Reazioni Nucleari Anomale Prodotte da Sollecitazioni Meccaniche

Giovedì 14 Aprile, 2011

Politecnico di Torino, Facoltà di Ingegneria,
Sala del Consiglio

Le reazioni piezonucleari dovute alla frattura fragile: Dalle evidenze di laboratorio ai riscontri su scala planetaria

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INERT AND NON-RADIOACTIVE MATERIALS

- Carpinteri, A., Cardone, F., Lacidogna, G., "Energy emissions from failure phenomena: Mechanical, electromagnetic, nuclear", *Experimental Mechanics*, 2009, 50, 1235-1243.
- 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., Chiodoni, A., Manuello, A., Sandrone, R.,"Compositional and microchemical evidence of piezonuclear fission reactions in rock specimens subjected to compression tests", *Strain*, doi: 10.1111/j.1475-1305.2010.00767.x, (2010).
- Carpinteri, A., Manuello, A., "Geomechanical and Geochemical evidence of piezonuclear fission reactions in the Earth's Crust", *Strain*, doi:10.1111/j.1475-1305.2010.00766.x, (2010).

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Energy Emissions from Failure Phenomena: Mechanical, Electromagnetic, Nuclear

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Abstract Characterizing the nature of the different forms of energy emitted during compressive failure of brittle materials is an open and debated argument in the scientific literature. Some research has been already conducted on this subject in the scientific community based on the signals captured by the acoustic emission measurement systems. On the other hand, there are not many studies yet about the emission of electromagnetic charge, and for the first time we are talking about piezonuclear neutron emissions from very brittle failure of rocks specimens in compression. The authors analyze these three different emissions from an experimental point of view.

Keywords Brittle failure · Acoustic emission · Electromagnetic emission · Neutron measurements · Piezonuclear reactions · Element evolution

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Introduction

It is possible to demonstrate experimentally that the failure phenomena, in particular when they occur in a brittle way, i.e. with a mechanical energy release, emit additional forms of energy related to the fundamental natural forces.

While the acoustic emission (AE), due to pressure waves travelling in the medium as it happens for earthquakes, is well-known and already exploited for monitoring purposes, the electromagnetic radiation (EM), due to an electric charge redistribution after material failure, can be considered a relatively new phenomenon, which is at present under investigation. As regards, then, the neutron emission, this is the first time that a similar phenomenon is captured [1, 2].

Only for fluids subjected to cavitation, analogous piezonuclear emissions of neutrons were previously found in the experiments. Totally accepted theories explaining such anomalous phenomena are still lacking in the literature. It is not in the aims of the present contribution to provide a theoretical physics explanation to piezonuclear emissions, although the emergence of these emissions in relation to a cusp catastrophe failure may result to be of interest also to Experimental Mechanics.

Acoustic Emission

A Fractal Criterion for AE Monitoring

Monitoring a structure by means of the AE technique, it proves possible to detect the occurrence and evolution of stress-induced cracks. Cracking, in fact, is accompanied by the emission of elastic waves which propagate within the bulk of the material. These waves can be received and recorded by transducers applied to the surface of structural

Carpinteri, A., Cardone, F., Lacidogna, G., "Energy emissions from failure phenomena: Mechanical, electromagnetic, nuclear", *Experimental Mechanics*, 50, 1235-1243 (2009).

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.

KEY WORDS: *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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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: $Fe^{30}_{26} \to 2Al^{14}_{13} + 2$ 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 cm³. 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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Compositional and Microchemical Evidence of Piezonuclear Fission Reactions in Rock Specimens Subjected to Compression Tests

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ABSTRACT: Energy-dispersive X-ray spectroscopy (EDS) is performed on different samples of external or fracture surfaces belonging to specimens used in piezonuclear tests [*Strain* 45, 2009, 332; *Strain* (in press); Phys. Lett. A. 373, 2009, 4158]. For each sample, different measurements of the same crystalline phases (phengite or biotite) are performed to obtain averaged information of the chemical composition and to detect possible piezonuclear transmutations from iron to lighter elements. The samples were carefully chosen to investigate and compare the same minerals both before and after the crushing failure. Phengite and biotite, which are quite common in the Luserna stone (20 and 2%, respectively), are considered owing to the high iron concentration in their chemical compositions. The results of EDS analyses show that, on the fracture surface samples, a considerable reduction in the iron content (~25%) is counterbalanced by an increase in Al, Si, and Mg concentrations.

KEY WORDS: *compressive tests, energy-dispersive X-ray spectroscopy, piezonuclear reactions*

Introduction

It has been shown that pressure, exerted on radioactive or inert media, can generate nuclear reactions and reproducible neutron emissions. In particular, low-energy nuclear reactions and heat generation have been verified in pressurised deuterium gas by Arata *et al.* [1, 2] and in radioactive deuterium-containing liquids during ultrasounds and cavitation by Taleyarkhan *et al.* [3]. The experiments recently proposed by Carpinteri *et al.* [4] and by Cardone *et al.* [5] follow a different path from those of other research teams and represent the first evidence of piezonuclear reactions and neutron emissions in inert, stable and non-radioactive solids under compression, as well as in non-radioactive liquids during ultrasound cavitation [6, 7]. The analyses of this paper are in strict connection with the results of piezonuclear tests presented by Carpinteri *et al.* [4, 8] and by Cardone *et al.* [5].

Neutron emission measurements, by means of helium-3 neutron detectors, have recently been performed on solid test specimens during crushing failure [4, 5]. Neutron emissions from 'Luserna stone' 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' occurred in the granitic gneiss samples, transforming heavier (Fe) into lighter (Mg, Al, Si) atoms in correspondence to brittle failure of the specimens. These reactions – 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 [4, 5, 8].

In this paper, energy-dispersive X-ray spectroscopy (EDS) is described on different samples of external or fracture surfaces belonging to the same two specimens used in the piezonuclear tests by Carpinteri *et al.* [4, 5] to correlate the neutron emission from the Luserna stone with the variations in rock composition due to brittle failure of the granitic gneiss specimens. These analyses lead to obtain averaged information of the mineral chemical composition and to detect possible piezonuclear transmutations from iron to lighter elements. The quantitative elemental analyses were performed by a ZEISS Supra 40 field emission scanning electron microscope (FESEM) equipped with an Oxford X-ray microanalysis. The samples were carefully chosen to investigate and

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Geomechanical and Geochemical Evidence of Piezonuclear Fission Reactions in the Earth's Crust

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ABSTRACT: Piezonuclear reactions, which occur in inert and non-radioactive elements, are induced by high pressure and, in particular, by brittle fracture phenomena in solids under compression. These low-energy reactions generally take place in nuclei with an atomic weight that is lower or equal to that of iron (Fe). The experimental evidence, obtained from repeatable measurements of neutron emissions [*Strain* 45, 2009, 332; *Strain* (in press); Phys. Lett. A. 373, 2009, 4158], can be also recognised considering the anomalous chemical balances of the major events that have affected the Earth's crust, oceans and atmosphere, over the last 4 billion years. These anomalies include (i) abrupt variations in the most abundant elements in correspondence with the formation of tectonic plates; (ii) the 'Great Oxidation Event' (2.7–2.4 billion years ago), with a sharp increase in atmospheric oxygen and the subsequent origin of life; (iii) the current climate acceleration partially because of 'carbon pollution'. Natural piezonuclear reactions are induced by fault sliding and plate subduction phenomena.

KEY WORDS: *carbon pollution, element evolution, Great Oxidation Event, neutron emissions, piezonuclear reactions, plate tectonics, rocks crushing*

Introduction

Over the last century, most recent scientific disciplines such as cosmology, astrophysics, and geology, have tried to answer questions concerning the origin of the Earth and the universe [1, 2]. Such questions have now given place to interrogatives concerning the substance that composes the universe, the heterogeneous distribution of the main elements on the Earth, and their evolution in time [1, 3–7].

The Earth's composition and its way of evolving throughout the geologic eras are topics that give rise to an abundancy of questions that have remained unanswered [3, 7]. In fact, we still do not know whether the distribution of the constituent elements is the result of the initial formation phases of the proto-Earth, or if it is the effect of slow transformations that started to occur after the beginning of terrestrial evolution, about 4.57 billion years (Gyrs) ago [5–7].

Significant events, such as the Great Oxidation Event (GOE), in which 10^5-fold increase in the concentration of oxygen took place in the Earth's atmosphere between 2.7 and 2.4 Gyrs ago [8–12], the strong iron depletion in the composition of the oceans and Earth's crust [6, 10, 13, 14], and the drastic decrease in nickel [14, 15], are just some of the major events pertaining to the Earth's dynamics and the evolution of chemical elements that have remained unresolved.

In this work, which is based on recent studies by Carpinteri *et al.* [16, 17] and Cardone *et al.* [18] concerning piezonuclear fission reactions, a geophysical and geological explanation is proposed to the main compositional variations in the Earth's crust and atmosphere, from their origin until present times.

It has been shown that pressure, exerted on radioactive or inert media, can generate nuclear reactions and reproducible neutron emissions. In particular, low-energy nuclear reactions and heat generation have been verified in pressurised deuterium gas by Arata *et al.* [19, 20] and in radioactive deuterium-containing liquids during ultrasounds and cavitation by Taleyarkhan *et al.* [21]. The experiments recently proposed by Carpinteri *et al.* [16] and by Cardone *et al.* [18] follow a different path from those of other research teams and represent the first evidence of piezonuclear reactions and neutron emissions in inert, stable, and non-radioactive solids under compression, as well as in non-radioactive liquids during ultrasound cavitation [22, 23].

Neutron emission measurements, by means of helium-3 neutron detectors, have recently been

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Carpinteri, A., Manuello, A., "Geomechanical and Geochemical evidence of piezonuclear fission reactions in the Earth's Crust", *Strain*, doi:10.1111/j.1475-1305.2010.00766.x, (2010).

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EXPERIMENTAL SETUP

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 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 cm^3.

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

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.

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

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.

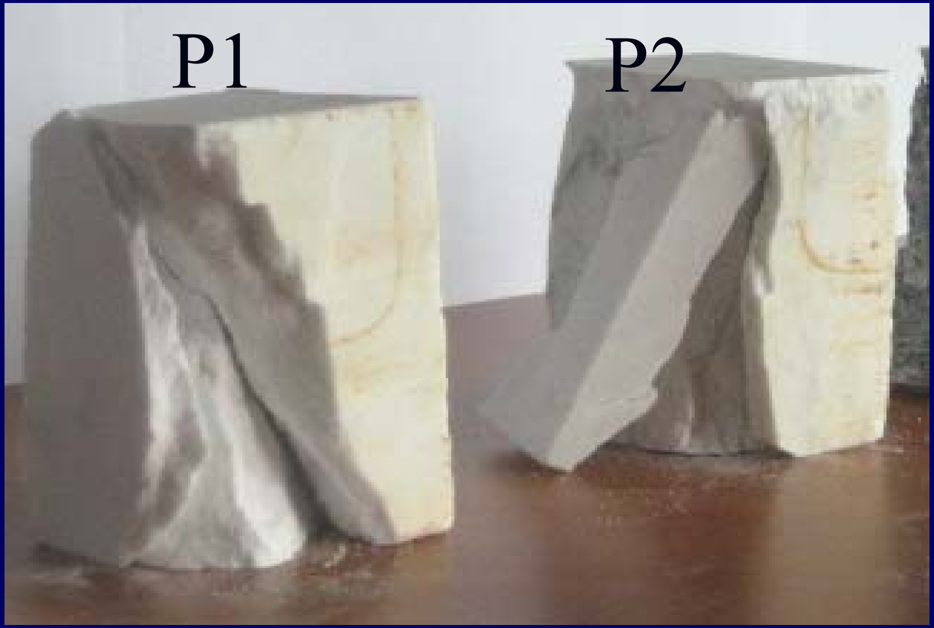
The average background count rate was:

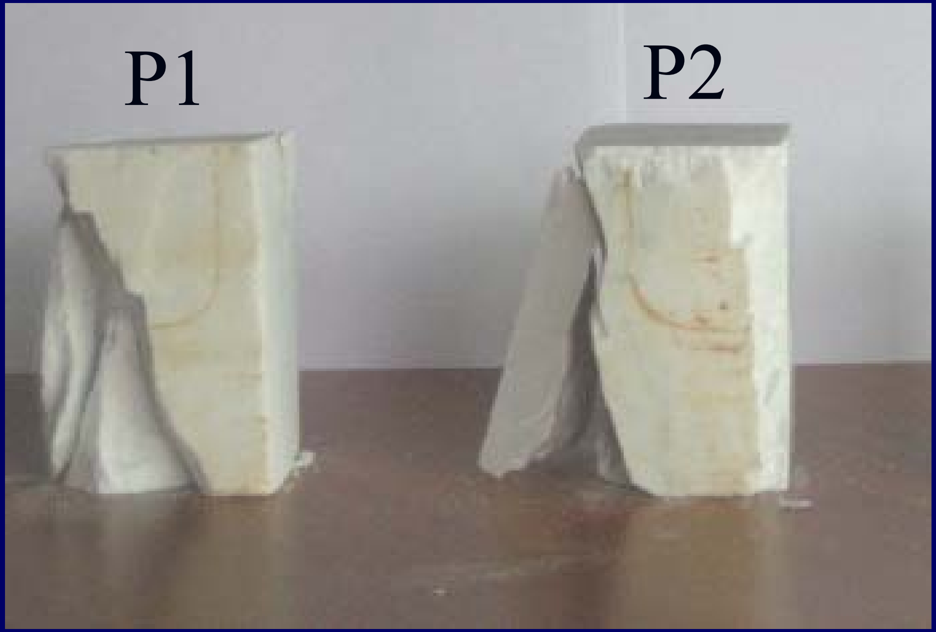
$$(3.8 \pm 0.2) \times 10^{-2} \text{ cps.}$$

During the loading tests

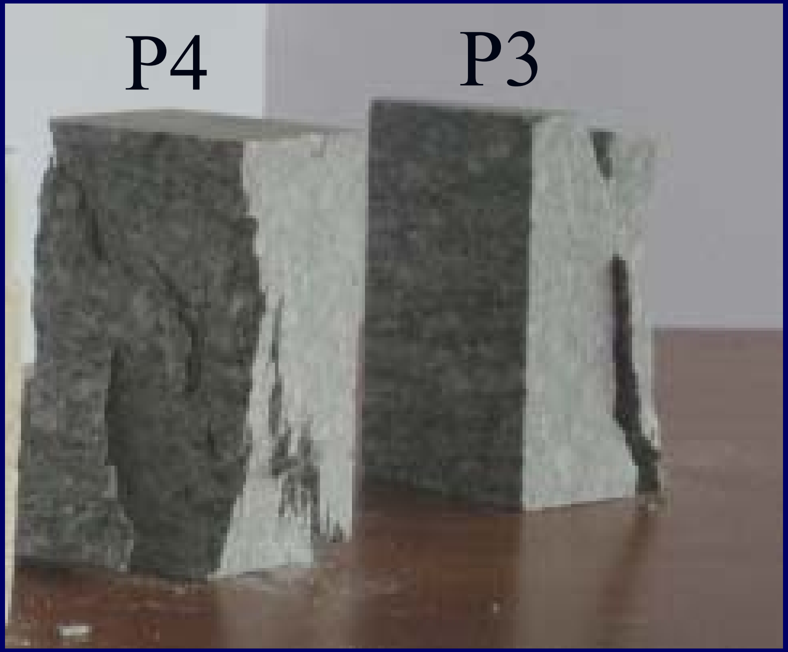
- The neutron measurements obtained on the two Carrara marble specimens yielded values comparable with the background, even at the time of test specimen failure.

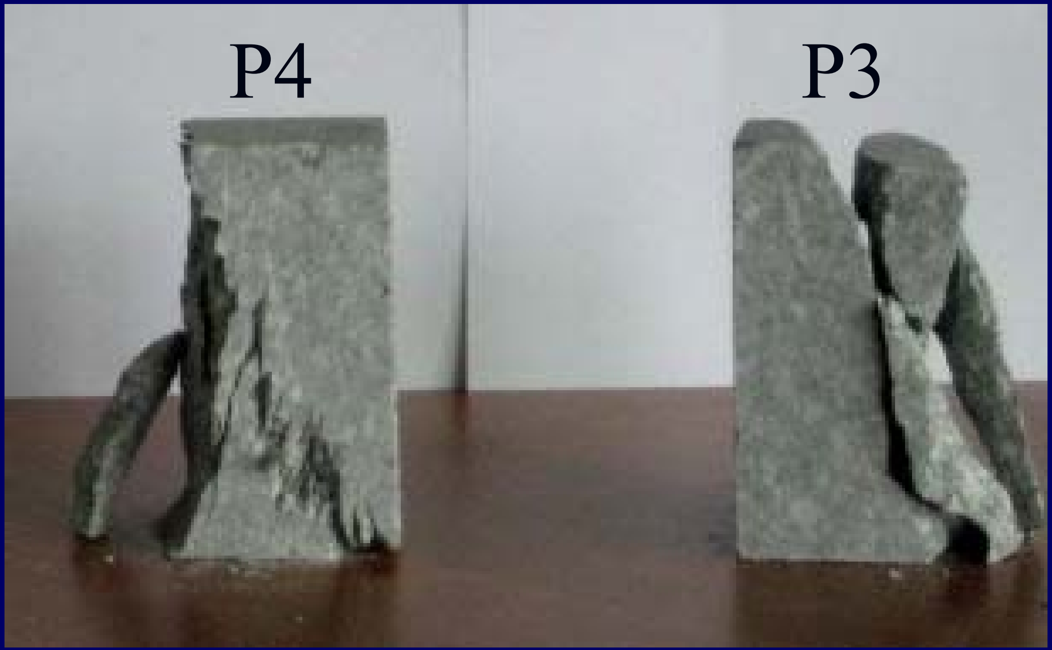
- The neutron measurements obtained on the two Luserna granite specimens, instead, exceeded the background value by about one order of magnitude at the test specimen failure.



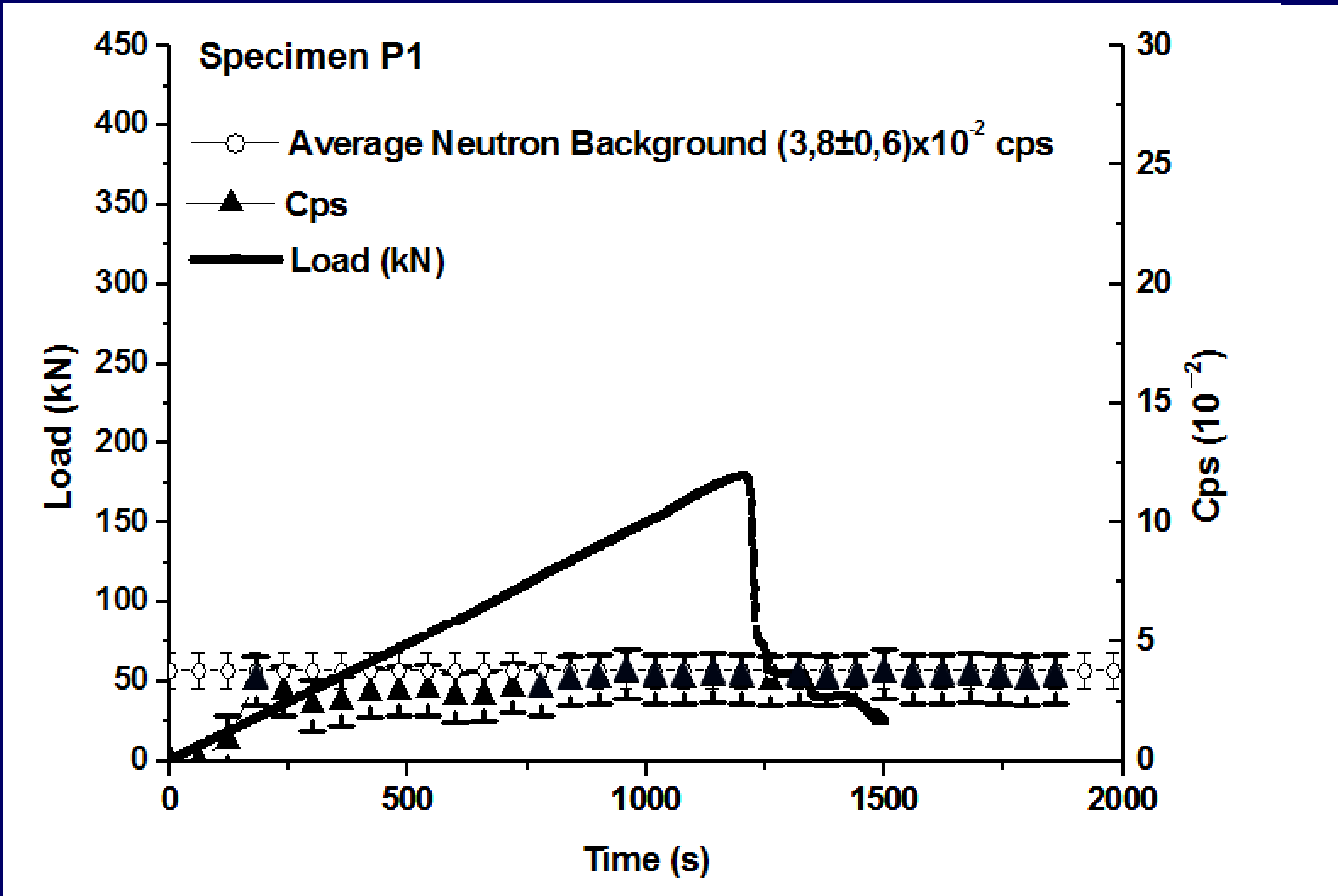


Specimens P1 and P2 in Carrara marble following compression failure.

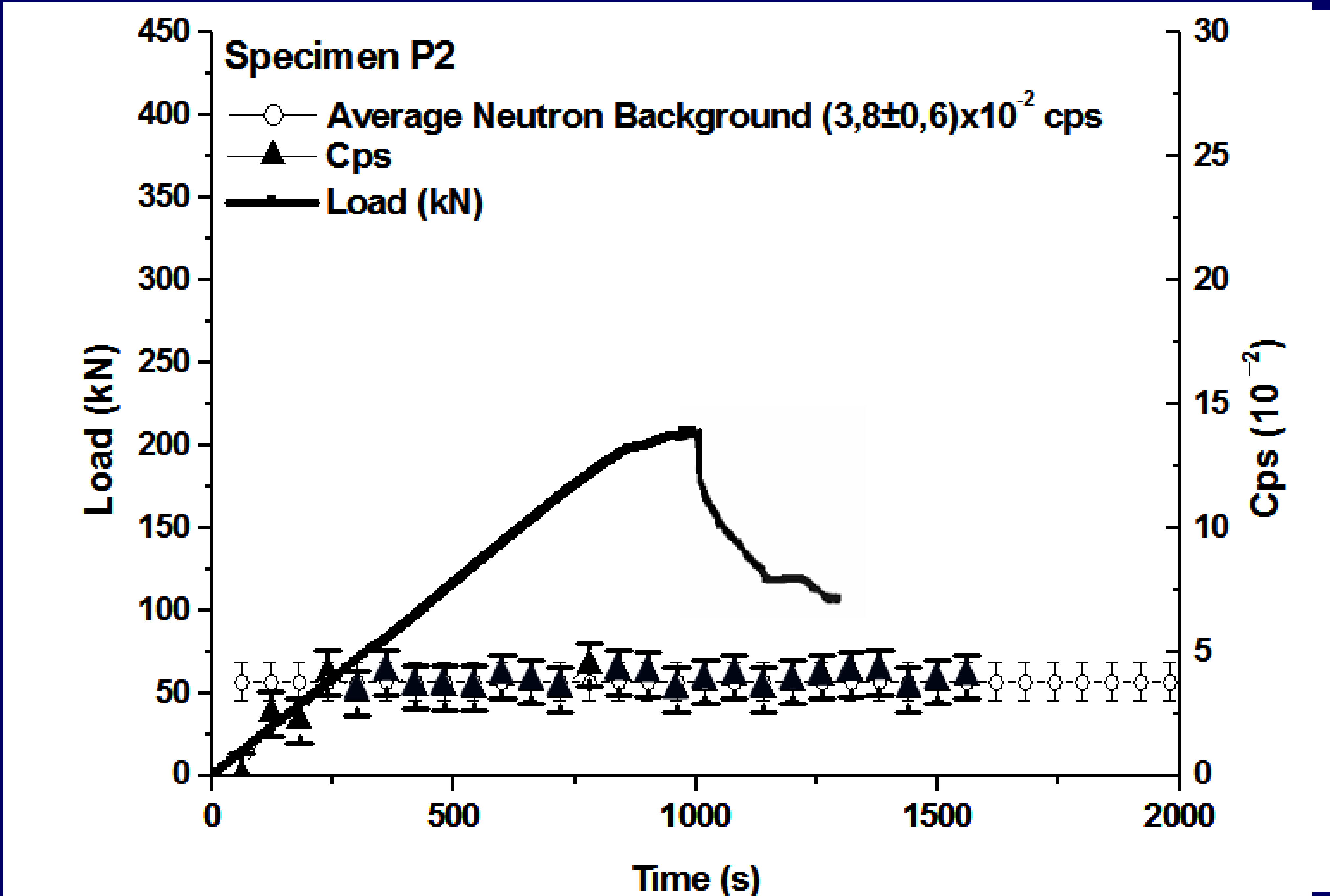




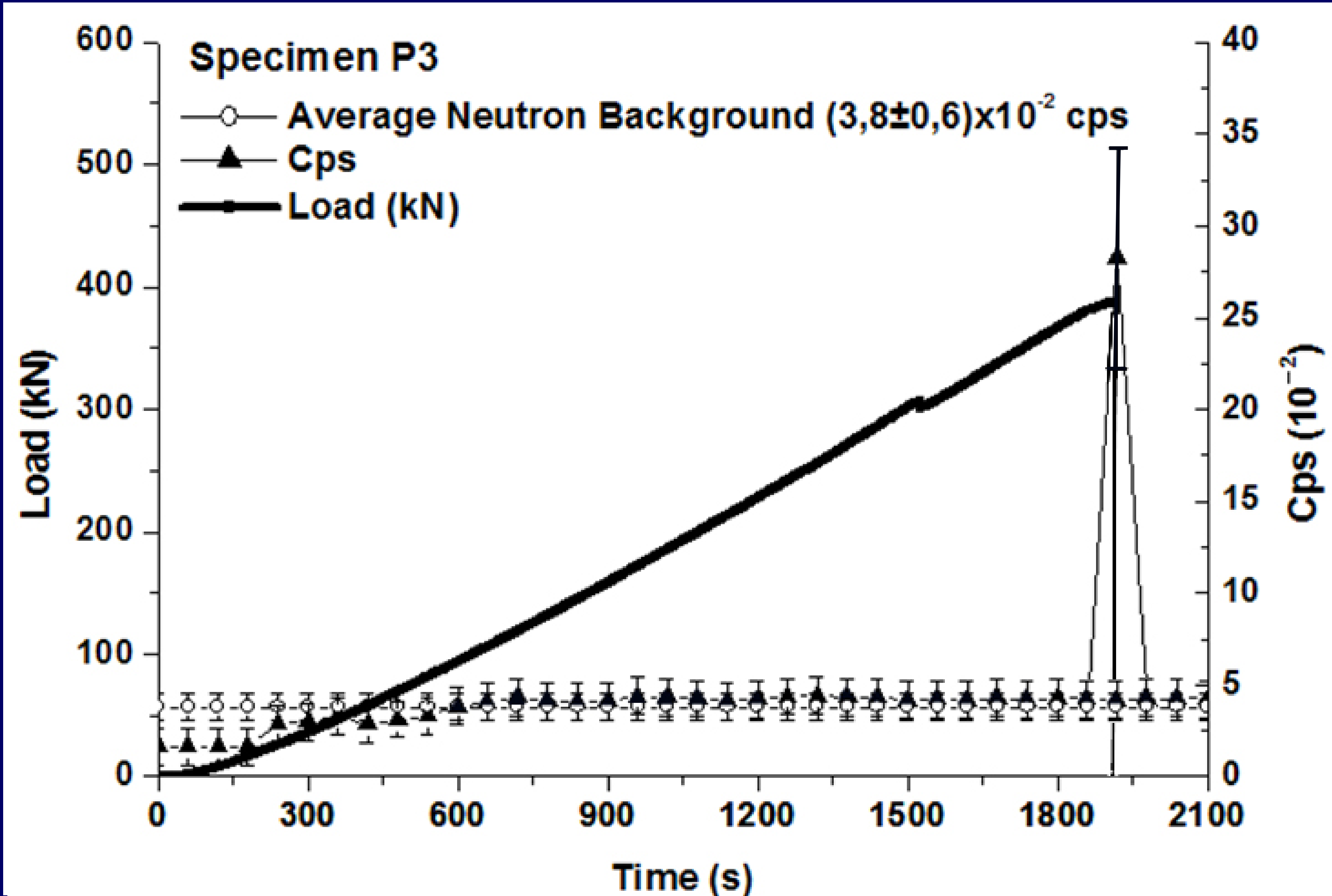
Specimens P3 e P4 in Luserna granite following compression failure.



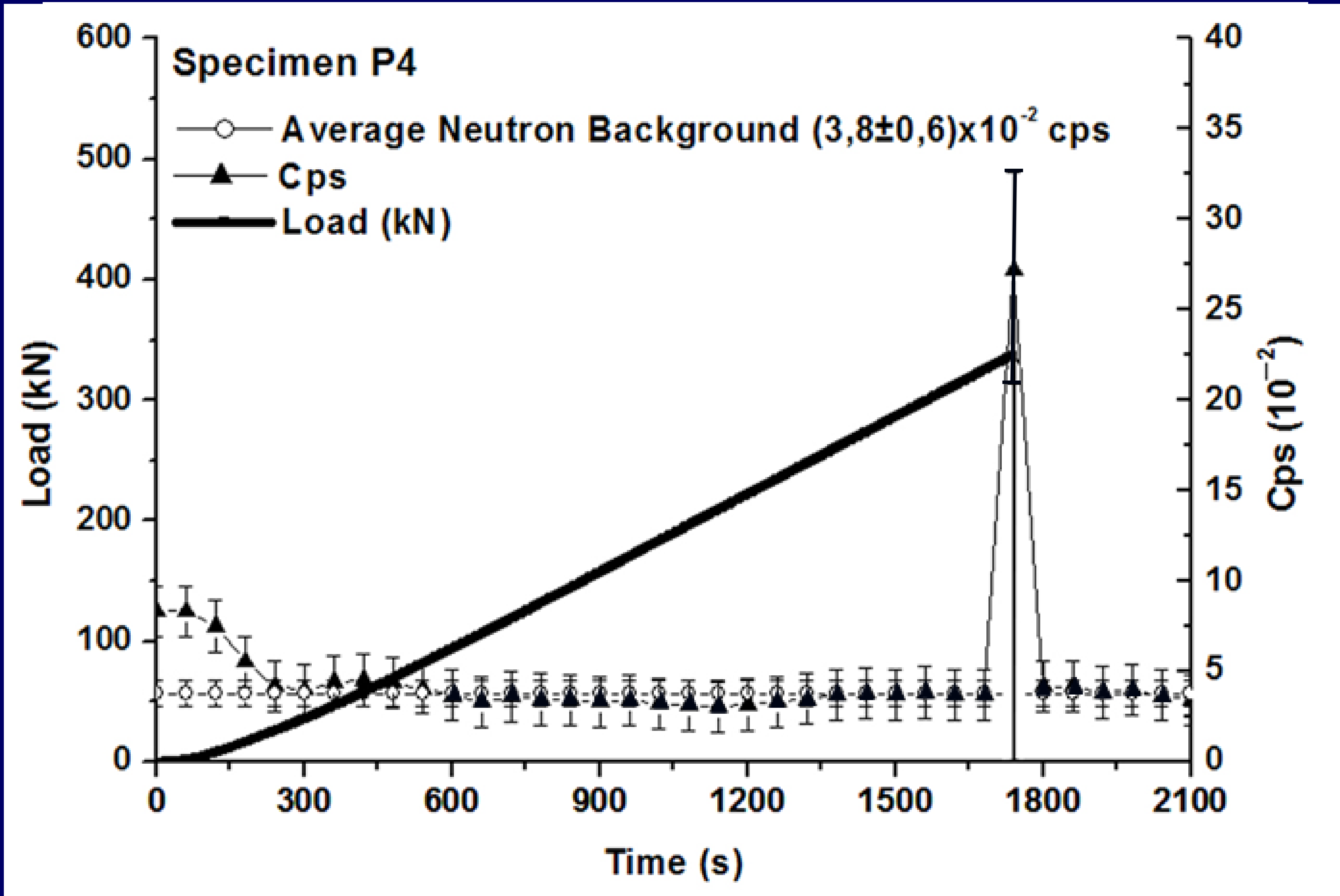
Load vs. time and cps curve for P1 test specimen in Carrara marble.



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

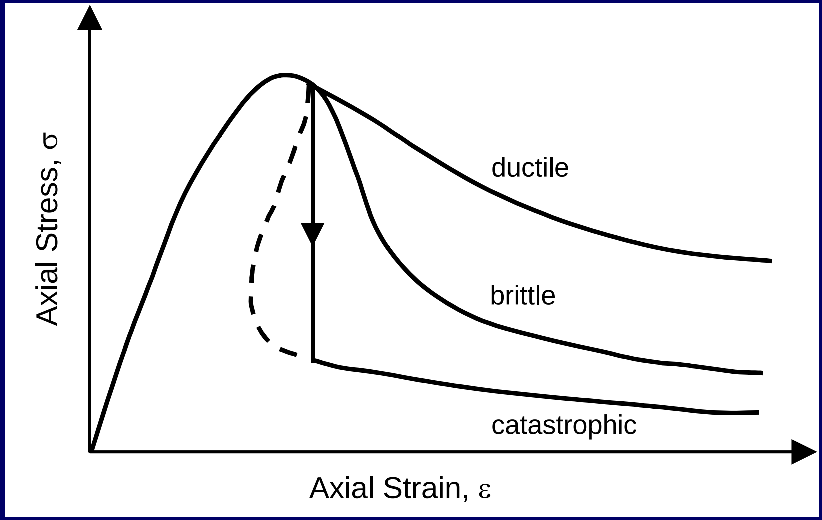


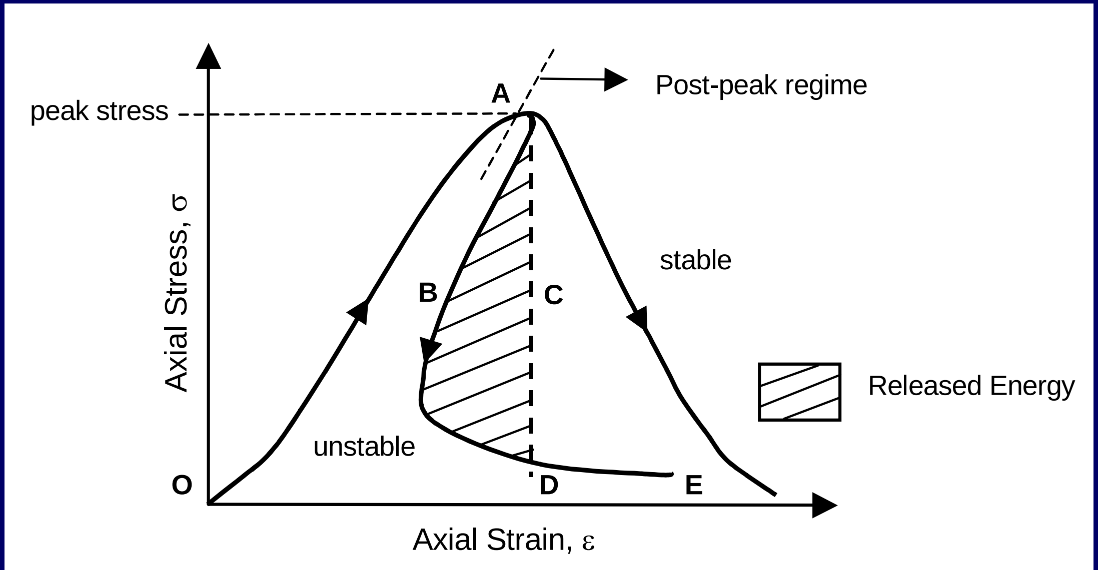
Load vs. time and cps curve for P3 test specimen in Luserna granite.



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

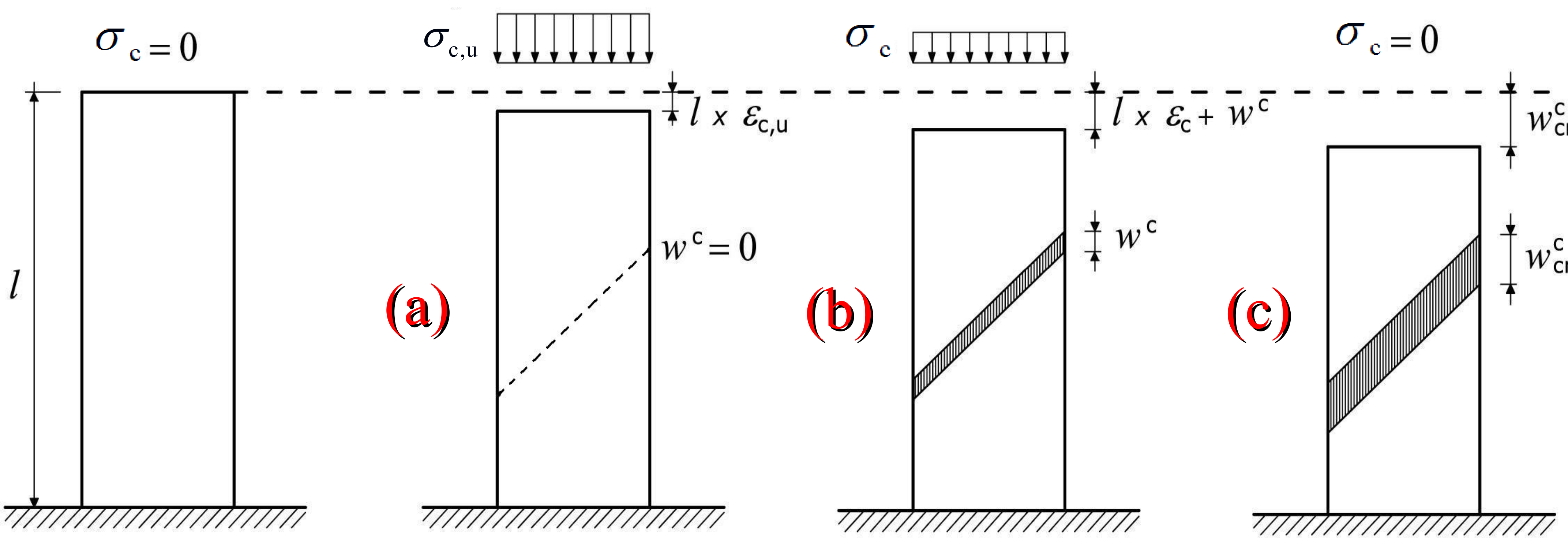
DUCTILE, BRITTLE AND CATASTROPHIC BEHAVIOUR





Energy release and stable vs. unstable stress-strain behaviour

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

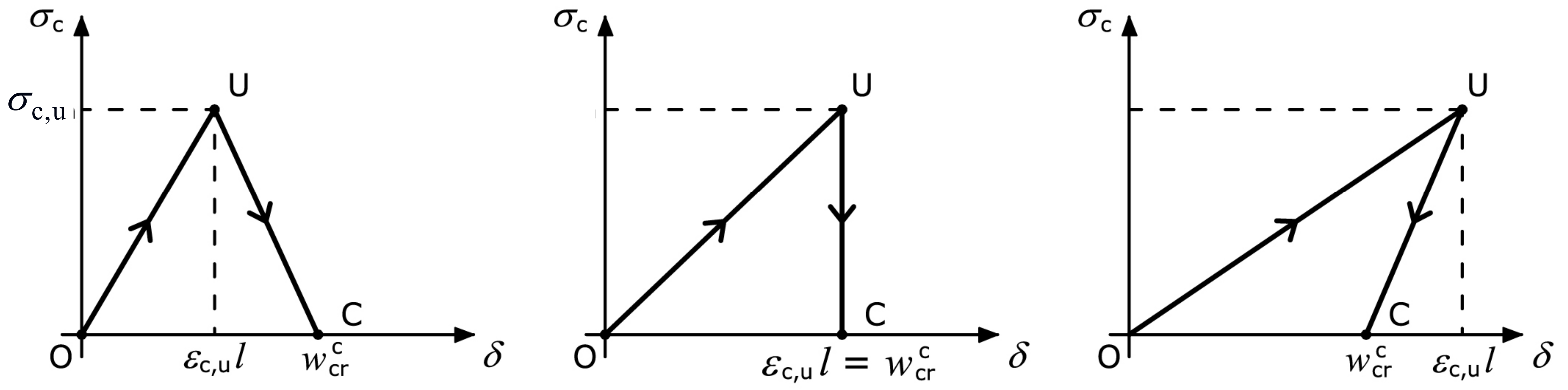


$$\delta = \varepsilon_c l = \frac{\sigma_c}{E} l; \qquad \delta = \frac{\sigma_c}{E} l + w^c; \qquad \delta \geq w^c_{cr}.$$

[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



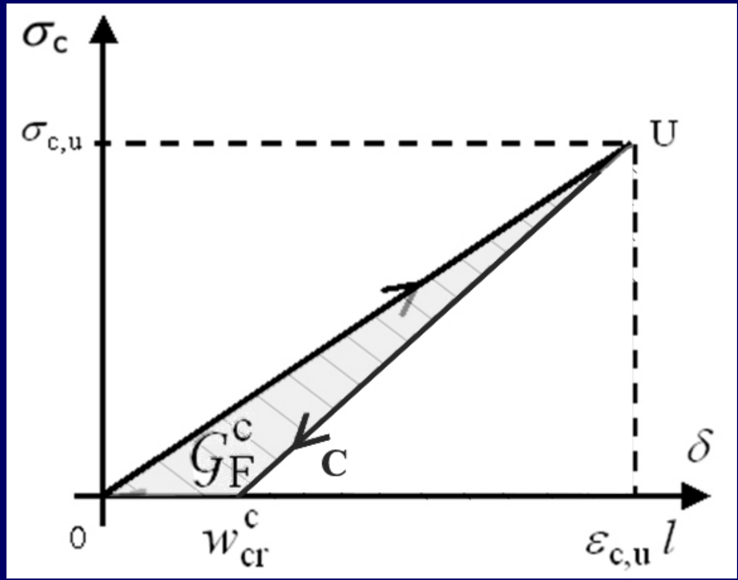
Normal softening | **Vertical drop** | **Catastrophic behaviour**

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:

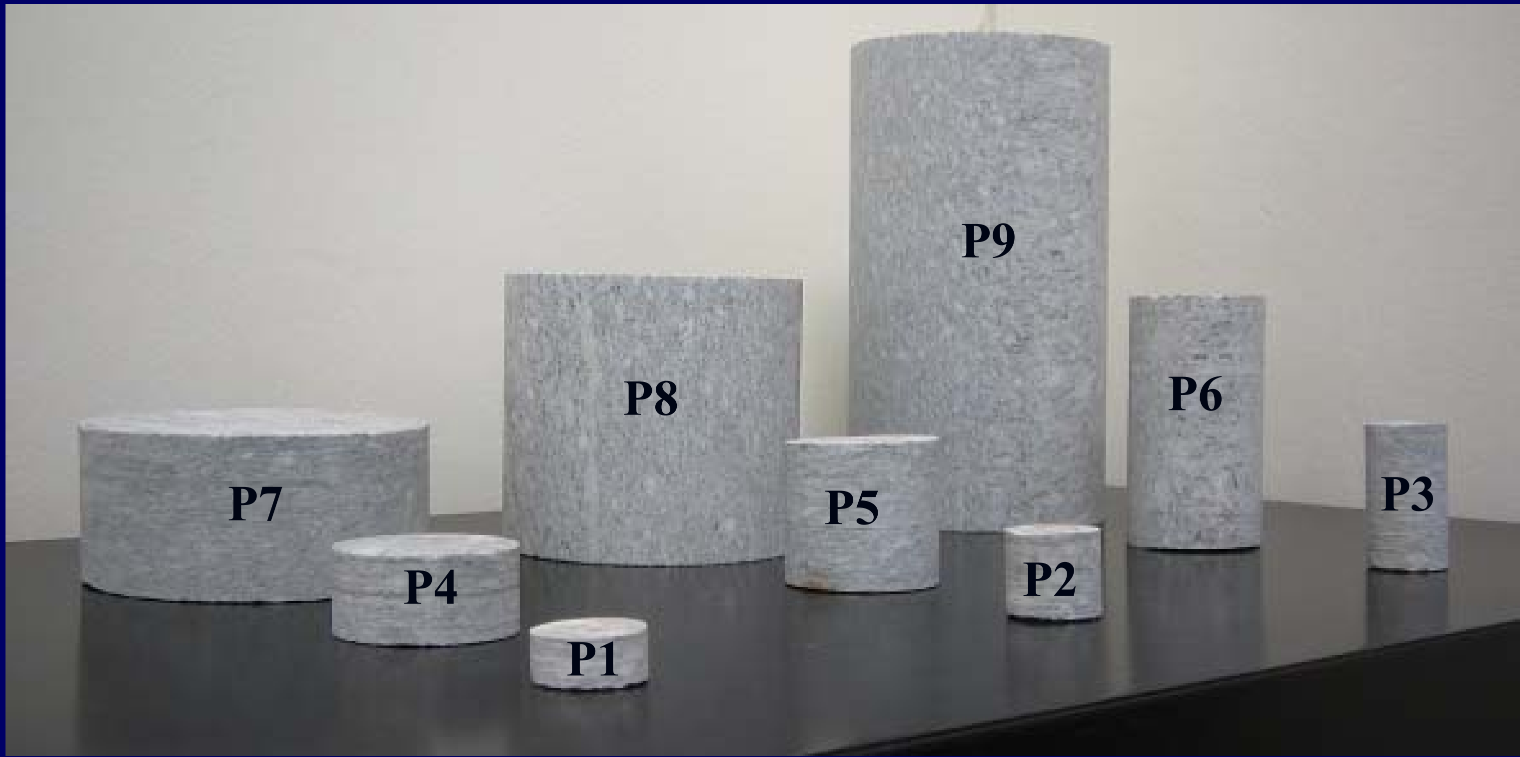
$$\Delta x \sim w_{cr}^{c}\ ?$$

(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 mm; λ= 0.5, 1.0, 2.0)**

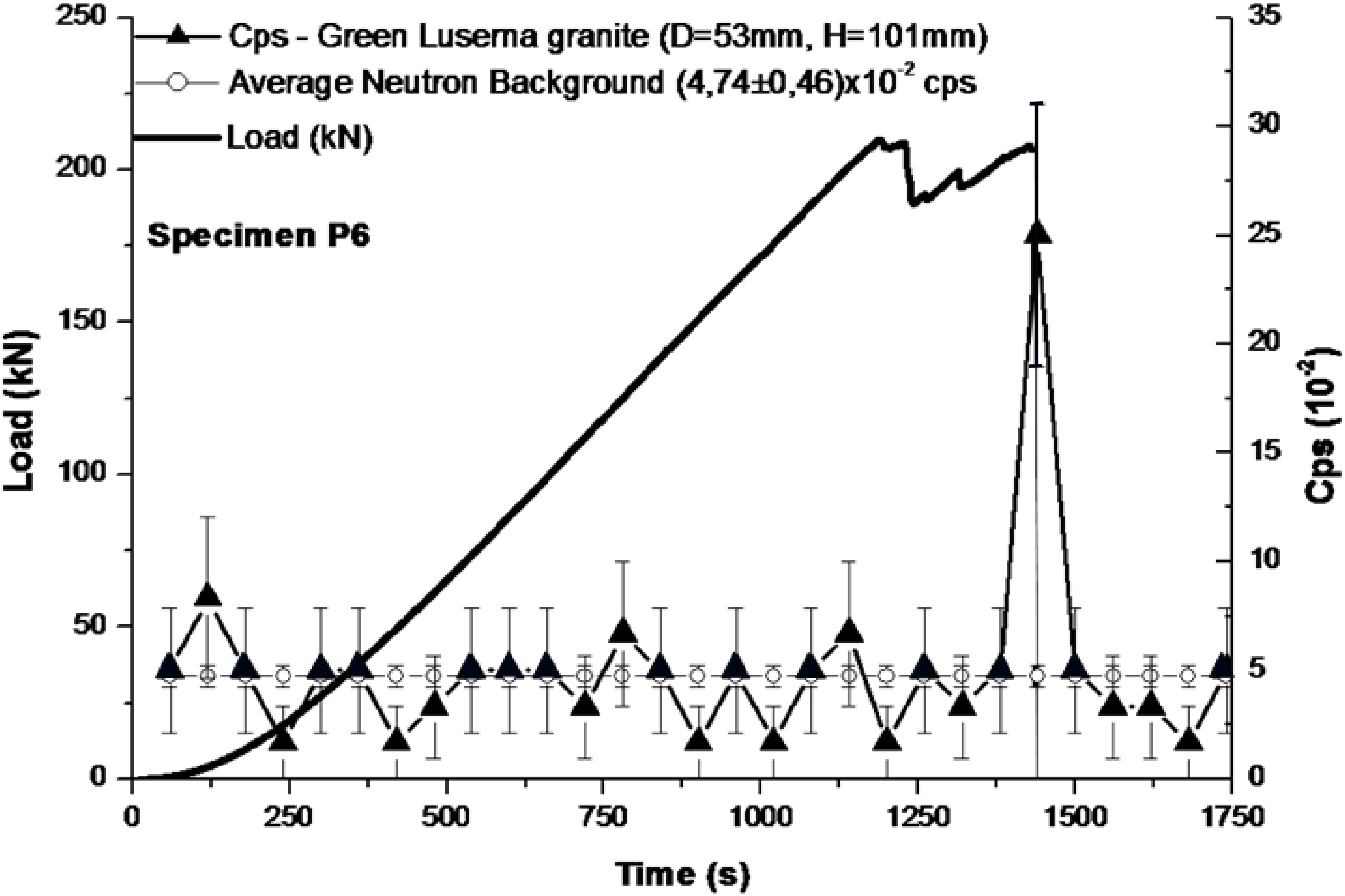
Monotonic Load: Experimental Results

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

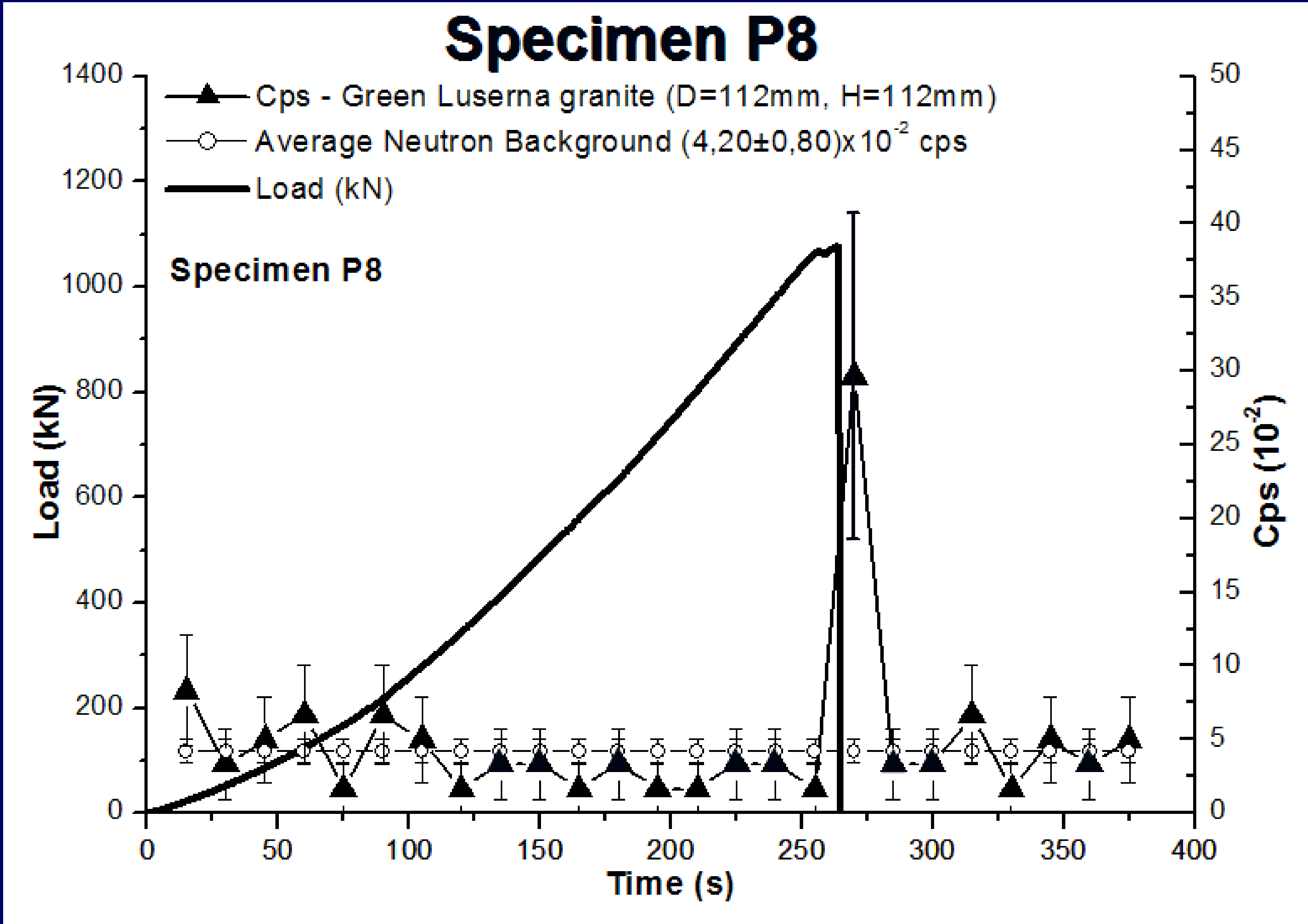
Neutron measurements of specimen P2, P3, P4, P7 yielded values comparable with the ordinary natural background.

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.

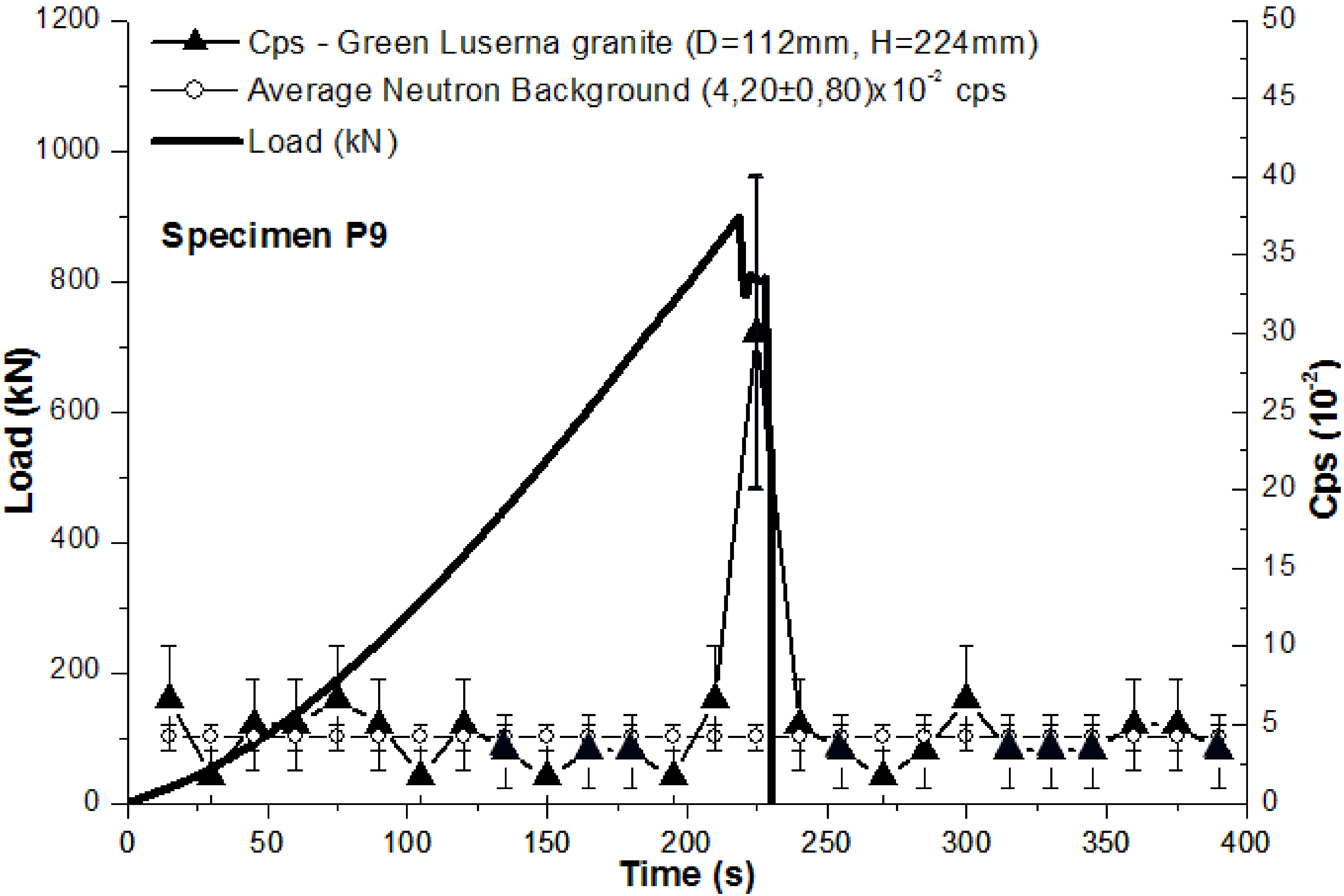
Specimen P6



Cps - Green Luserna granite (D=53mm, H=101mm)
Average Neutron Background (4,74±0,46)x10^-2 cps
Load (kN)
Specimen P6
Load (kN)
Cps (10^-2)
Time (s)
0
250
500
750
1000
1250
1500
1750
50
100
150
200
5
10
15
20
25
30
35


Specimen P8
Cps - Green Luserna granite (D=112mm, H=112mm)
Average Neutron Background (4,20±0,80)x10^-2 cps
Load (kN)
Specimen P8
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

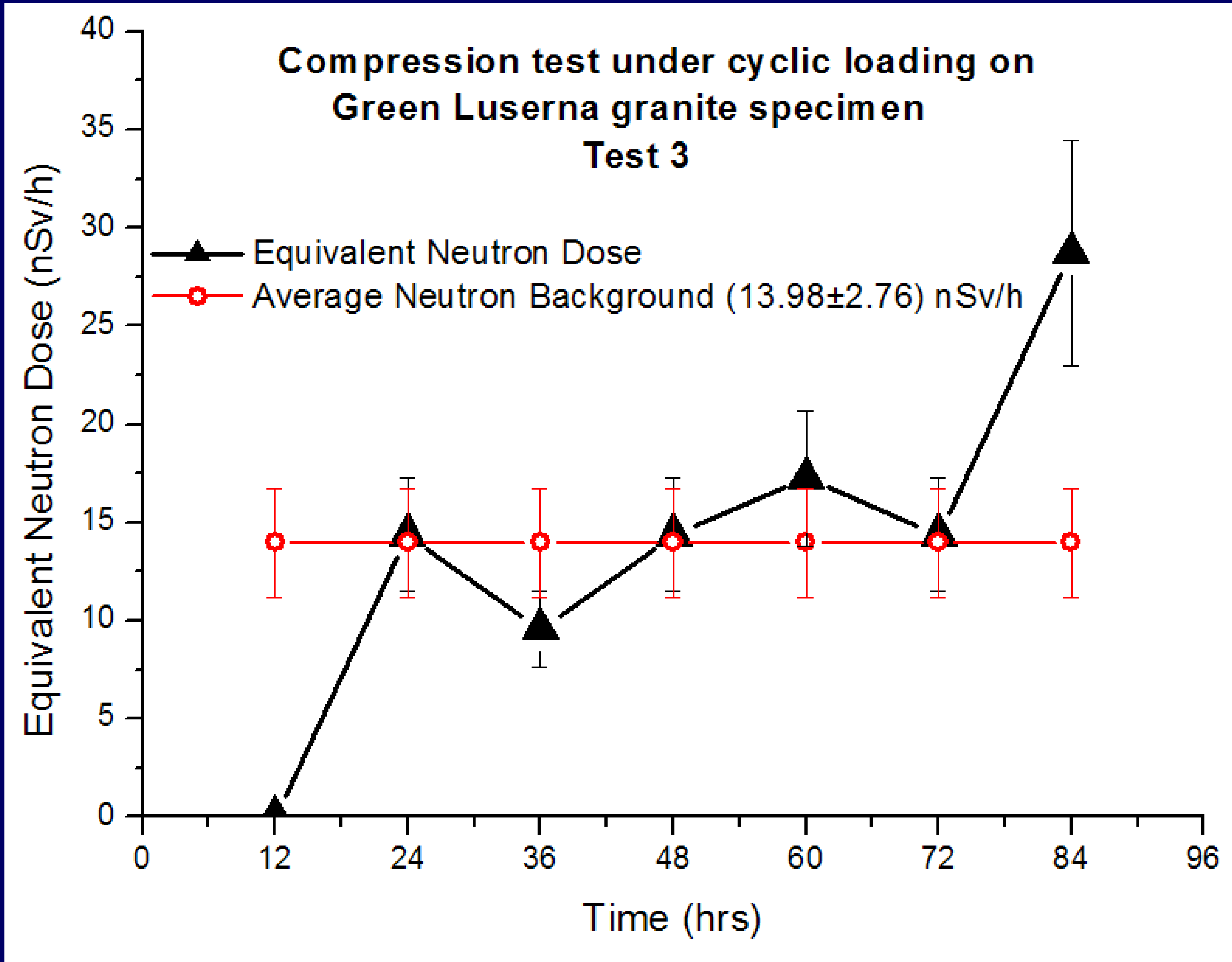
Specimen P9



Cps - Green Luserna granite (D=112mm, H=224mm)
Average Neutron Background (4,20±0,80)x10-2 cps
Load (kN)
Specimen P9
Load (kN)
Cps (10-2)
Time (s)
0
50
100
150
200
250
300
350
400
200
400
600
800
1000
1200
5
10
15
20
25
30
35
40
45
50

Cyclic Loading

Neutron emissions from compression tests under cyclic loading (frequency= 2 Hz) 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.

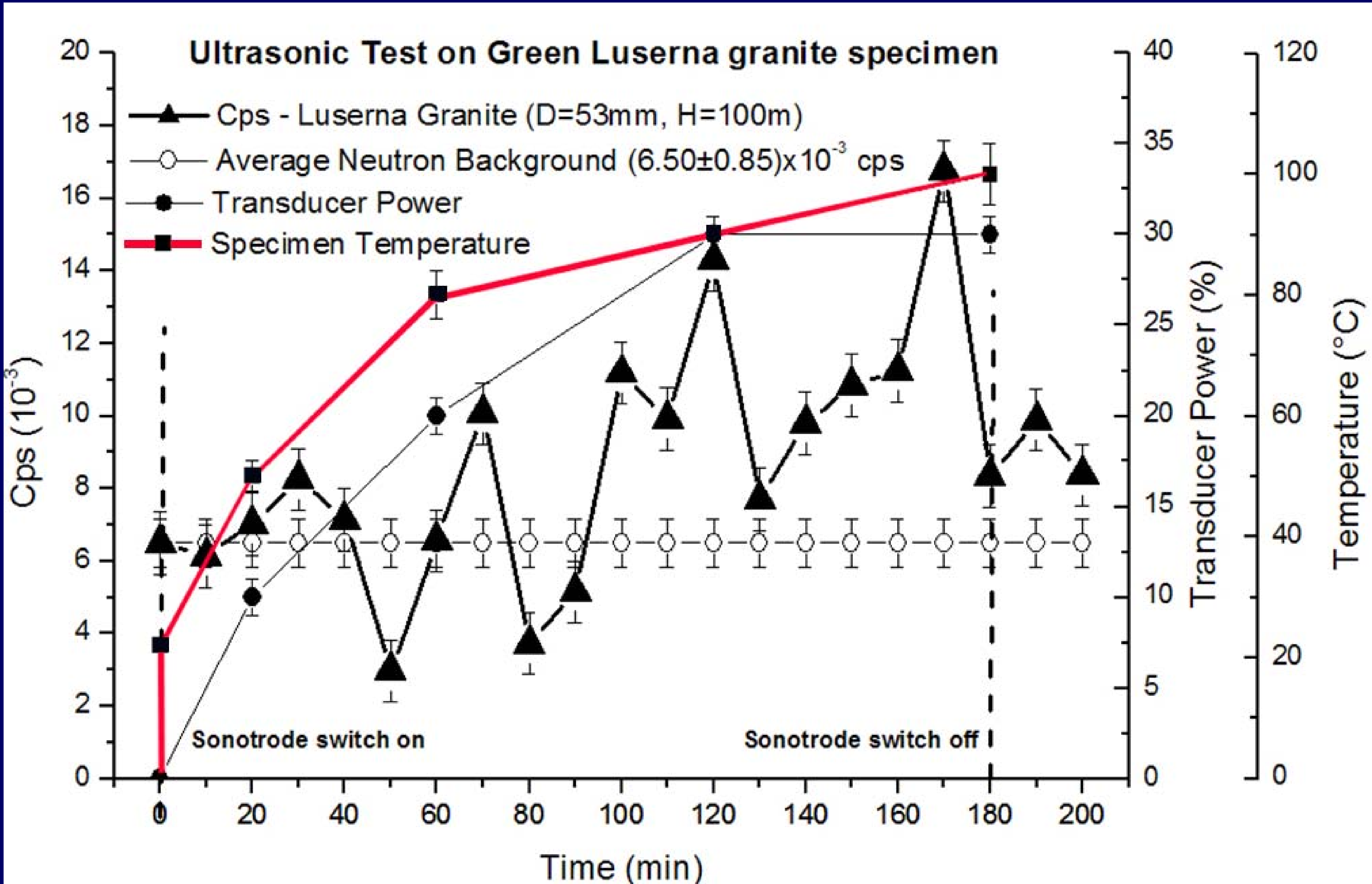


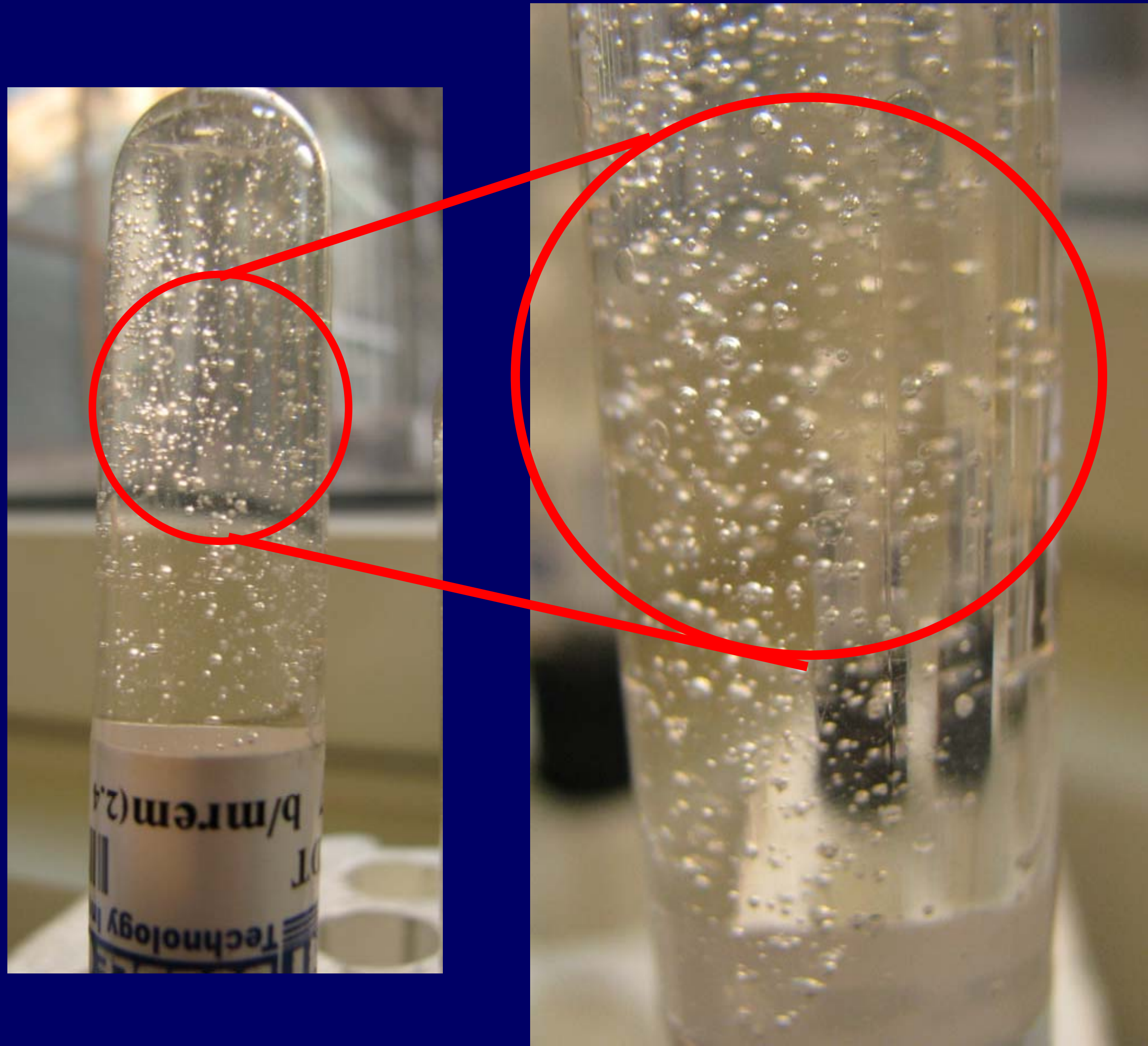
The equivalent neutron dose variation, evaluated during the third cyclic loading test, is shown. An increment of more than twice with respect to the background level was detected at specimen failure.

Vibrational Loading

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

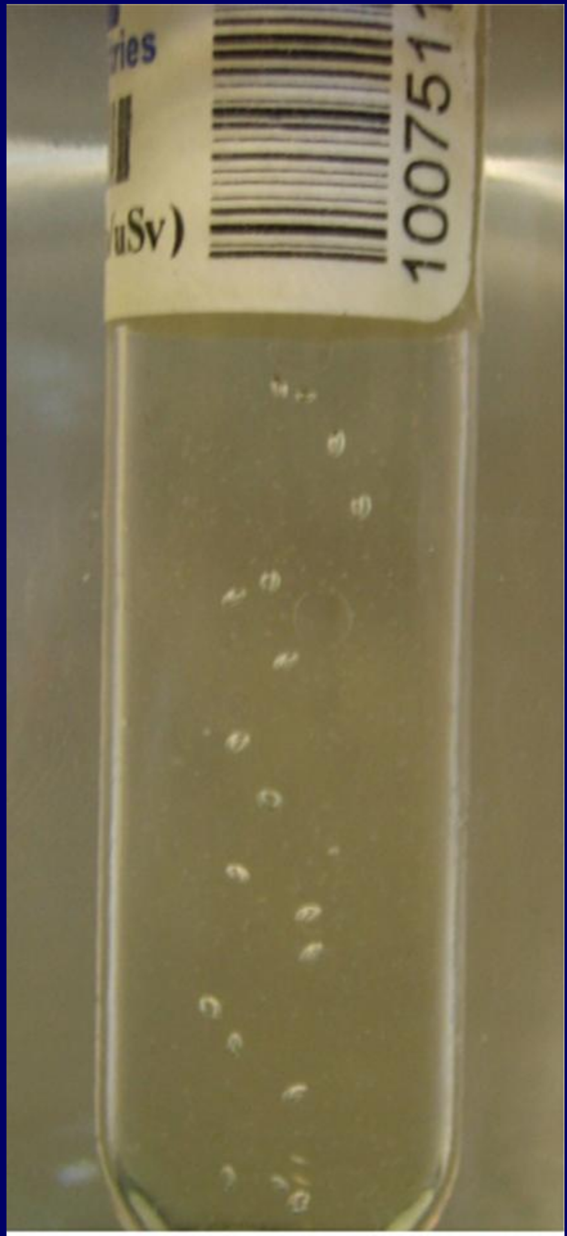


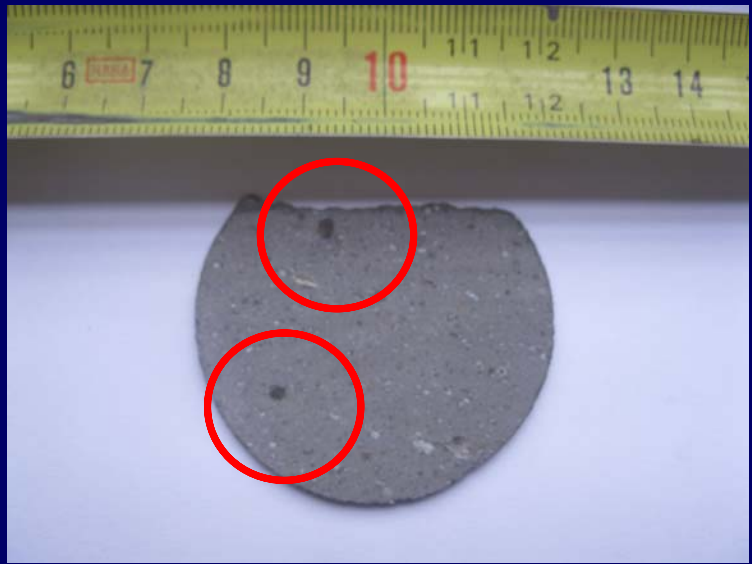


The equivalent neutron dose, at the end of the test on Basaltic Rock, was 2.62 ± 0,53 μSv/h (Average Background Dose = 41.95 ± 0,85 nSv/h).

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

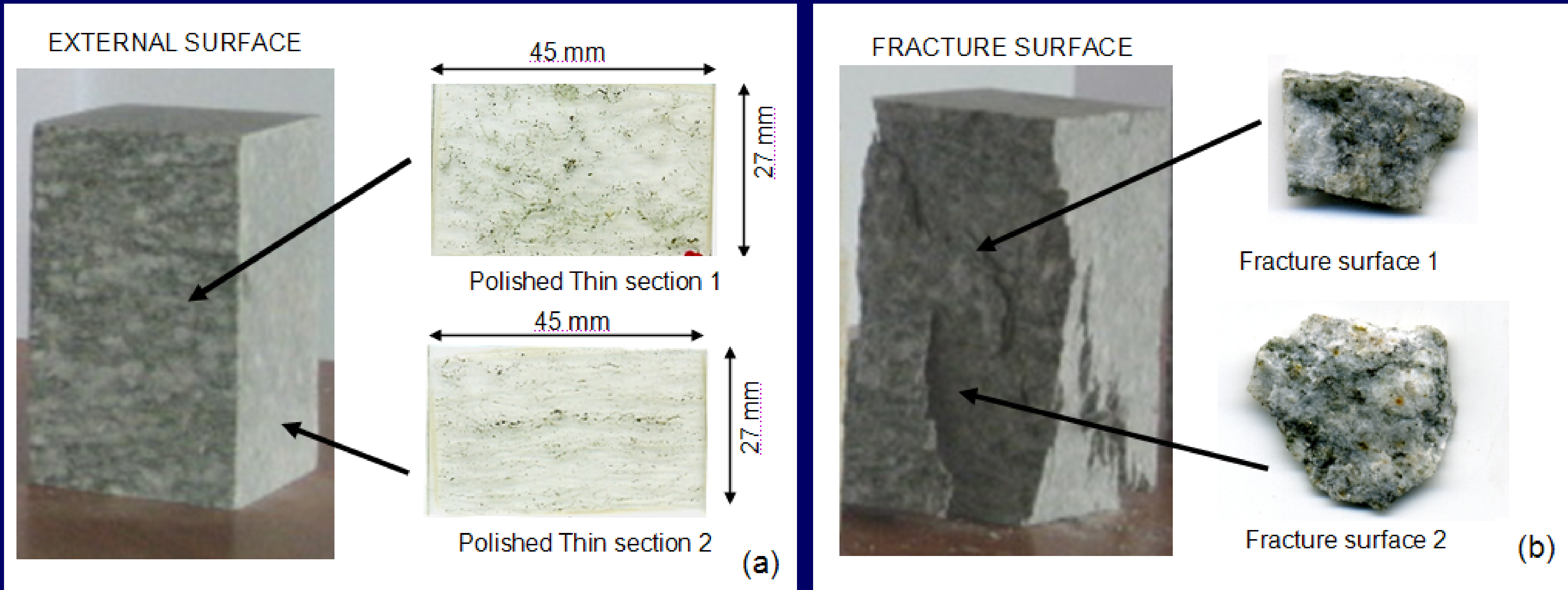
Microcraters and Explosions in Basalt Specimens





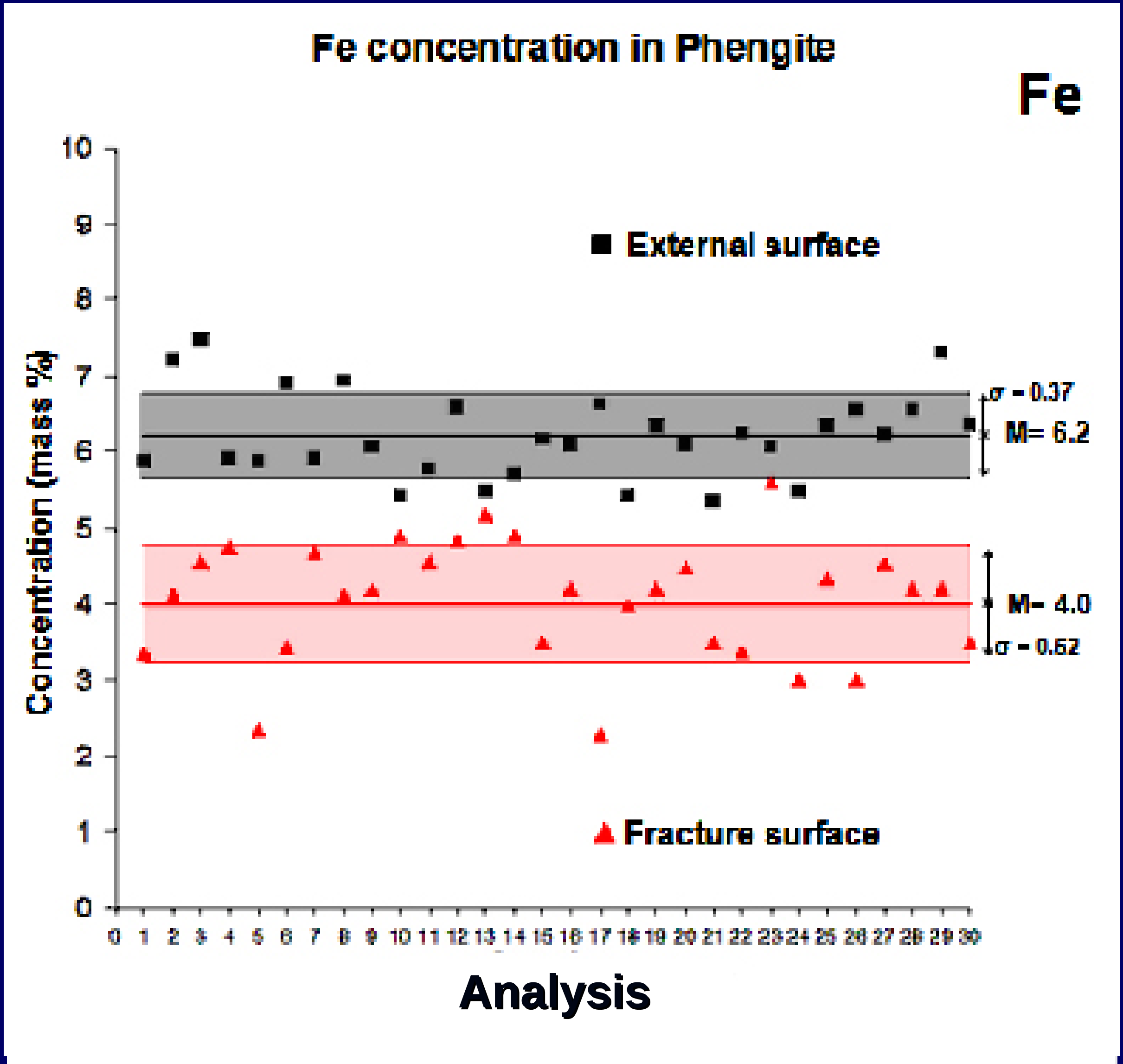
DIRECT EVIDENCE: EDS COMPOSITIONAL ANALYSIS

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.

Phengite: Fe concentrations



External Surf.:

Fe content M= 6.20%

Fracture Surf.:

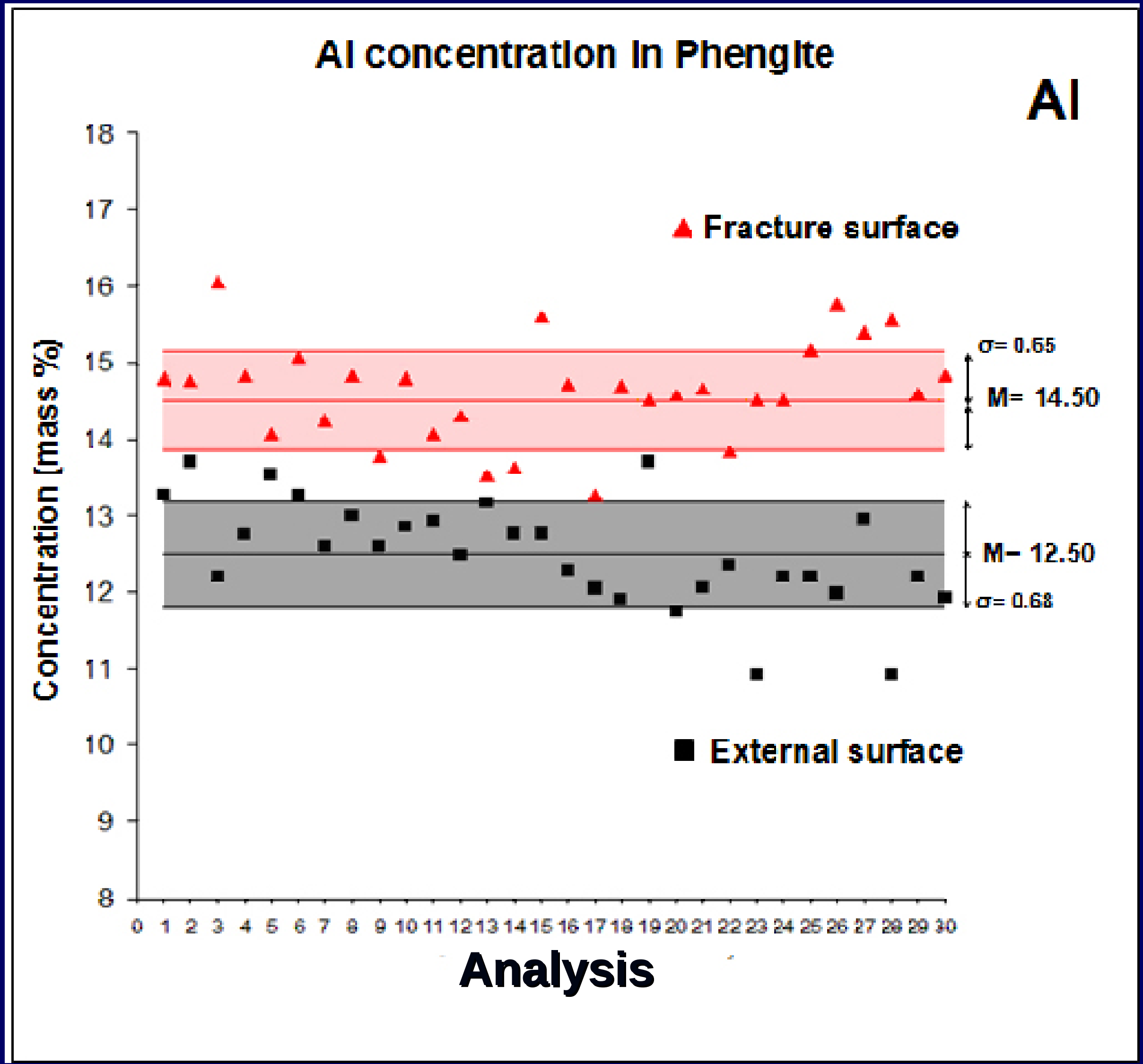
Fe content M= 4.00%

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%

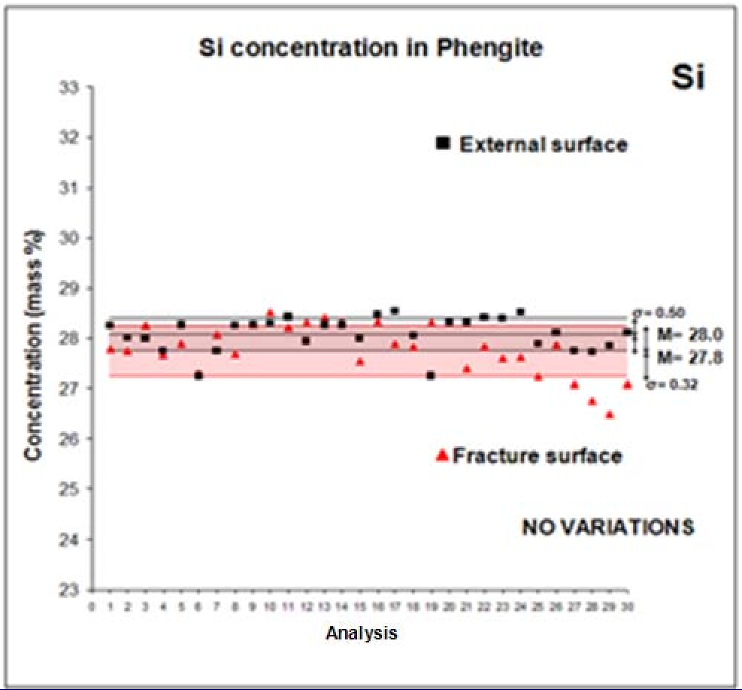
Al content increase

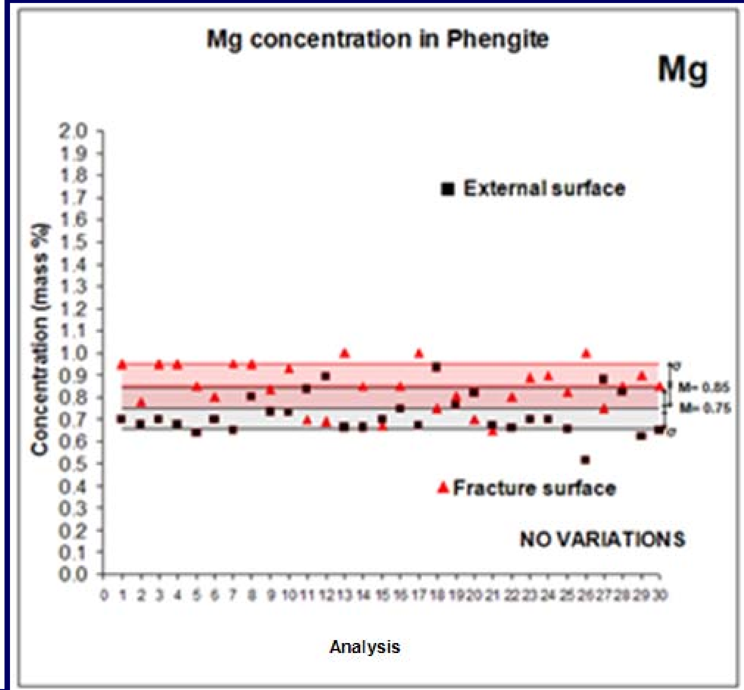
+2.00%

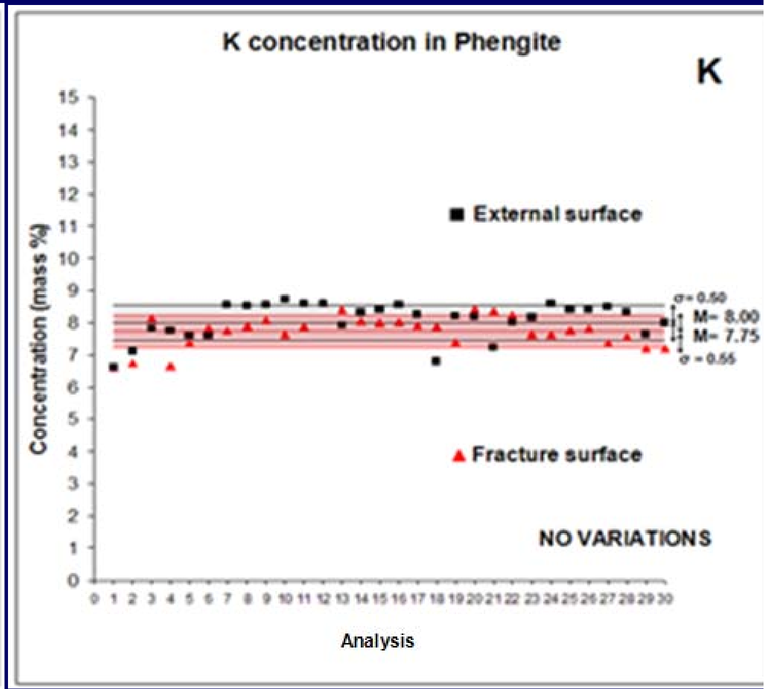
For Al contents, the observed variations show a mass percentage increase approximately equal to that of Fe. The average increase in the distribution, corresponding to the fracture surfaces is about 2.00% of the phengite mineral.

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.

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%.

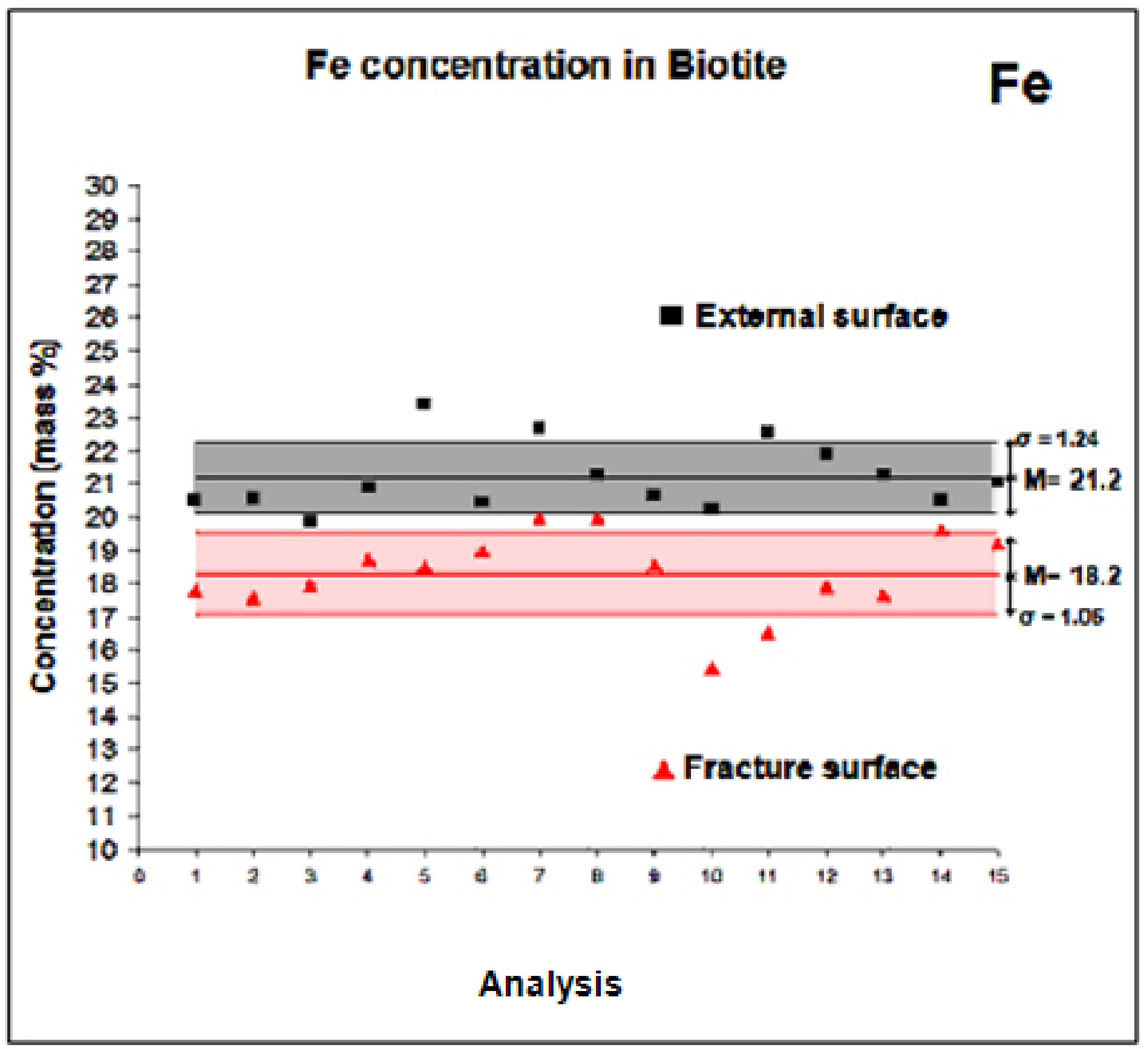
	External surface mean value (wt%)	Fracture surface mean value (wt%)	Increase/ decrease with respect to phengite	Increase/ decrease with respect to the same element
Fe	6.20	4.00	–2.20%	–35%
Al	12.50	14.50	+2.00%	+16%
Si	28.00	27.80	NO VARIATIONS	NO VARIATIONS
Mg	0.75	0.85	NO VARIATIONS	NO VARIATIONS
K	8.00	7.75	NO VARIATIONS	NO VARIATIONS

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

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

has occurred in the rock specimens.

Biotite: Fe concentrations



External Surf.:

Fe content M= 21.20%

Fracture Surf.:

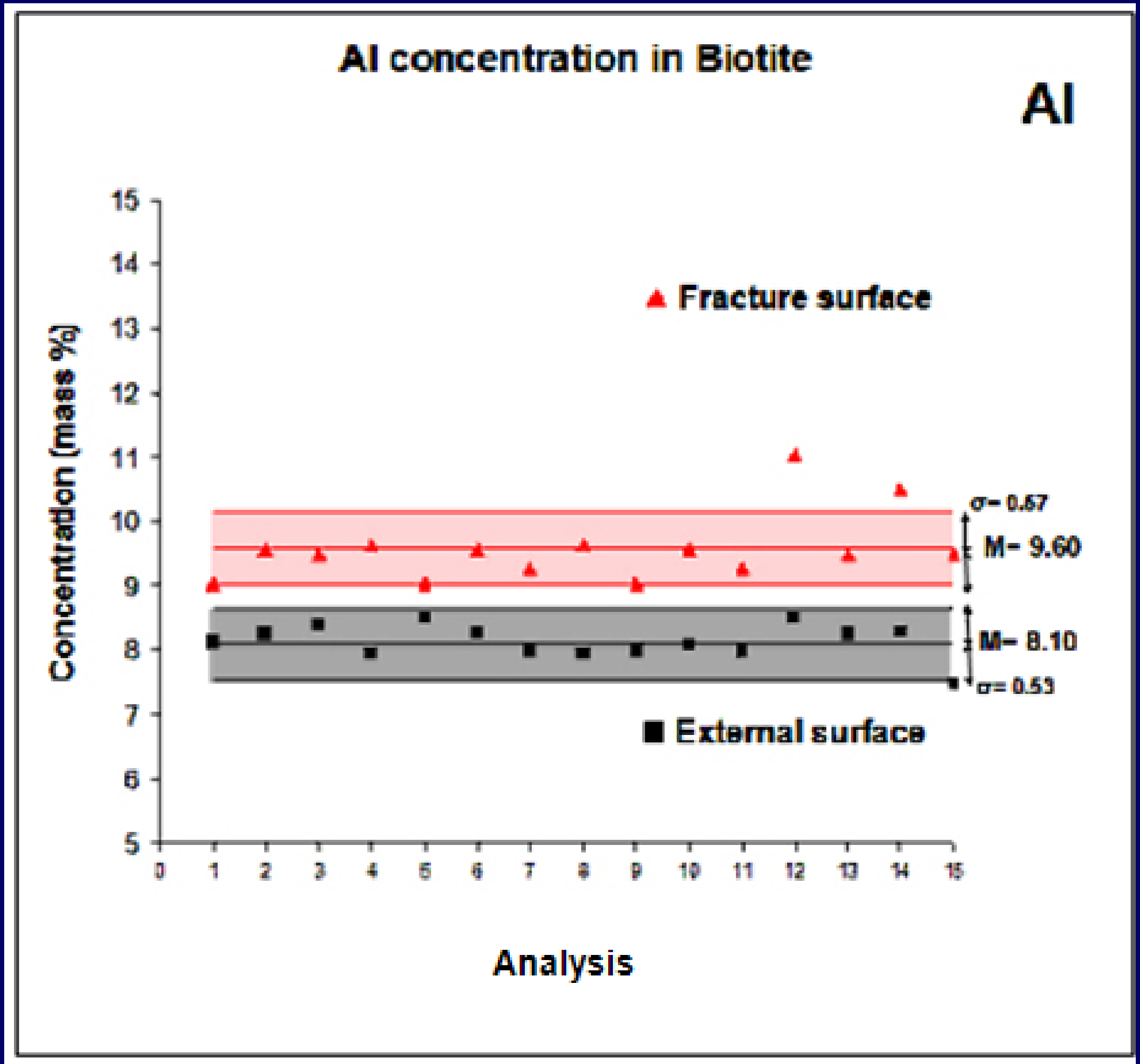
Fe content M= 18.20%

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%

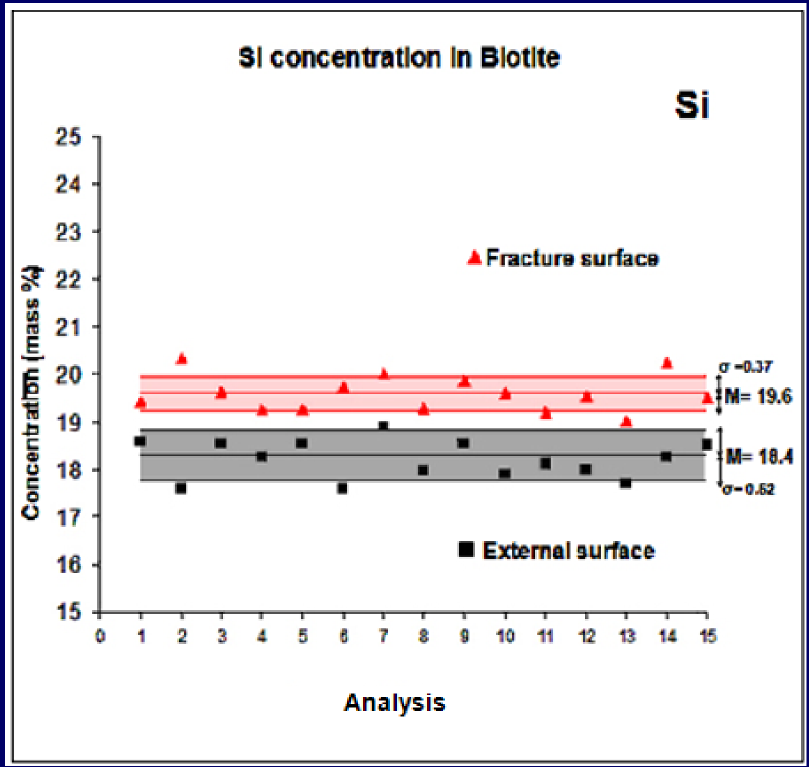
External Surf.:

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.:

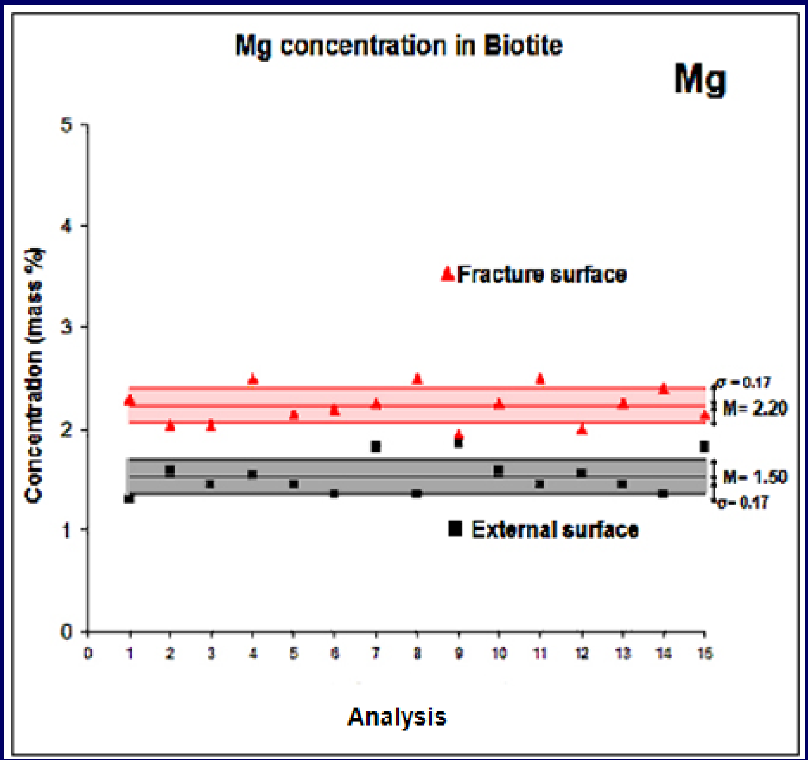
Si content M= 19.60%

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%

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:

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

Neutron Emissions from Earthquakes

Natural Hazards and Earth System Sciences (2003) 3: 255–262

Natural Hazards and Earth System Sciences

Distribution of neutrons near the Earth's surface

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Abstract. The distribution of the count rate of neutrons (per second) near the Earth's surface for two directions: towards the Earth and away from it, is studied using the experimental data, obtained in Moscow during 1996. The analysis shows that the mathematical approximation of the neutron count rate distribution can be described by a sum of two functions: a Poison distribution and a log-normal distribution. This is in agreement with the two known sources of the total neutron flux near the Earth's surface: generation of neutrons in nuclear interactions of high-energy cosmic ray particles with the Earth's atmosphere and neutron production in the Earth's crust. The log-normal distribution describes the contribution of the Earth's crust to the total neutron flux near the Earth. Therefore, these dynamic processes in the Earth's crust change the parameters of the log-normal distribution.

1 Introduction

Composition, time variations and spatial distribution of nuclear radiation particles have been studied in the lower atmosphere for about 50 years. In the present work we study only the neutral component (neutrons) of nuclear irradiation.

In previous works scientists did not distinguish between the different sources of neutrons and their contribution to the total neutron flux near the Earth's crust. Many scientists studied the energy spectrum and the altitude, latitude and longitude distributions of the neutron flux in the atmosphere (Gorshkov et al., 1966). The results of these studies lay within the following frames: the neutron component of nuclear radiation in the atmosphere is produced in interactions between high-energy primary cosmic ray particles and nuclei of the atmospheric elements. It was also revealed that in the lower atmosphere the neutron flux is characterized by a very weak latitudinal dependence and an unusual altitude dependence. In one of his experiments, Yuan (Yuan, 1948) obtained that the neutron flux decreases (with increasing altitudes), up to an altitude of several hundreds meters and then increases.

In earlier studies (Kuzhevskij et al., 1995, 1996), we reported that up to altitudes of 1–2 km from the Earth's surface the neutron count rate has no altitude dependence. We called this phenomenon "the neutron field of the Earth". The time distribution of the neutron flux in the neutron field of the Earth can be described as:

$$F(t) = n(t)v, \qquad (1)$$

where $n(t)$ is the time distribution of neutron concentration in the neutron field of the Earth, v is the velocity of neutrons.

Experimental studies of the energetic spectrum of neutrons near the Earth's crust (Belisova, 1999) have shown that for over 70% of the neutrons the energy does not exceed 0.5 eV. Theoretical consideration of propagation of neutrons with primary energy of about 1 MeV have shown, that during a period of less than 1 s (its actual value is about 0.1 s), they are thermalized and during a period less than 0.1 s, they are captured by atmospheric nitrogen (Kuzhevskij, 2000). As a result, the neutron velocity in Eq. (1), v, is some mean velocity, and the time variation $F(t)$, as we mentioned above, will be defined only by the time variation of neutron concentration $n(t)$. Actual neutron measurements give us the following expression for the neutron count rate $N(t) = F(t)S$, where S is the detector area. Thus, the mathematical approximation of the experimental count rate data:

$$N(t) = n(t)vS \qquad (2)$$

will, in fact, be the mathematical approximation of neutron concentration in the neutron field of the Earth. Analysis of this approximation permits us to study properties of the neutron source and the nature of flux variations.

Earlier experiments (Kuzhevskij, 2000, 2001b), which included studies of the neutron flux in different geographic locations (on balloons: Apatity, Kolskij peninsula; Dolgoprudny, Moscow region; Ryl'sk, Kaluga region; ground-based experiments at different altitudes above sea level: Moscow; Golitsino, Moscow region; Seliger Lake, Tver'

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Natural Hazards and Earth System Sciences (2003) 3: 637–645

Natural Hazards and Earth System Sciences

Neutron flux variations near the Earth's crust. A possible tectonic activity detection

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Abstract. The present work contains some results of observations of neutron flux variations near the Earth's surface. The Earth's crust is determined to be a significant source of thermal and slow neutrons, originated from the interaction between the nuclei of the elements of the Earth's crust and the atmosphere and α–particles, produced by decay of radioactive gases (Radon, Thoron and Actinon). In turn, variations of radioactive gases exhalation is connected with geodynamical processes in the Earth's crust, including tectonic activity. This determined relation between the processes in the Earth's crust and neutrons' flux allow to use variations of thermal and slow neutrons' flux in order to observe increasing tectonic activity and to develop methods for short-term prediction of natural hazards.

1 Introduction

Composition, variations in time and spatial distribution of the particles of nuclear radiation in the lower atmosphere have been studied for about 50 years.

Many scientists studied the energy spectrum and the altitudinal, latitudinal and longitudinal distribution of neutrons' fluxes in the lower atmosphere (Gorshkov et al., 1966;). The results of these studies lay in the following frames: neutron component of nuclear irradiation in the lower atmosphere is produced during the interaction between high-energy primary particles of cosmic origin and nuclei of the elements existing in the lower atmosphere. Vertical control traverse of the counting rate of neutrons has a maximum at the altitude of 16–17 km, while near the Earth's surface the most part of neutron flux consists of the particles of thermal energies. Speaking about vertical control traverse of neutrons counting rate, it's necessary to take into consideration the average elevation rate of the balloon, which is about 300 m/min. So, during the studies of altitudinal distribution of neutrons in the lower atmosphere balloon flies through the near-Earth layer up to the altitudes of several kilometers in 7–8 min. Counting rate in the near-Earth surface layer of the atmosphere is low and in the case of low detector's lumen the most part of the scientists, as a rule, averaged neutrons' counting rate during 5 min. Such averaging does not allow to conclude anything about detailed character of the distribution (and consequently about the sources) of neutron component in the lower atmosphere up to the altitude of several kilometers.

In 1990 we launched a balloon with neutrons' detector near Apatity, Kol'sky peninsula. The total sensitive area of the detector was 1500 cm^2. Such lumen output of the device allowed to get reliable information per minute. Figure 1 presents the vertical control traverse of neutrons' counting rate, which, in general, is in agreement with the results of other scientists. Detailed vertical control traverse of neutrons' counting rate up to the altitude of 5 km is presented at small axes in Fig. 1. Altitude dependence if described with a function:

$$N(h) = \begin{cases} 50.3h^{2.1}\exp(-0.03h) & 2 \le h < 8 \\ 50.3h^{2.1}\exp(-0.03h) & \\ \quad + \left(1 + \frac{h_{max}-h}{5}\right)h^3 & 8 \le h \le h_{max} \\ 250(116 - 3h) & h > 18 \end{cases}$$

where h is in kilometer scale, $h_{max} = 17$ km.

It's easy to see that approximately up to the altitude of 2 km, the counting rate essentially did not depend on the altitude.

Later the device, which allowed to detect neutrons' fluxes simultaneously in two vertical directions, from and to the Earth, was launched with balloons in Dolgoprudny, Moscow region (18 June 1991) and in Ryl'sk, Kursk region (13 February 1992). During the experiment in Dolgoprudny, which took place in summer (1991), the vertical control traverse of neutrons' counting rate was not found up to approximately 2 km. In Ryl'sk experiment, which took place in winter (1992), freedom of neutrons' counting rate from the altitude was not distinctly detected (Fig. 2). During the first

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(1) 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).

(2) 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).

INDIRECT EVIDENCE: 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 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.

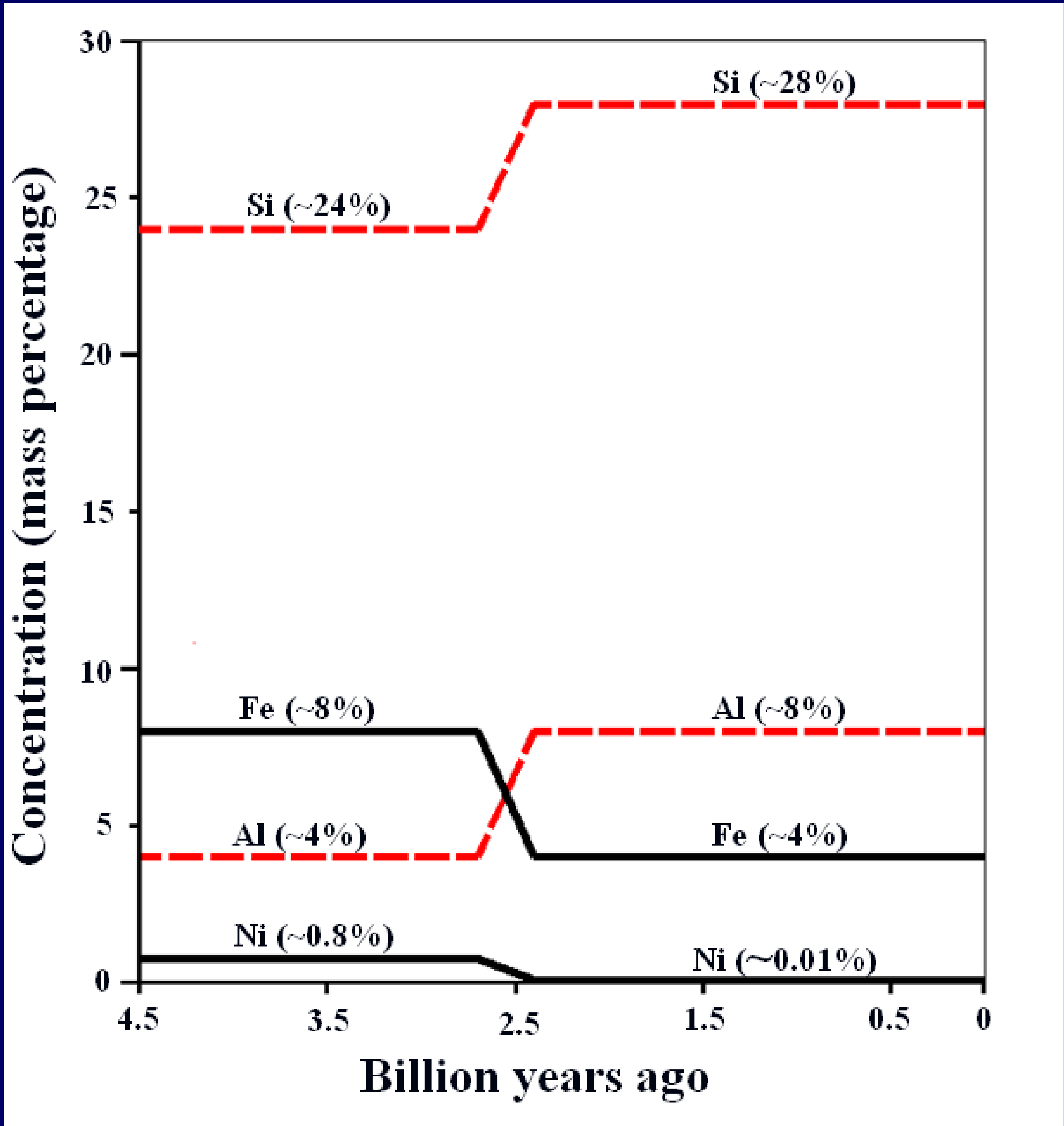
- If we consider the evolution of the percentages of the most abundant elements in the Earth crust during the last 4 billion years, we realize that iron and nickel have drastically diminished, whereas aluminum and silicon have as much increased:

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

$$Ni_{28}^{59} \rightarrow 2Si_{14}^{28} + 3 \ \text{neutrons}$$

- 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.

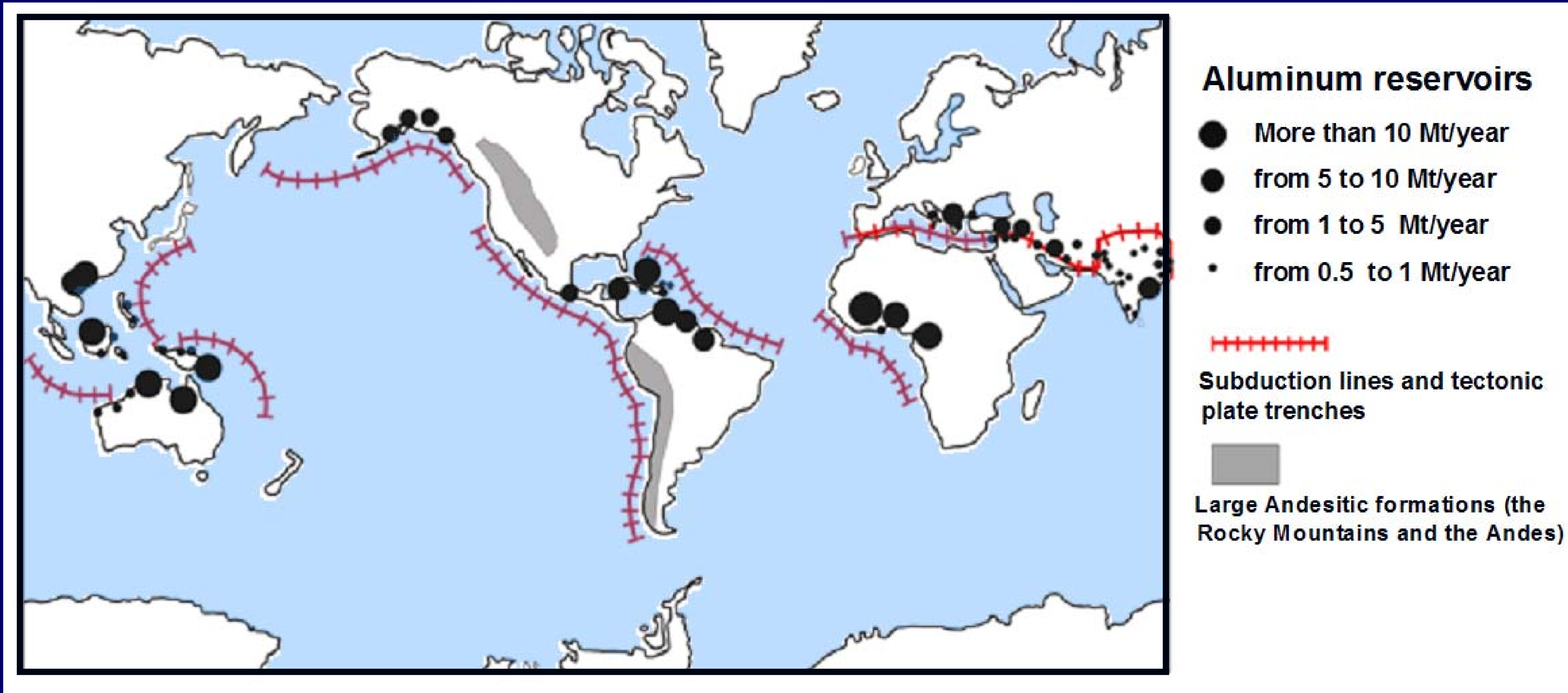

Concentration (mass percentage)
30
25
20
15
10
5
0
Si (~28%)
Si (~24%)
Fe (~8%)
Al (~8%)
Al (~4%)
Fe (~4%)
Ni (~0.8%)
Ni (~0.01%)
4.5
3.5
2.5
1.5
0.5
0
Billion years ago

Localization of iron mines

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

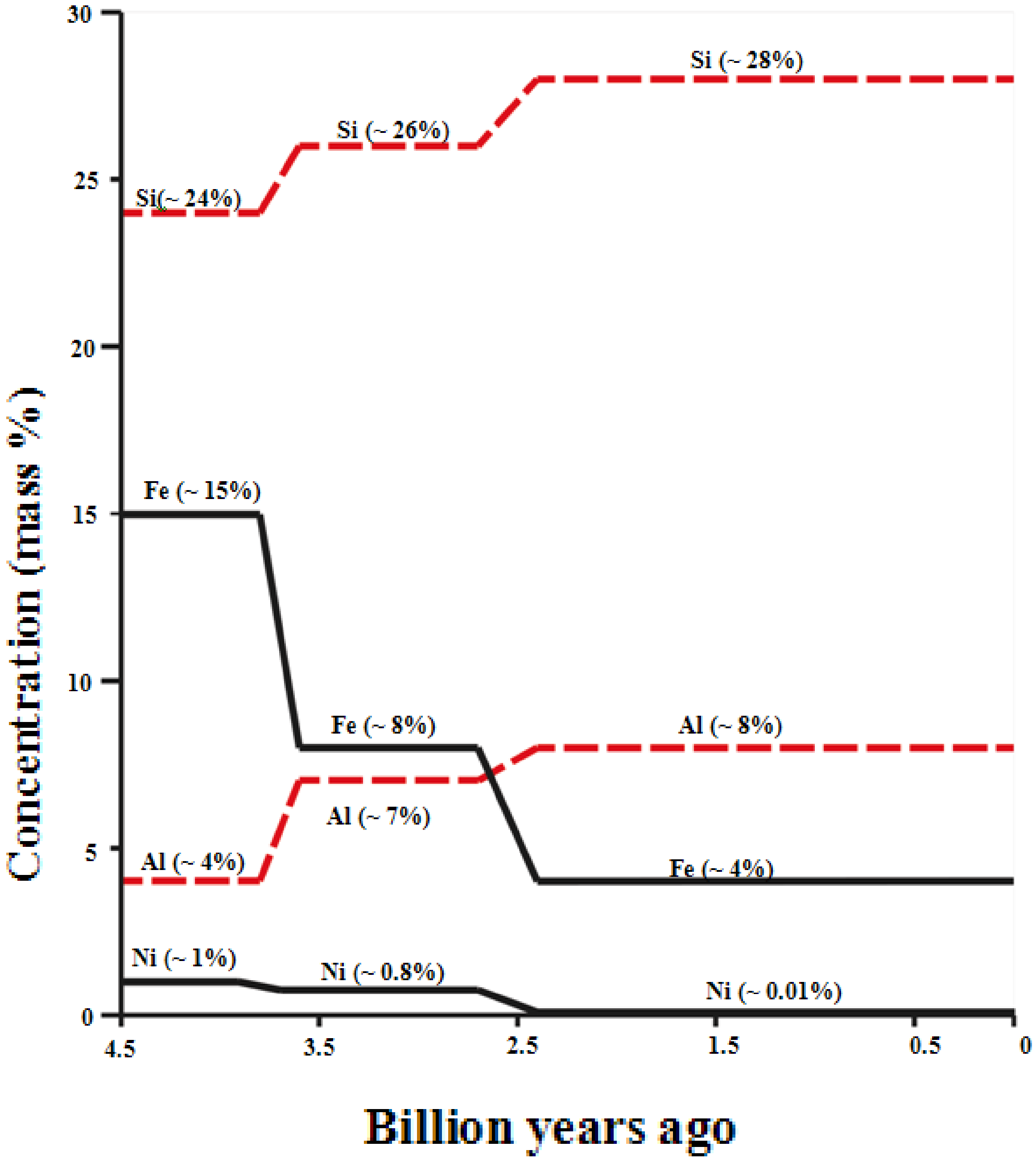
(**) World Mineral Resources Map. Available at http://www.mapsofworld.com/world-mineral-map.html.

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.



3.8 Billion years ago:

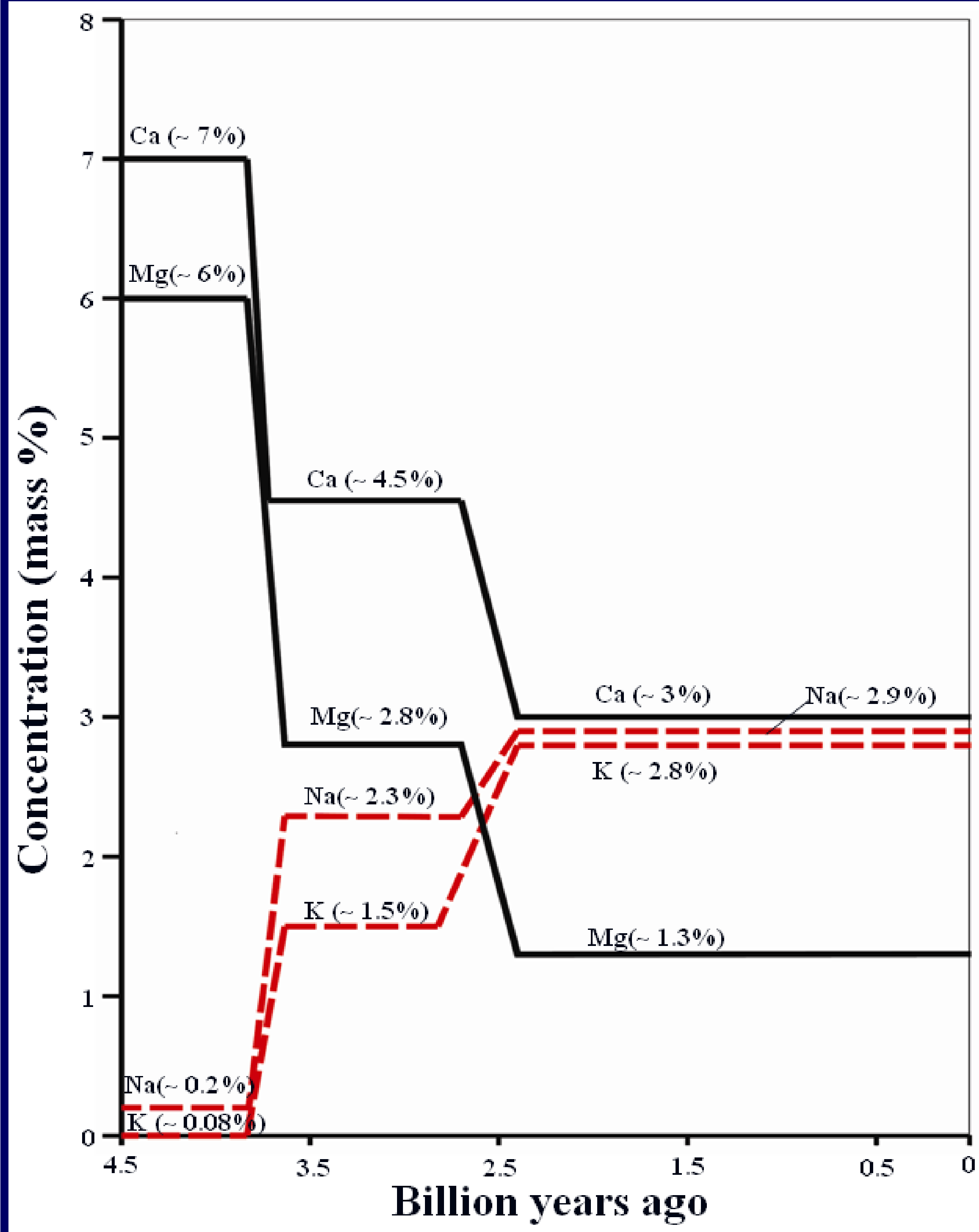
Fe (–7%) + Ni (–0.2%) =

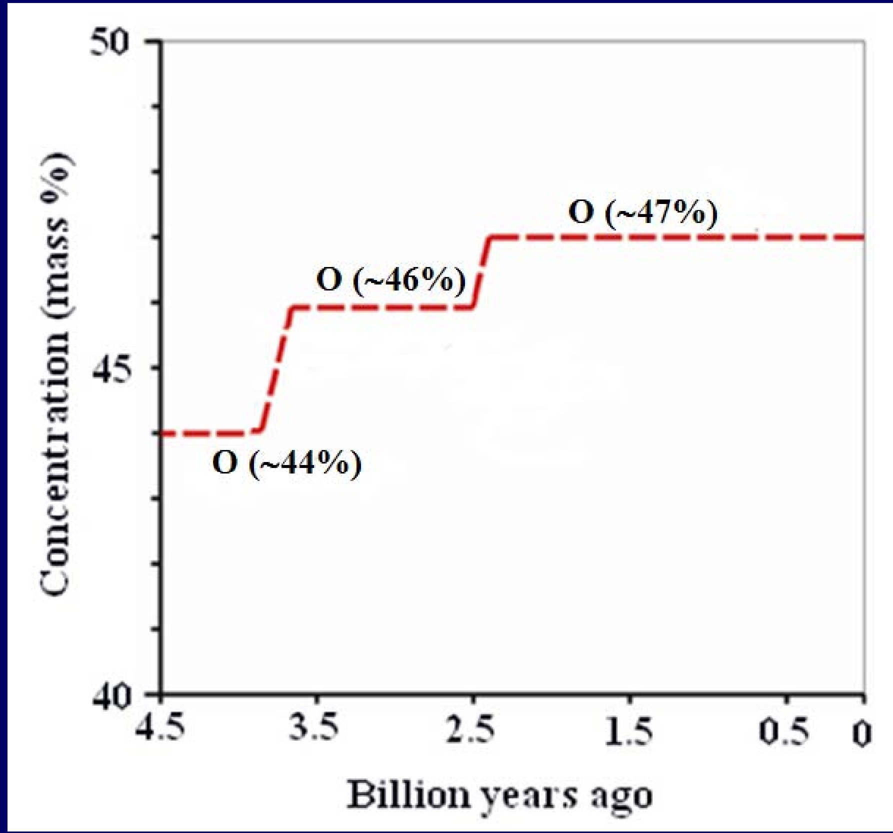
=Al (+3%) + Si (+2.2%) + Mg (+2%)

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%)

Piezonuclear reactions in the Earth's Crust

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

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

$$(3)\quad Co^{59}_{27} \rightarrow Al^{27}_{13} + Si^{28}_{14} + 4\ \text{neutrons}$$

Piezonuclear reactions in the Earth's Crust

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

(3) $Co_{27}^{59} \rightarrow Al_{13}^{27} + Si_{14}^{28} + 4 \text{ neutrons}$

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

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

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

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

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

(8) $Mg_{12}^{24} \rightarrow O_{8}^{16} + 4H_{1}^{1} + 4$ neutrons

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

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

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(11) $Si_{14}^{28} \rightarrow 2\,N_{7}^{14}$

(12) $Si_{14}^{28} \rightarrow C_{6}^{12} + O_{8}^{16}$

(13) $Si_{14}^{28} \rightarrow O_{8}^{16} + 2He_{2}^{4} + 2H_{1}^{1} + 2$ neutrons

(14) $Al_{13}^{27} \rightarrow C_{6}^{12} + N_{7}^{14} + 1$ neutron

Calcium depletion in the Earth Crust and ocean formation

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

$$Ca_{20}^{40} \rightarrow K_{19}^{39} + H_1^1$$
$$Ca_{20}^{40} \rightarrow 2O_8^{16} + 4H_1^1 + 4 \text{ neutrons}$$

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

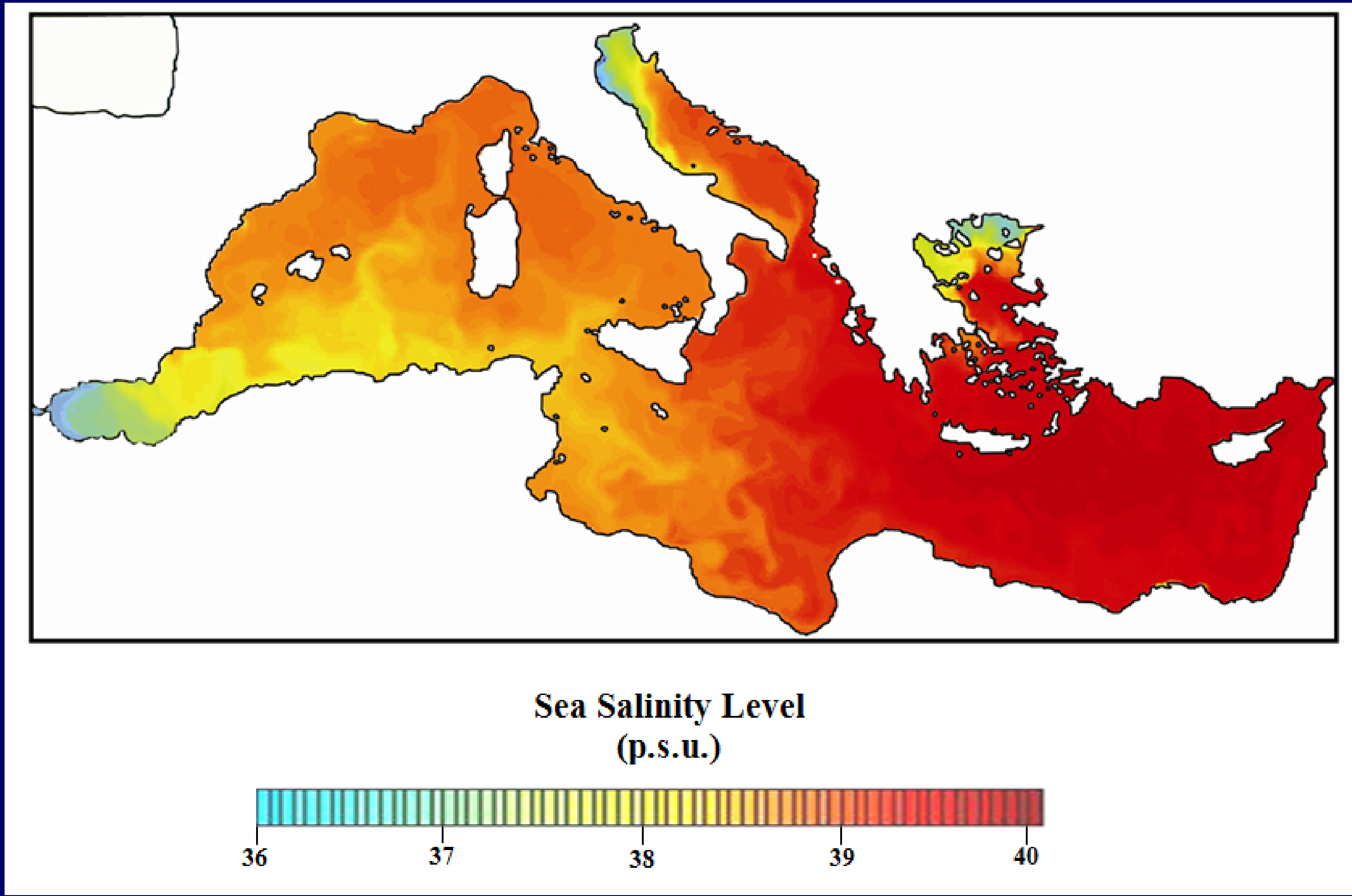
Considering a global ocean surface of 3.607 $\times 10^{14}$ m^2, and an average depth of 3950 m, we obtain a mass of water of about 1.35 $\times 10^{21}$ kg.

Partial decrease in Ca
1.41 $\times 10^{21}$ kg

→

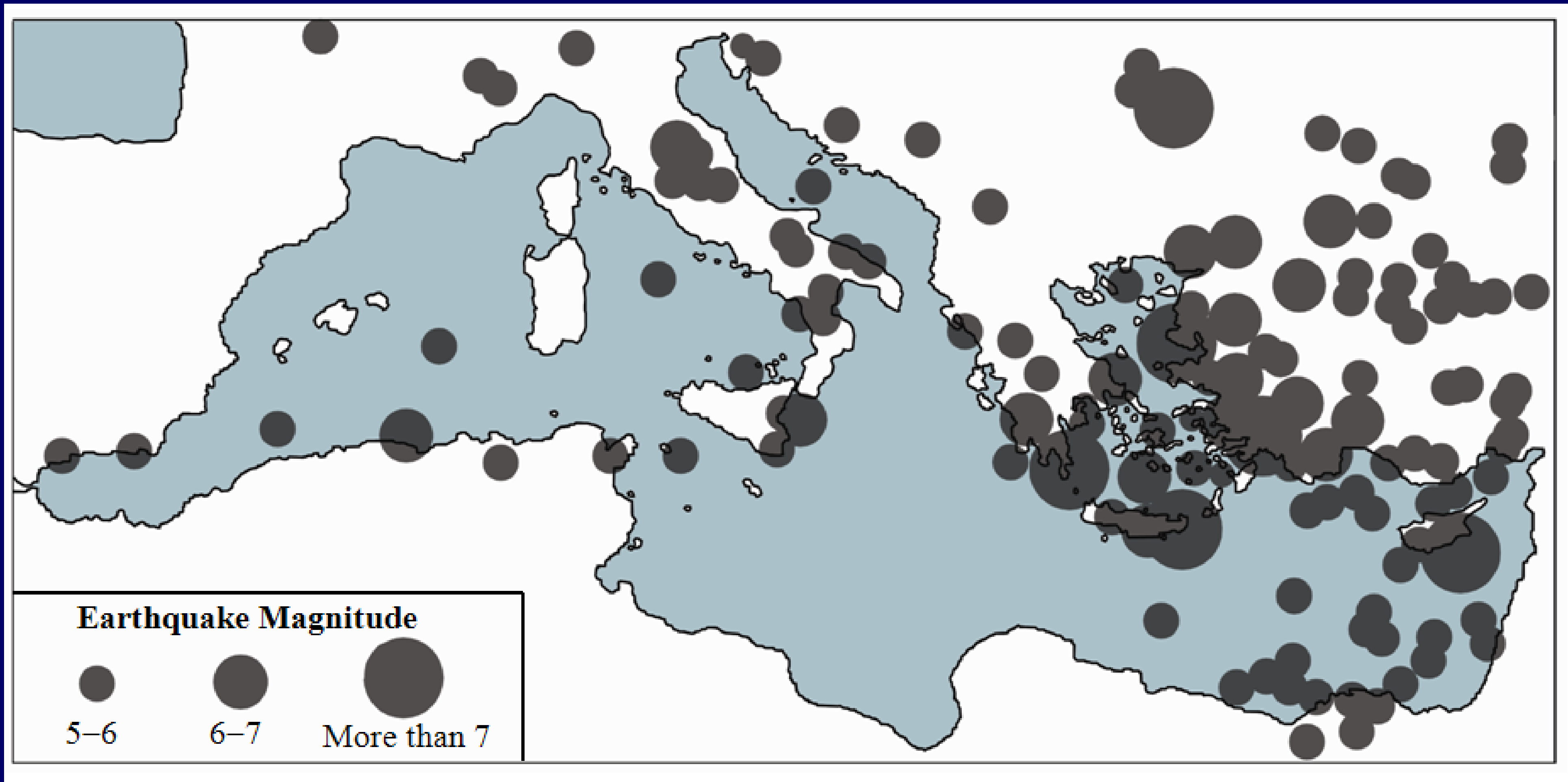
Mass of H_2O in the oceans today
1.35 $\times 10^{21}$ kg

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.



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

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
- Great Oxidation Event (2.5 Billion years ago) and origin of life
- Carbon pollution and climatic variations
- Production of Rn, CO_2, neutrons during earthquakes

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**
- Disposal of **radioactive wastes**
- Clean nuclear **energy production** (?)