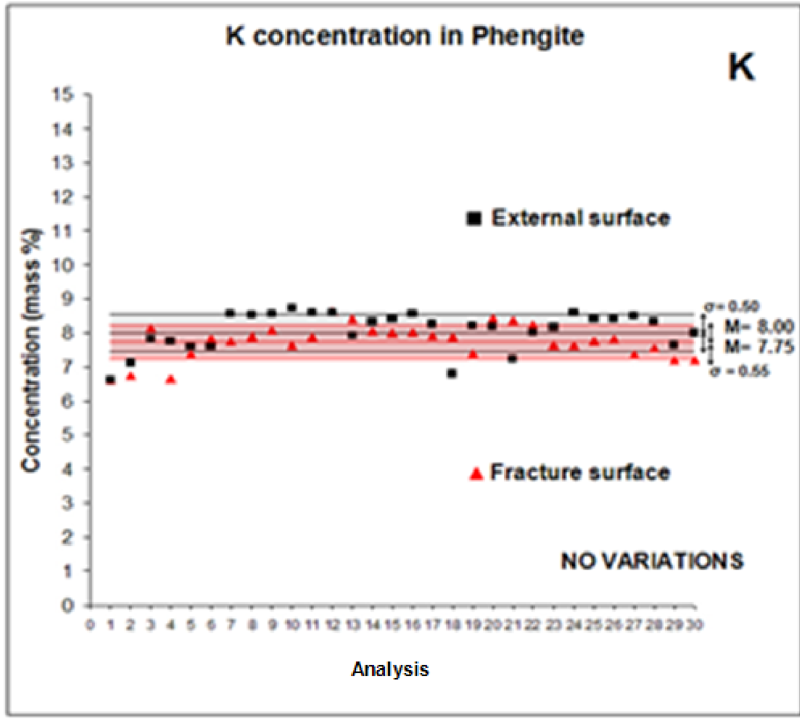
For Al contents, the observed variations show a mass percentage increase approximately equal to that of Fe. The average increase in the distribution, corresponding to the fracture surfaces is about 2.00% of the phengite mineral.

Phengite: Si, Mg and K concentrations

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

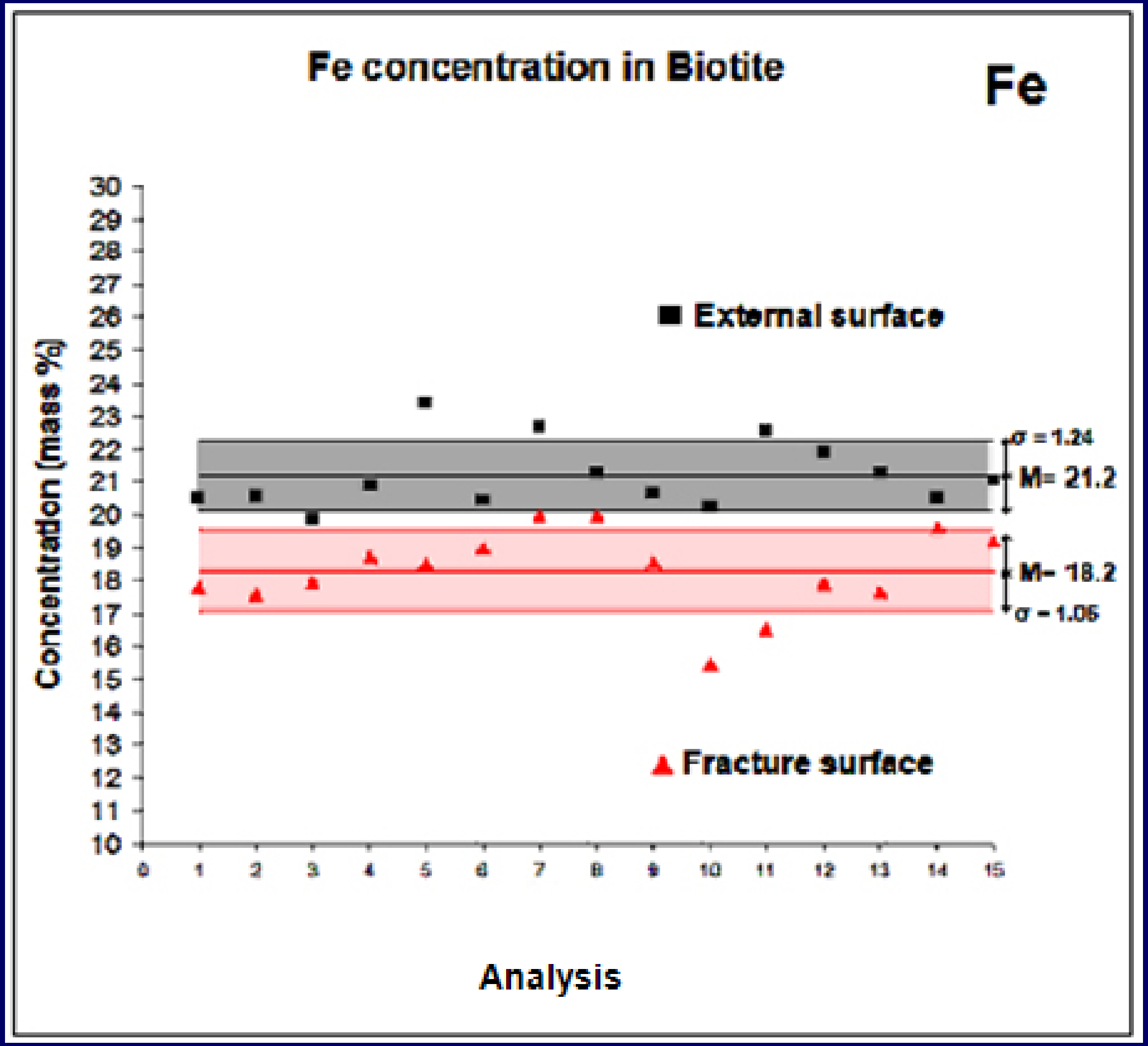






The Si, Mg, and K concentration distributions are reported for external and fracture surfaces. In this case, no appreciable variations can be recognized between the average values.

Biotite: Fe concentrations



External Surf.:

Fe content M= 21.20%

Fracture Surf.:

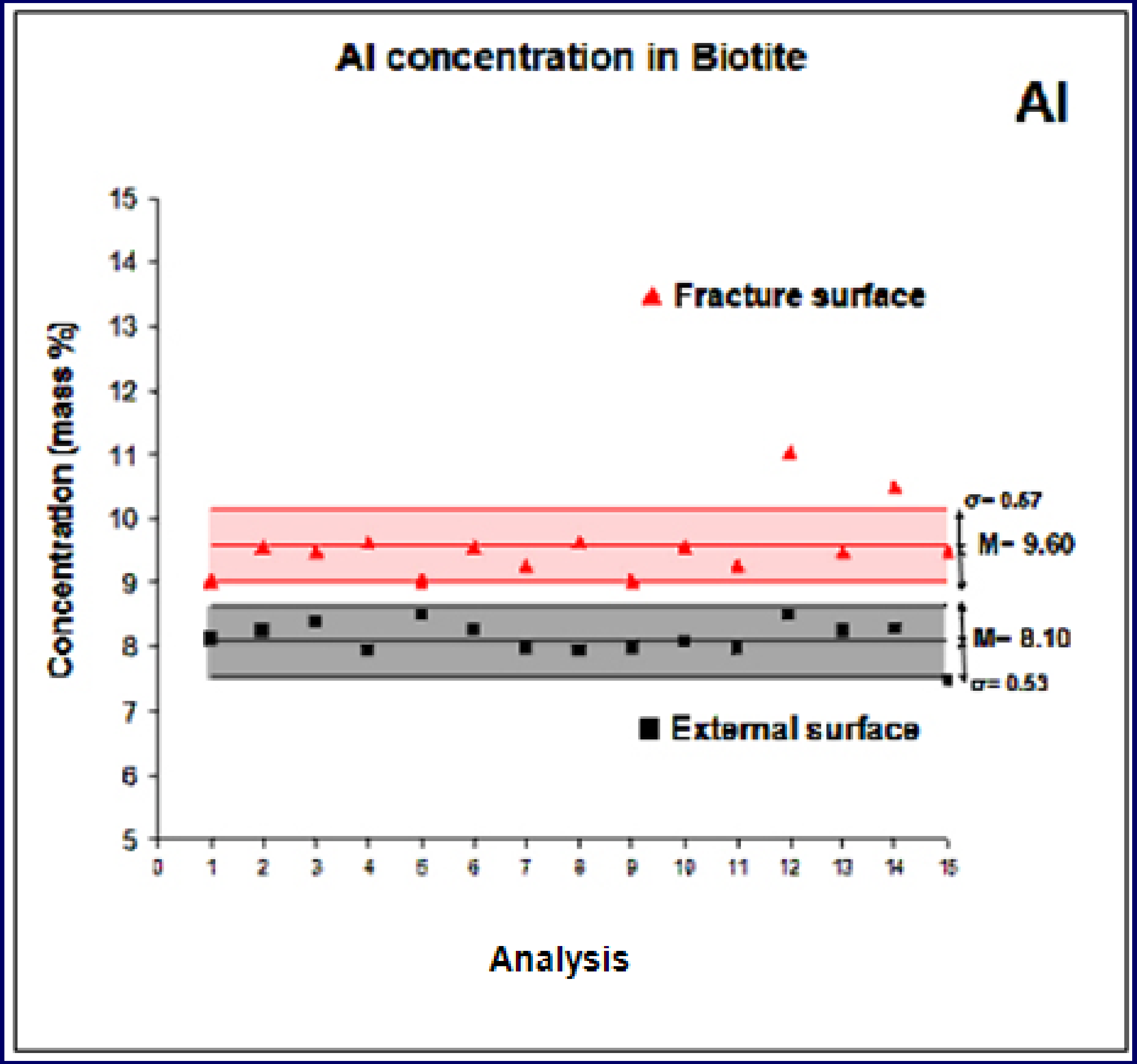
Fe content M= 18.20%

Fe content decrease

–3.00%

Similar analysis can be done for biotite. In this case the distribution of Fe concentrations for the external surfaces shows an average value of the distribution equal to 21.20%. On the other hand, the distribution of Fe concentrations on fracture samples is equal to 18.20%.

Biotite: Al, Si and Mg concentrations



Fracture Surf.:

Al content M= 9.60%

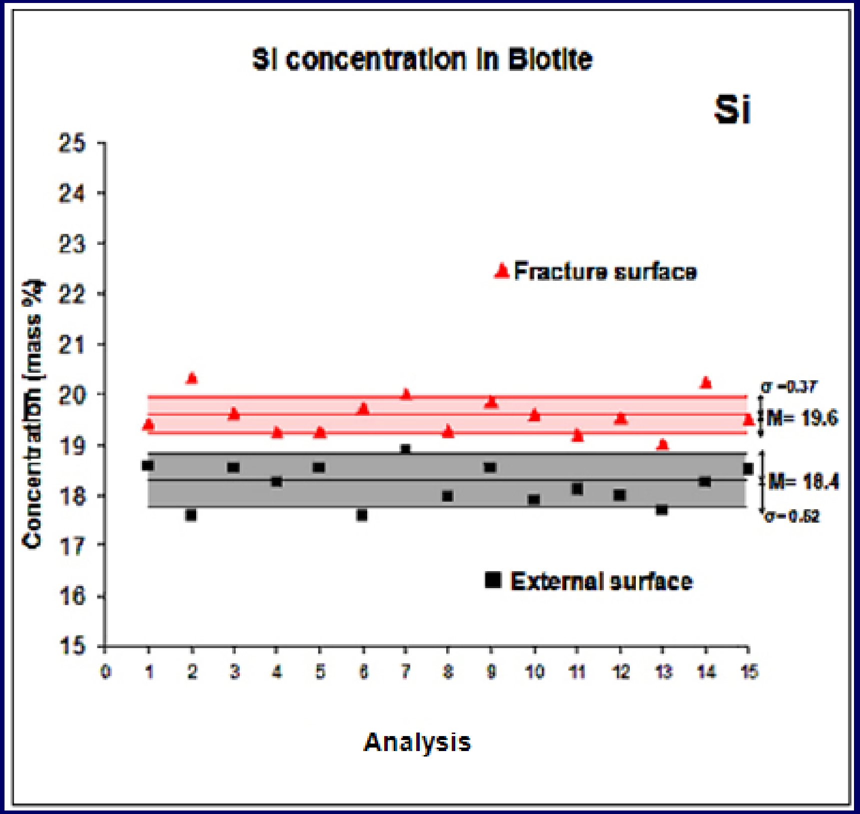
External Surf.:

Fe content M= 8.10%

Al content increase

+1.50%

Similarly, Al mass percentage concentrations are considered in both cases of external and fracture samples. For Al contents the observed variations show an average increase of about 1.50% in the biotite mineral.



Fracture Surf.:

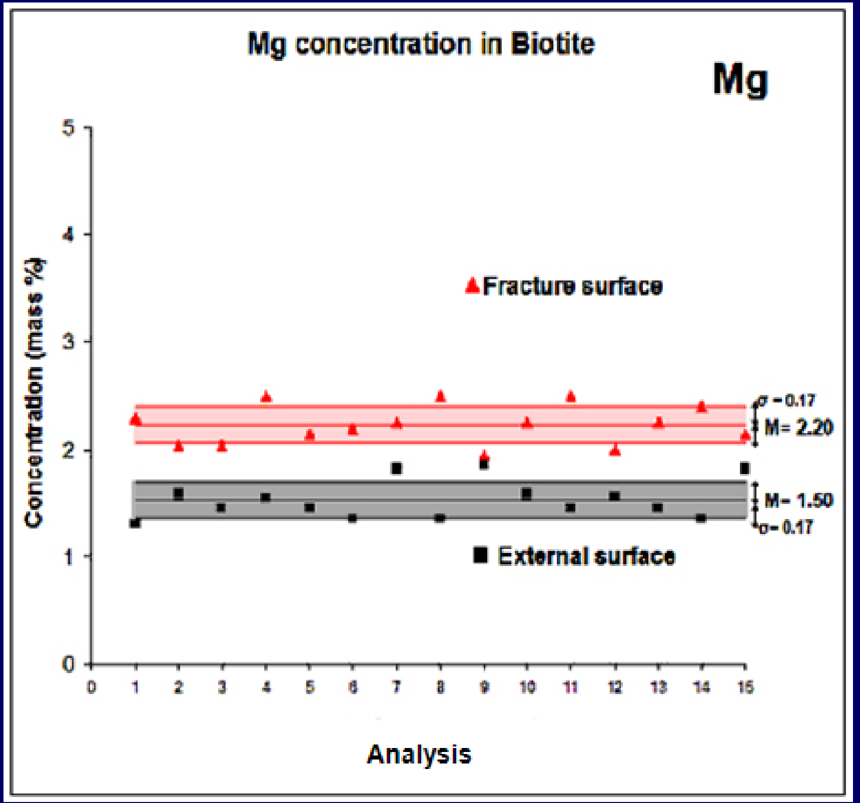
Si content M= 19.60%

External Surf.:

Si content M= 18.40%

Si content increase

+1.20%



Fracture Surf.:

Mg content M= 2.20%

External Surf.:

Mg content M= 1.50%

Mg content increase

+0.70%

EVOLUTION 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:

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

- The present natural abundance of aluminum (~8% in the Earth crust), which is less favoured than iron from a nuclear point of view, is possibly due to the above piezonuclear fission reaction.

- This reaction –less infrequent than we could think– 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.

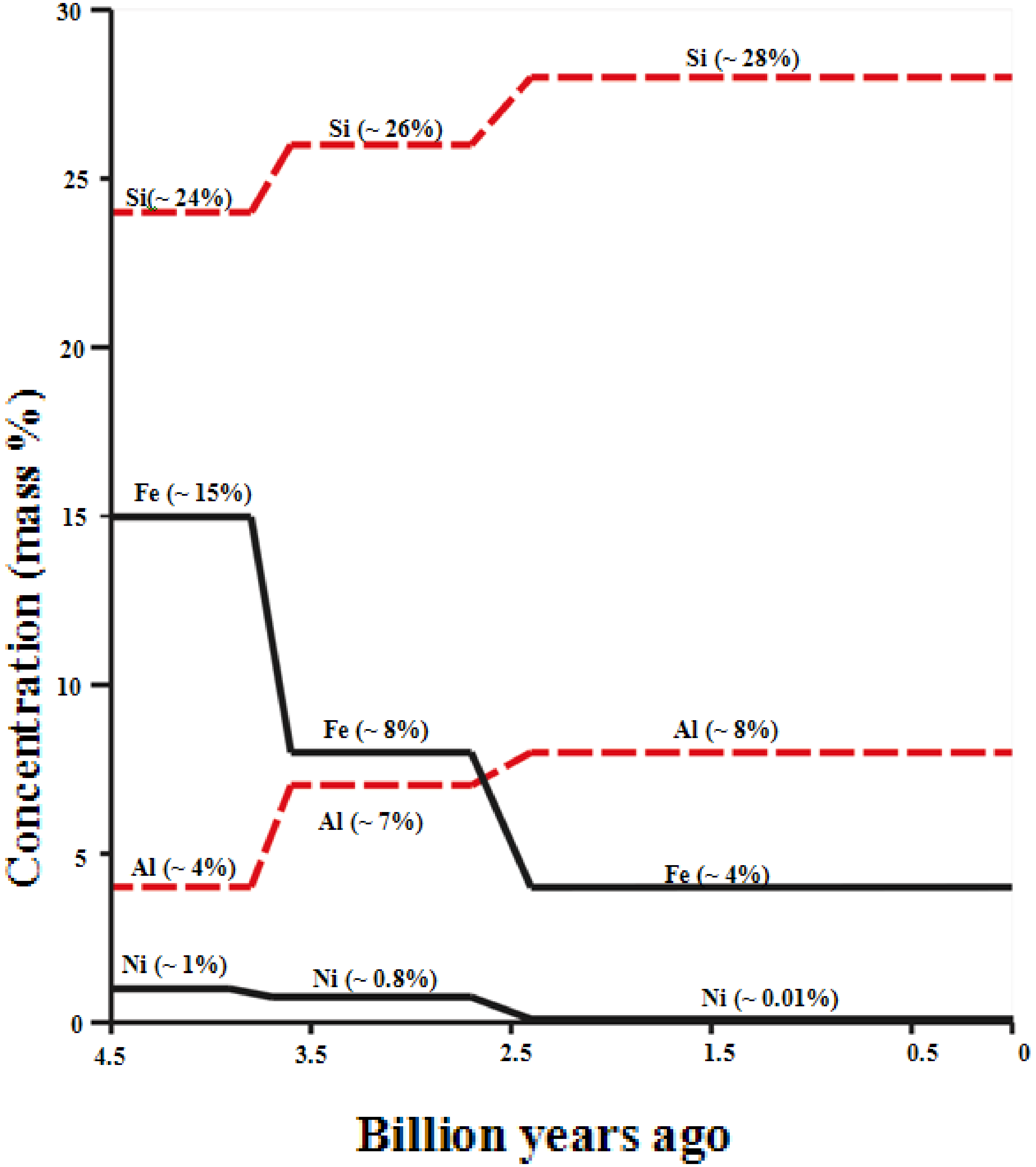
- If we consider the evolution of the percentages of the most abundant elements in the Earth crust during the last 4 billion years, we realize that iron and nickel have drastically diminished, whereas aluminum and silicon have as much increased:

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

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

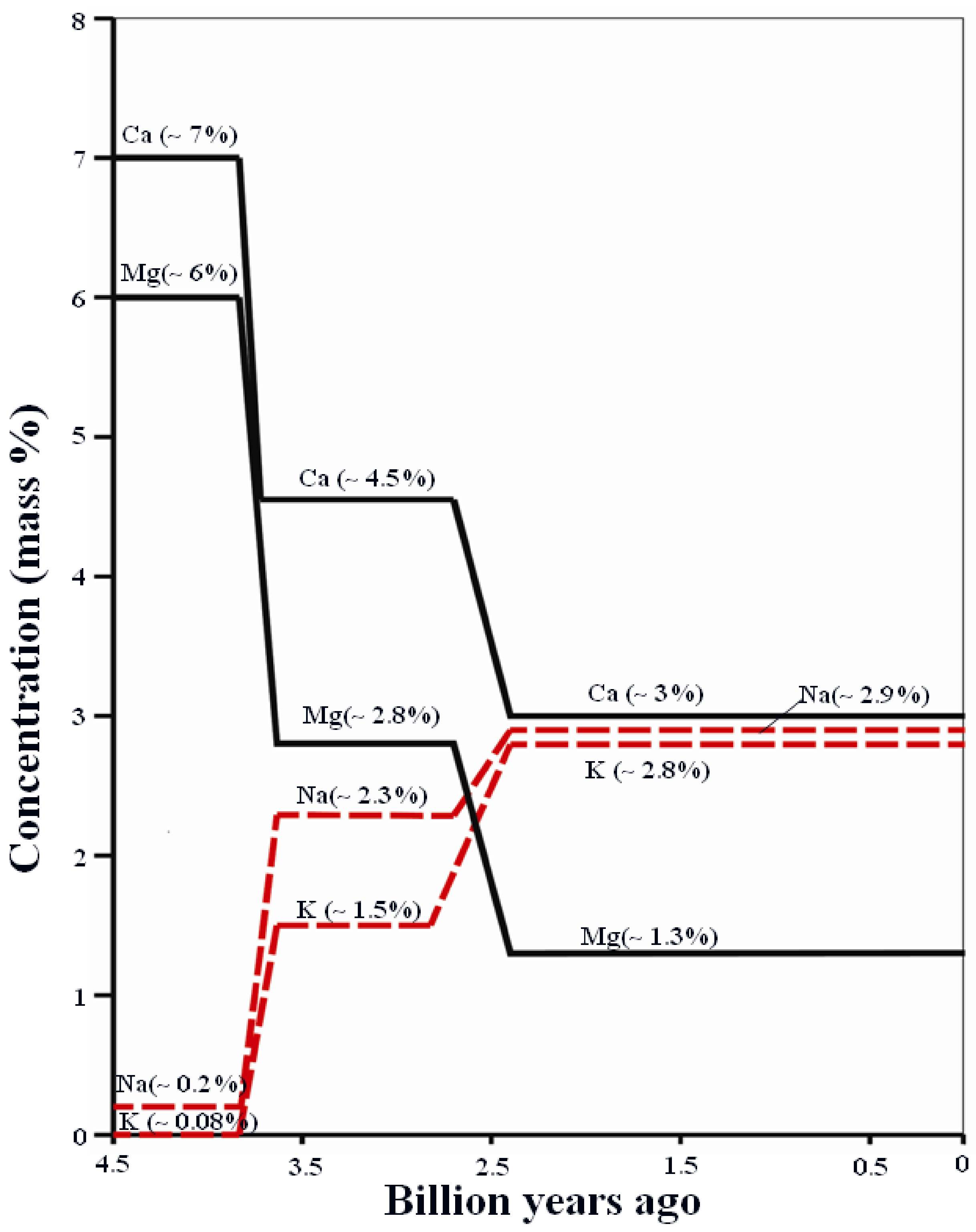
- It is also interesting to realize that such increases have developed mainly in the tectonic regions, where frictional phenomena between the continental plates occurred.

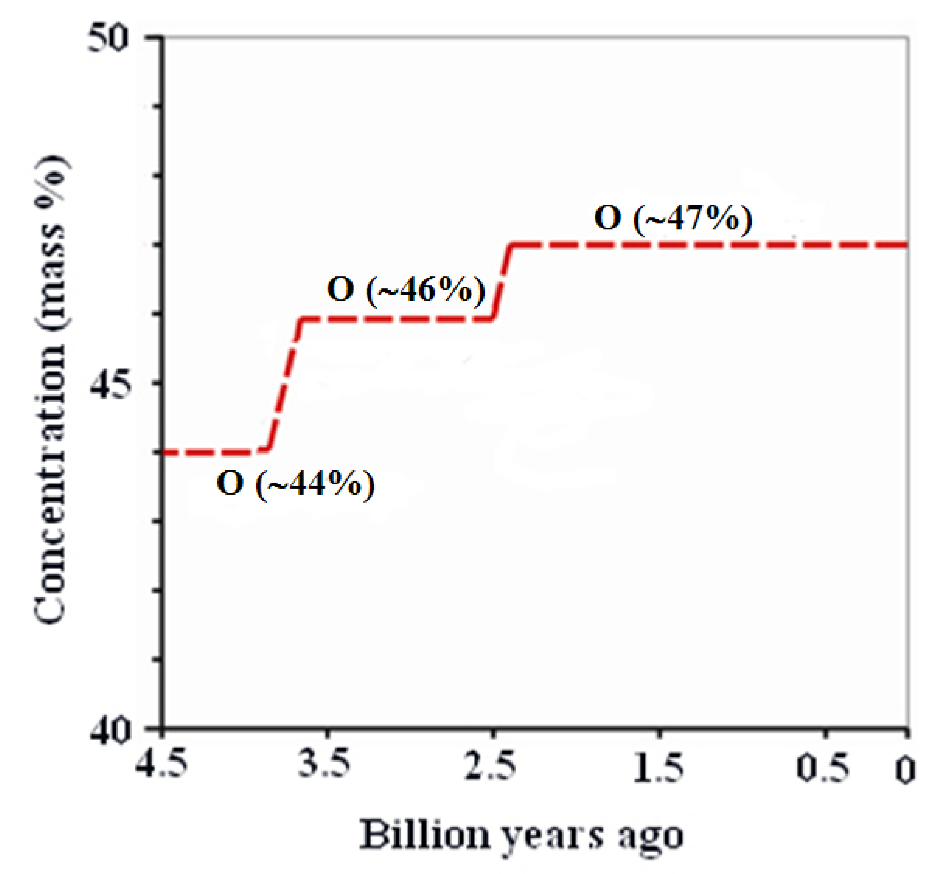
- Additional clues and quantitative data will be presented in favour of the piezonuclear fission reactions.



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

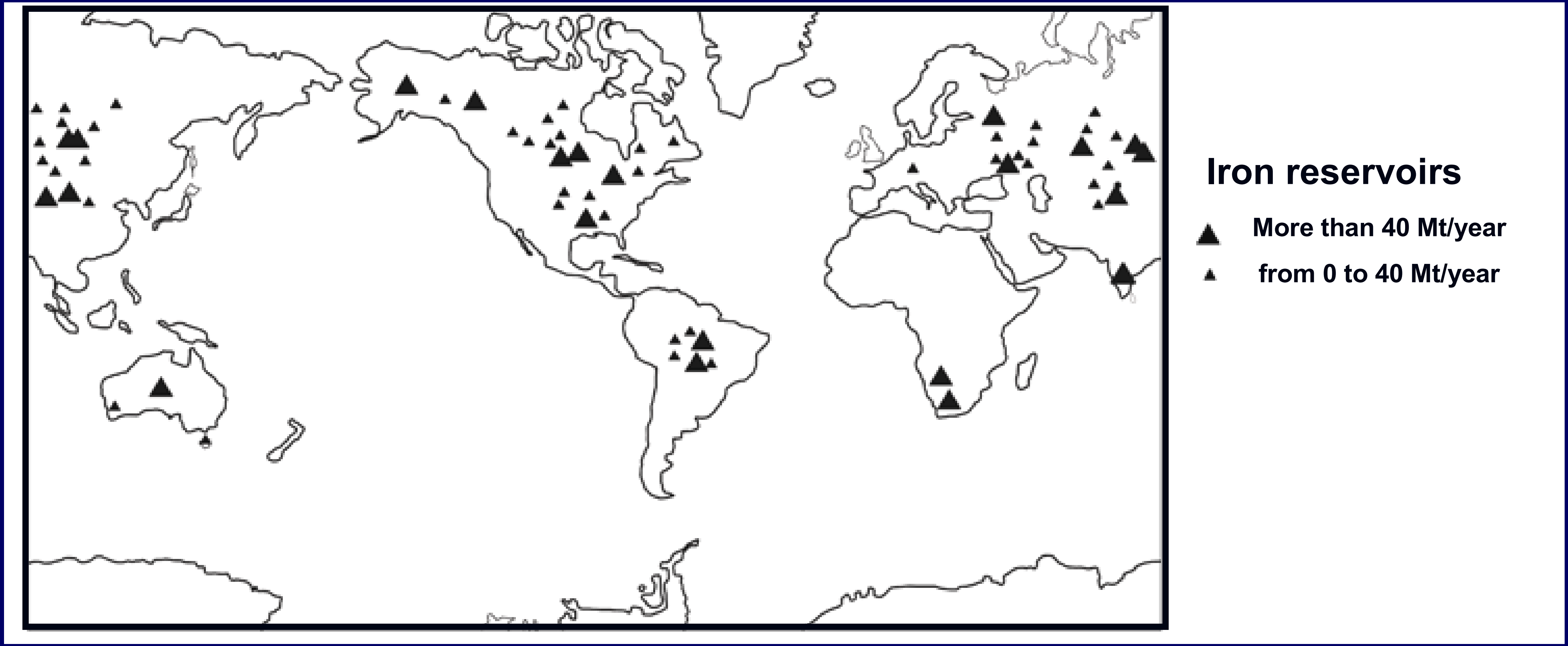
2.5 Billion years ago:
Fe (–4%) + Ni (–0.8%) =
=Al (+1%) + Si (+2.3%) + Mg (+1.5%)





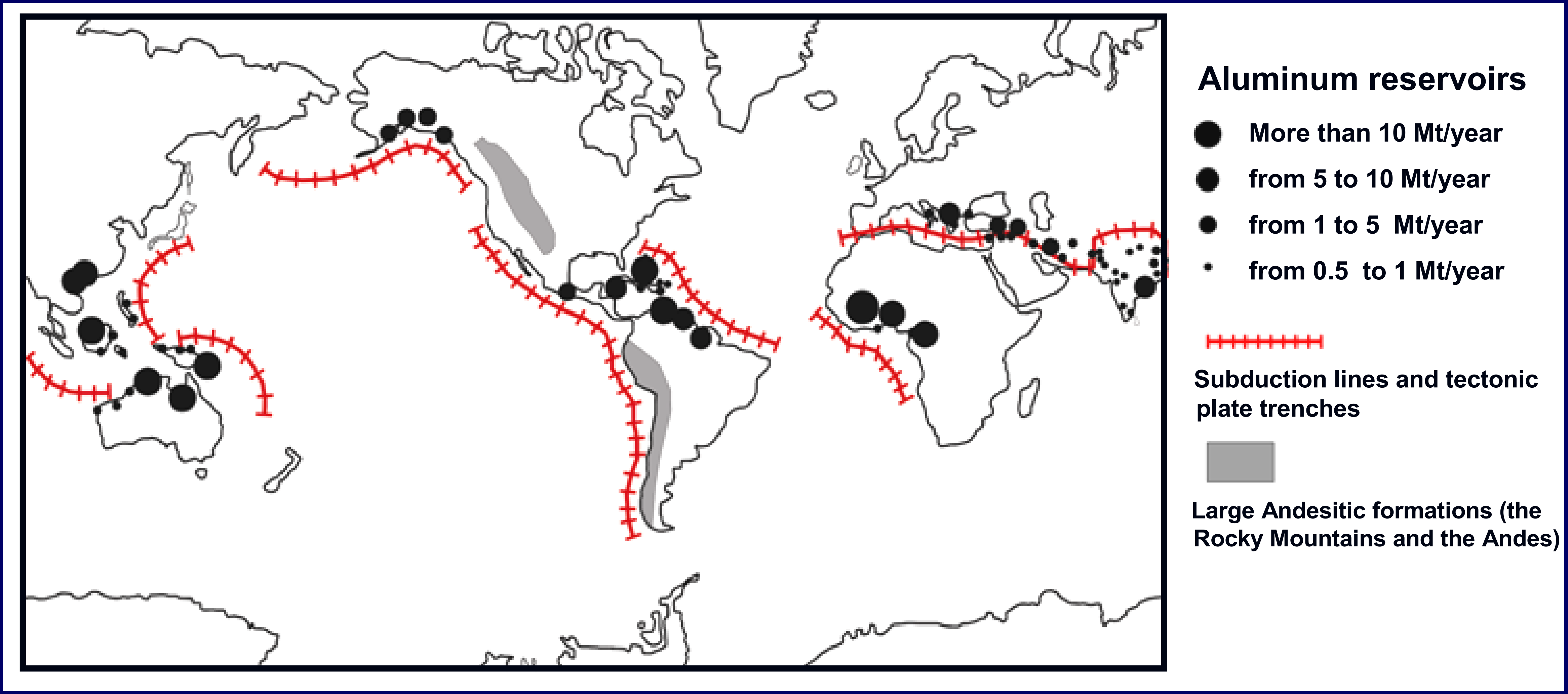
3.8 Billion years ago:
Ca (–2.5%) + Mg(–3.2%) =
= K (+1.4%) + Na (+2.1%) + O (+2.2%)

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



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

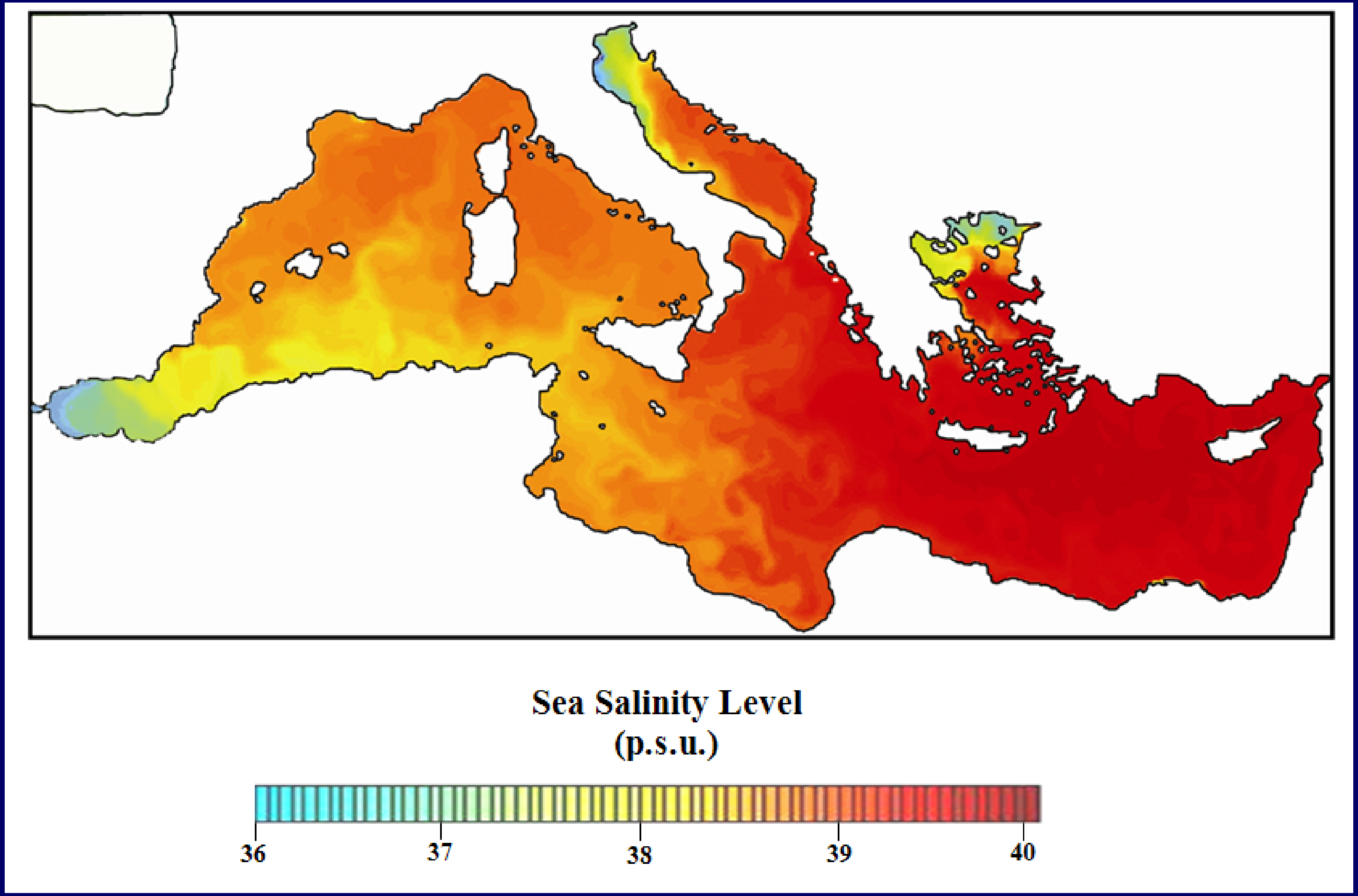
(**) World Mineral Resources Map. Available at http://www.mapsofworld.com/world-mineral-map.html.



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

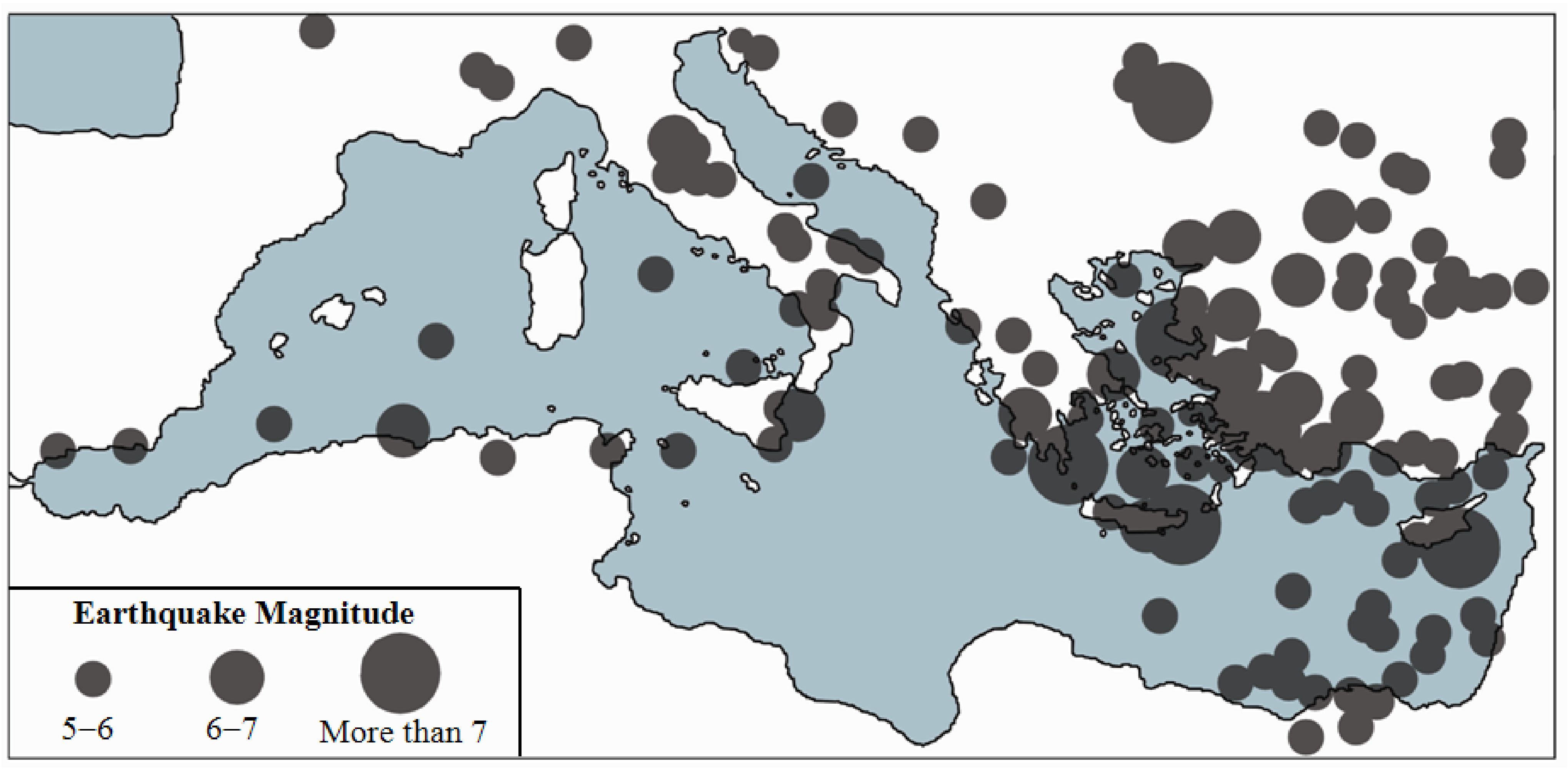
(**) World Mineral Resources Map. Available at http://www.mapsofworld.com/world-mineral-map.html.

Piezonuclear effects on 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.



$$Ni_{28}^{59} \rightarrow Na_{11}^{23} + Cl_{17}^{35} + 1 \text{ neutron}$$

CONCLUSIONS

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}, Mg_{12}, K_{19}, Ca_{20})
- Great Oxidation Event (2.5 Billion years ago)
- Carbon pollution and climatic variations
- Production of Rn, CO_2, neutrons during earthquakes

- Short-term prediction and monitoring of earthquakes

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(2) Konhauser, K O. et al., “Oceanic Nickel Depletion and a Methanogen Famine Before the Great Oxidation Event, *Nature*, 458, 750–754 (2009).

(1) Anbar A. D.,” Elements and Evolution”, *Science*, 322, 1481-1482 (2008).

(4) Taylor, S.R. and McLennan, S. M., “Planetary Crusts: Their Composition, Origin and Evolution”, Cambridge University Press, Cambridge. (2009).

(5) Tel-Aviv University Weather Research Center (TAU WeRC). Available at http://wind.tau.ac.il/salt-ina/salt.html; last accessed October 2009.

(6) European-Mediterranean Seismological Centre. Available at http://www.portergeo.com.au /tours/iron2002/-iron2002depm2b.asp; last accessed October 2009.

(7) Earthquake hazards program, Earthquake list&maps. Available at http://earthquake.usgs gov/earthquakes/eqarchives/year; last accessed October 2009.

(8) Kuzhevskij, B. M., Yu. Nechaev, O., Sigaeva, E. A. and Zakharov, V. A. “Neutron flux variations near the Earth’s crust. A possible tectonic activity detection”, *Nat. Hazards Earth Sys. Sci.,* 3, 637–645 (2003).

(9) Kuzhevskij, B. M., Yu Nechaev, O. and Sigaeva, E. A. “Distribution of neutrons near the Earth’s surface”, *Nat. Hazards Earth Sys. Sci.,* 3, 255–262 (2003).