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Evidence of Piezonuclear Reactions: From Geological and Tectonic Transformations to Neutron Detection and Measurements

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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).

- Preparata, G., “A new look at solid-state fractures, particle emissions and «cold» nuclear fusion”, *Il Nuovo Cimento*, 104 A, 1259-1263 (1991).

- Derjaguin, B. V., et al., “Titanium fracture yields neutrons?”, *Nature*, 34, 492 (1989).

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 × 6 × 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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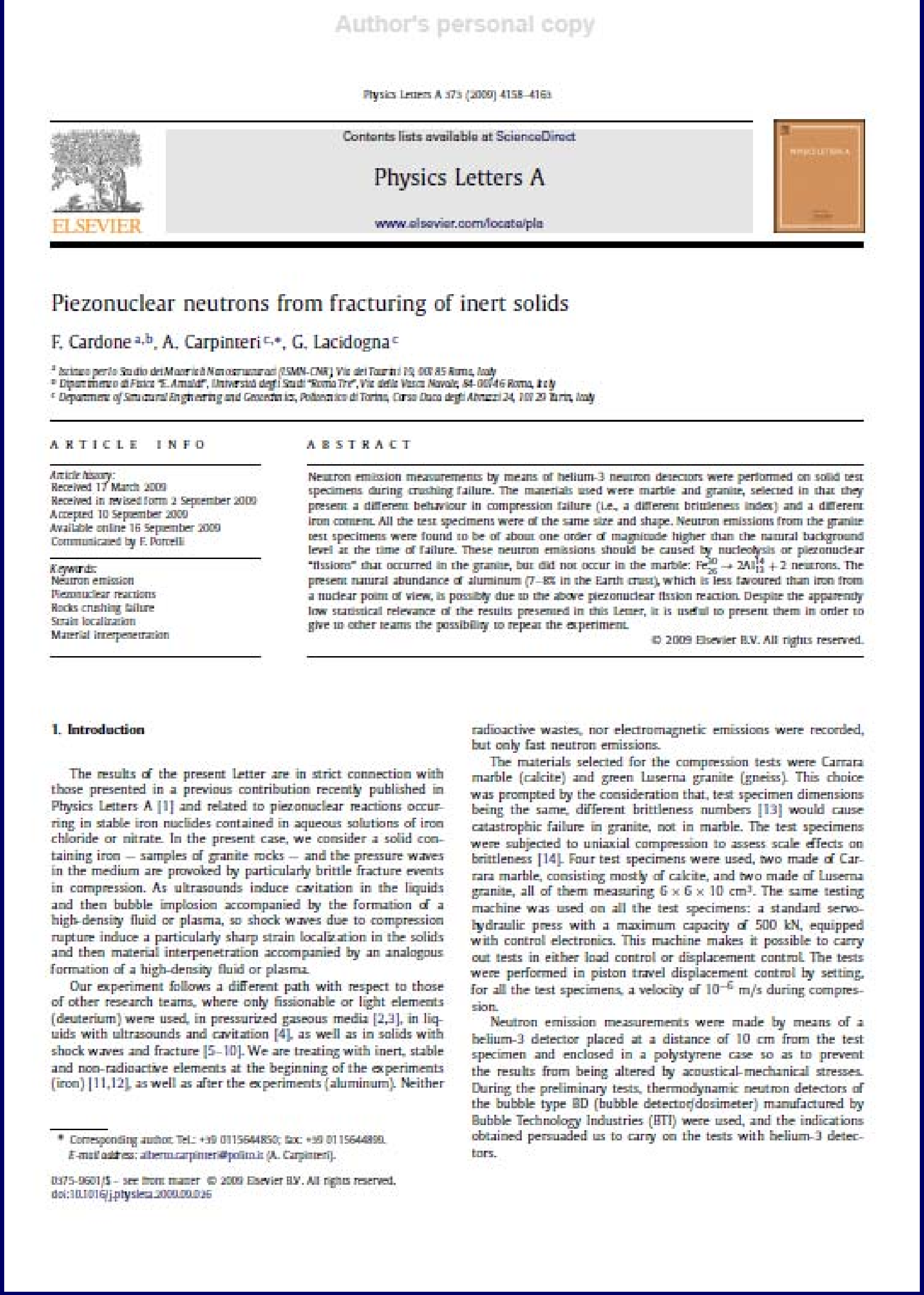
[1] Presented at the Turin Academy of Sciences on December 10, 2008.

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: $Fe^{56}_{26} \to 2Al^{27}_{13} + 2$ 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.

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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 $6 \times 6 \times 10$ 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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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

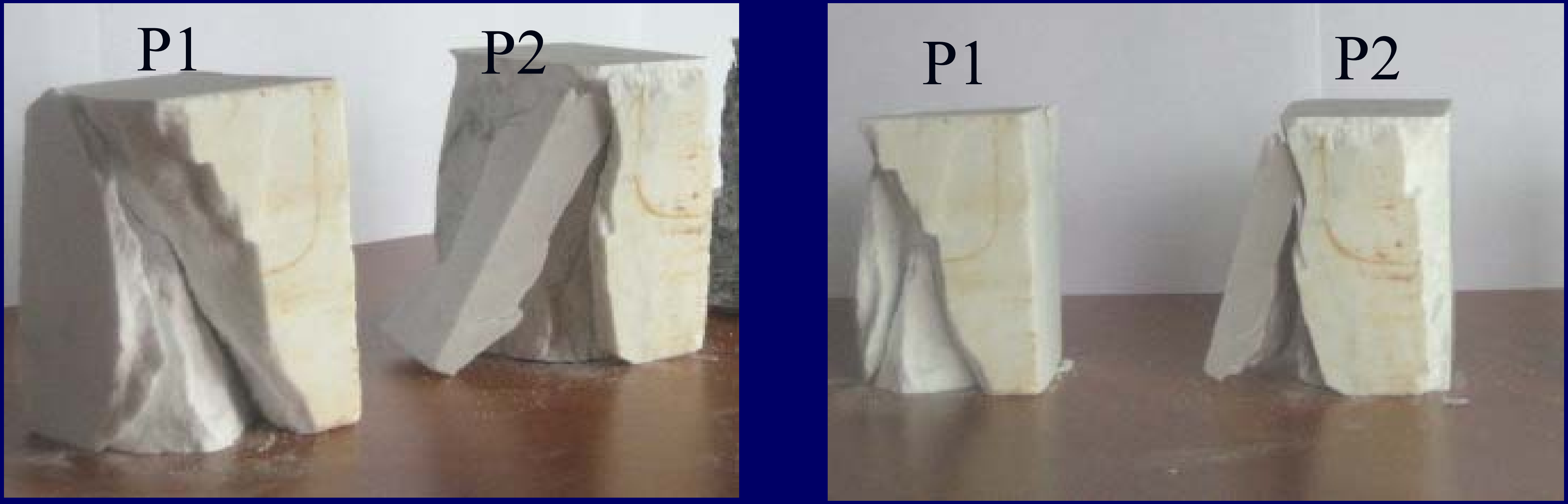
The neutron background was measured at 600 s time intervals to obtain sufficient statistical data with the detector in the position shown in the previous figure.

The average background count rate was:

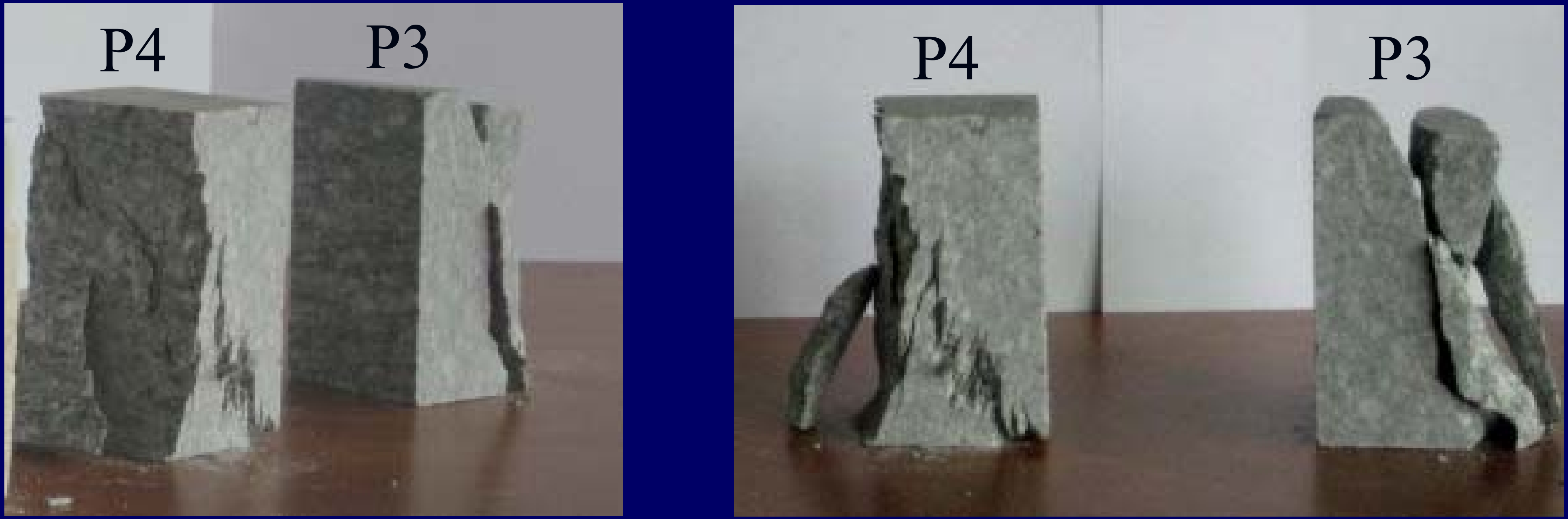
$$3.8\times10^{-2} \pm 0.2\times10^{-2} \text{ cps.}$$

During the loading tests

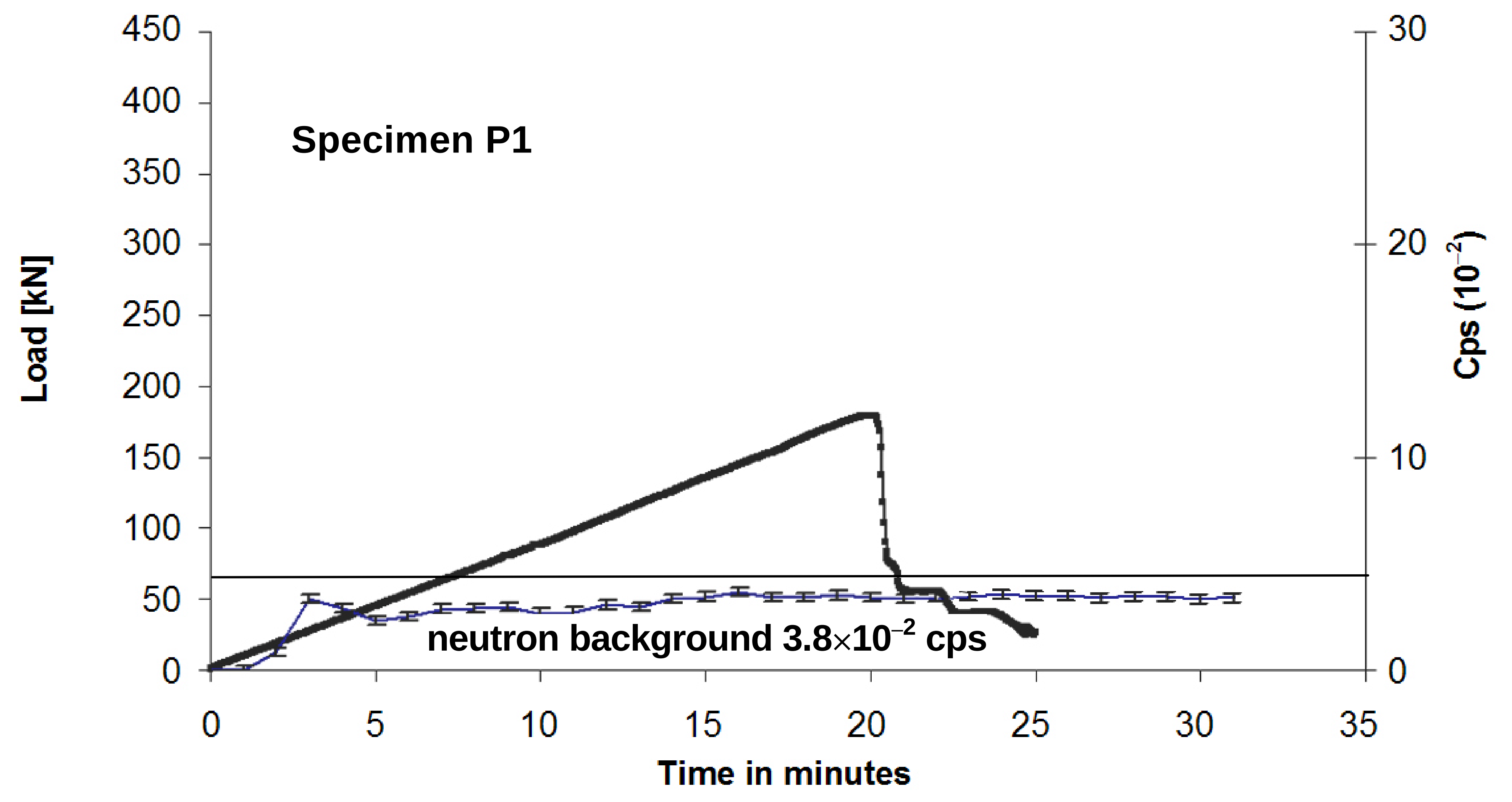
- The neutron measurements obtained on the two Carrara marble specimens yielded values comparable with the background, even at the time of test specimen failure.
- The neutron measurements obtained on the two Luserna granite specimens, instead, exceeded the background value by about one order of magnitude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



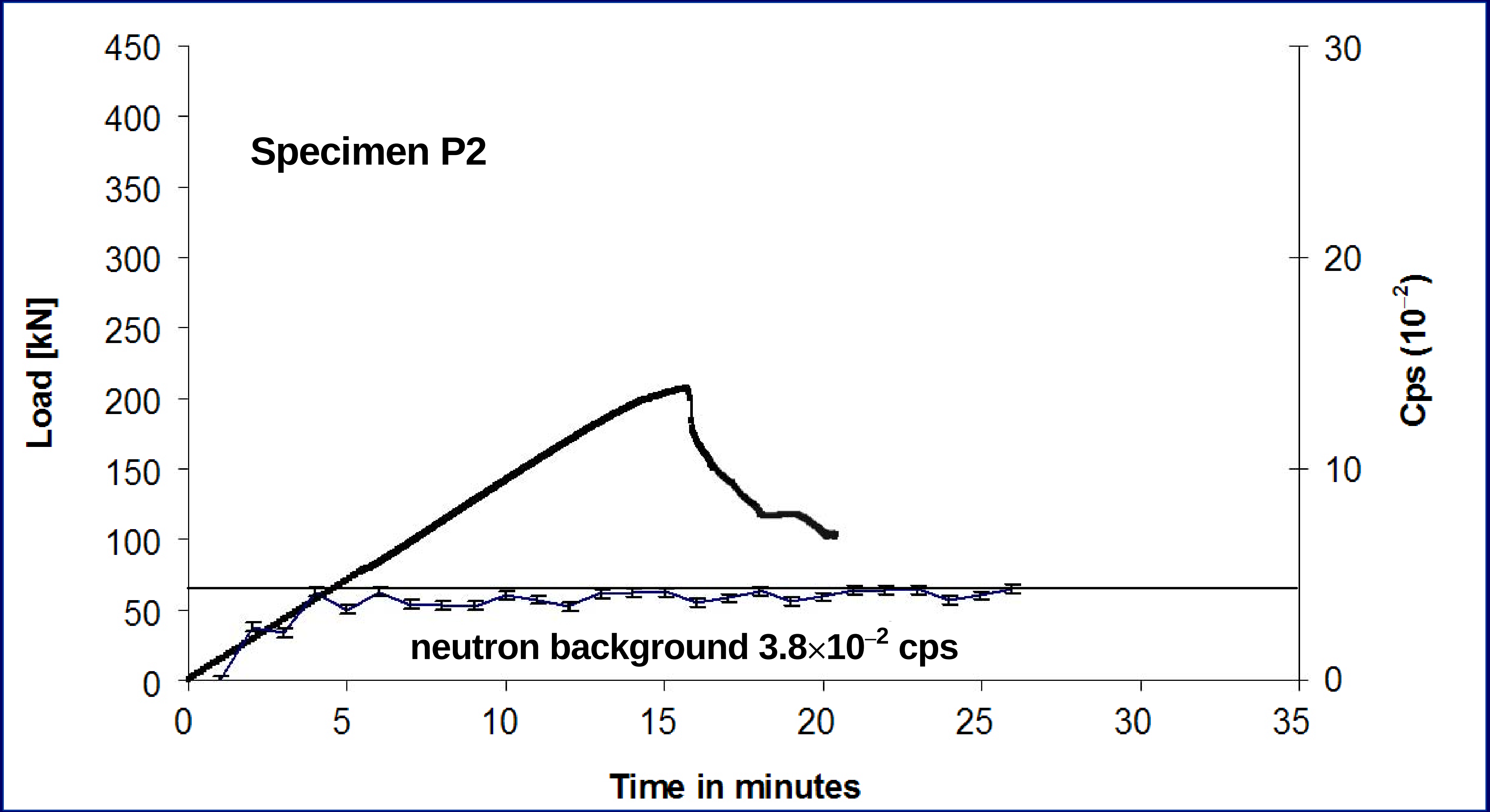
Specimens P1 and P2 in Carrara marble following compression failure.



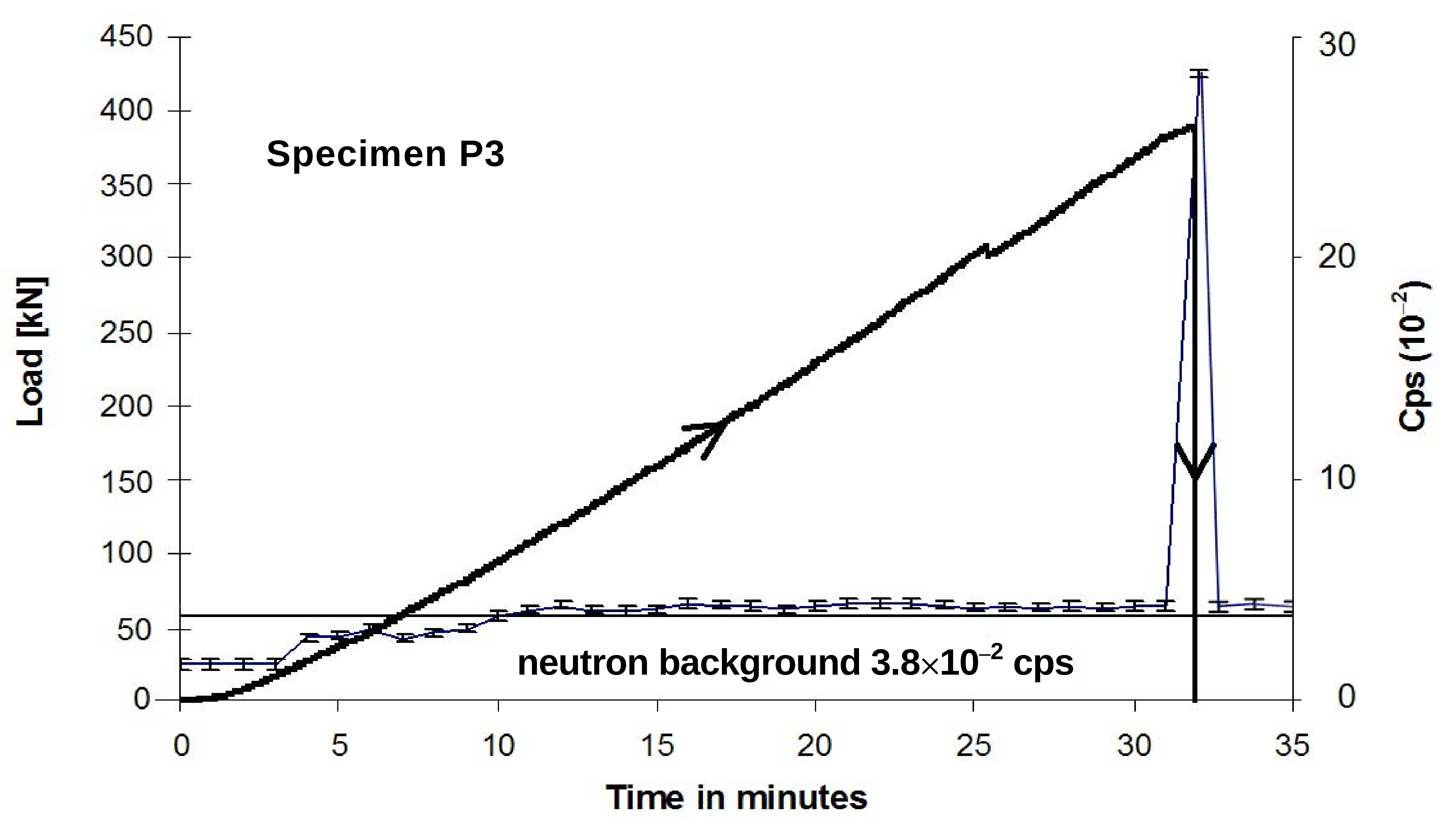
Specimens P3 e P4 in Luserna granite following compression failure.



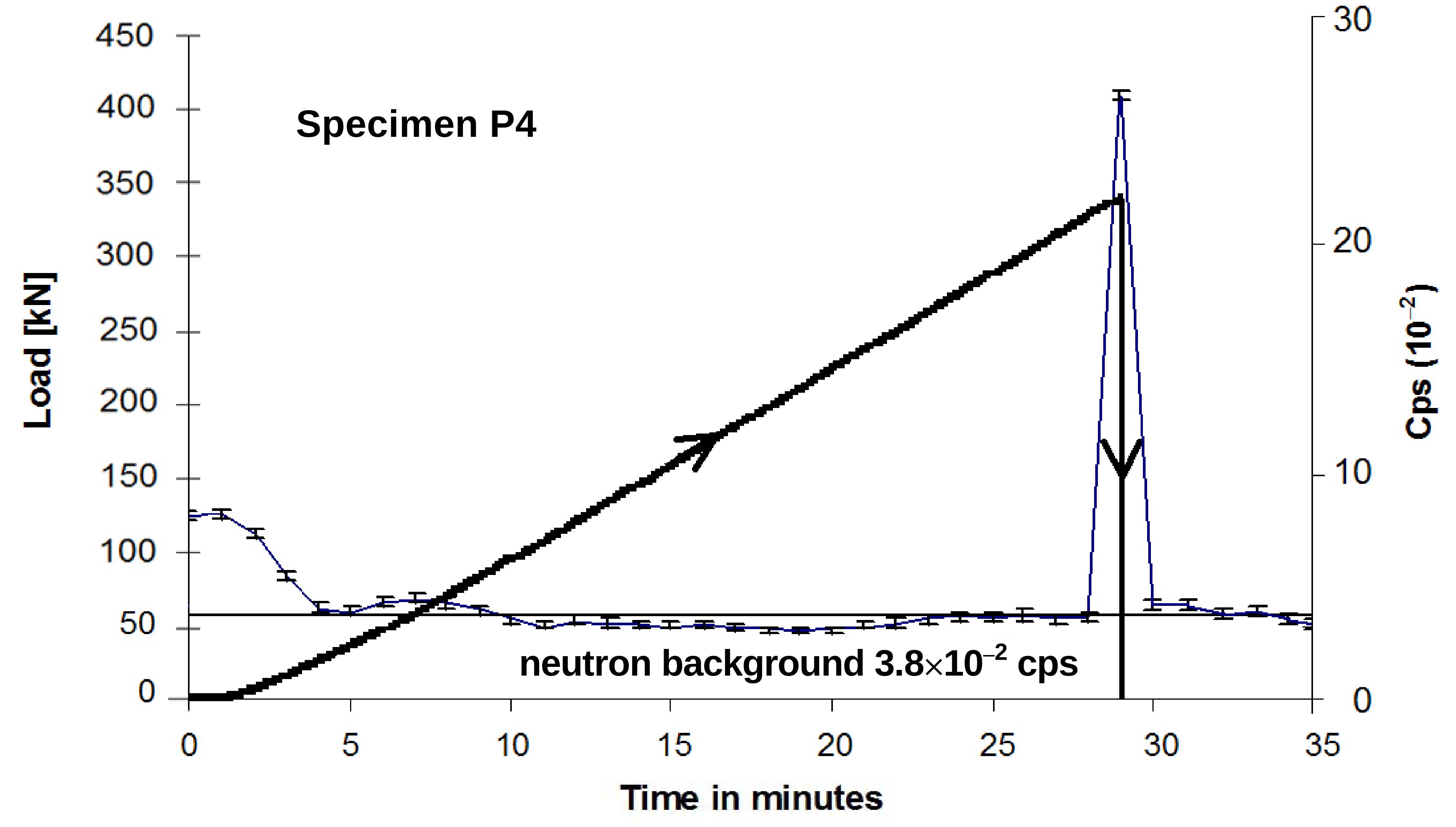
Load vs. time and cps curve for P1 test specimen in Carrara marble.



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

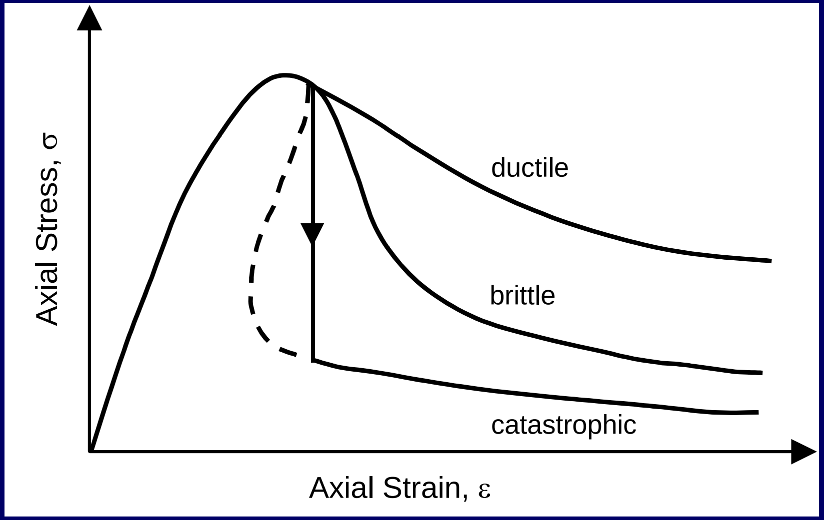


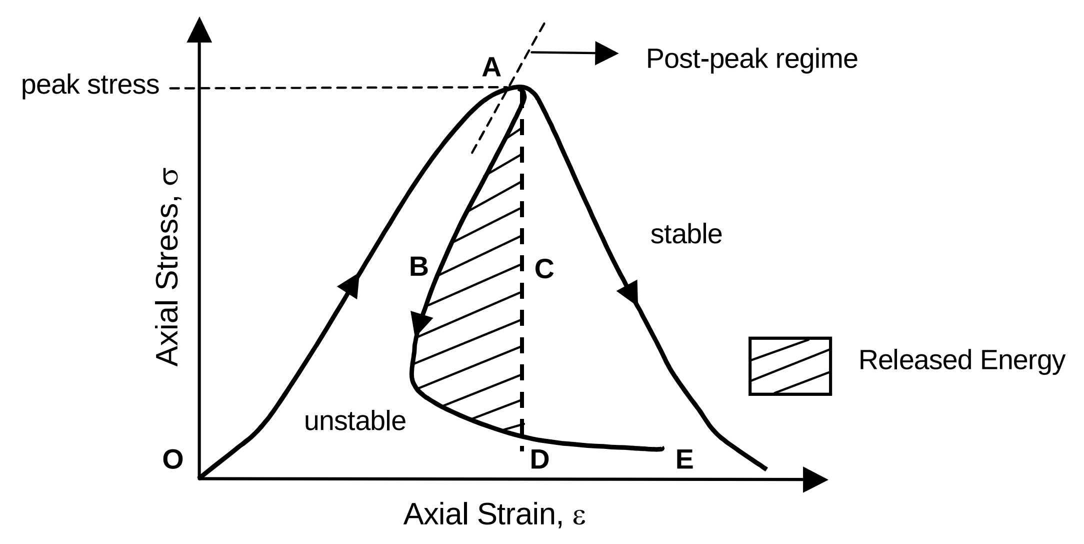
Load vs. time and cps curve for P3 test specimen in Luserna granite.



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

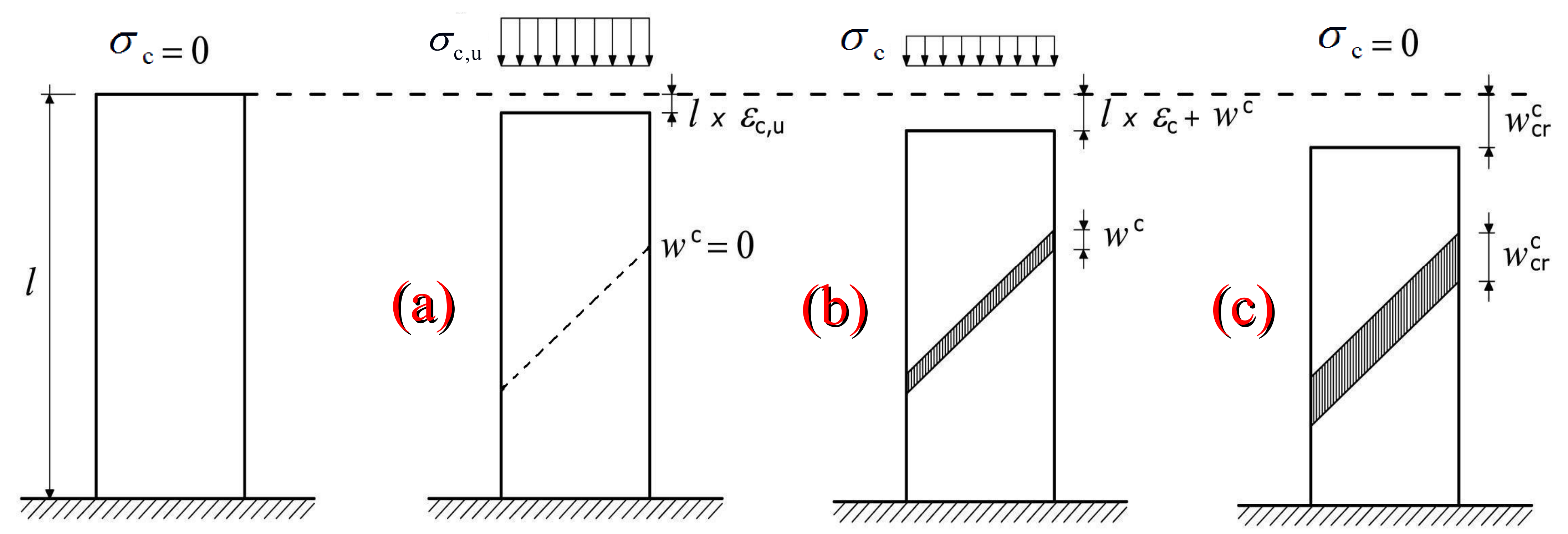
DUCTILE, BRITTLE AND CATASTROPHIC BEHAVIOUR





Energy release and stable vs. unstable stress-strain behaviour

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

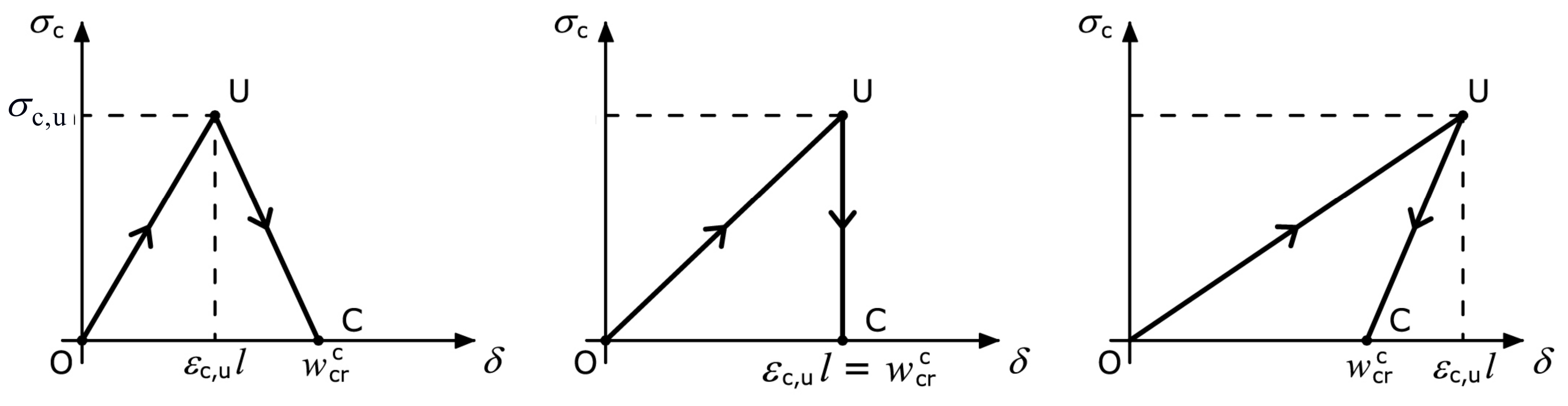


$$\delta = \varepsilon_c l = \frac{\sigma_c}{E} l; \qquad \delta = \frac{\sigma_c}{E} l + w^c; \qquad \delta \geq w^c_{cr}.$$

(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):

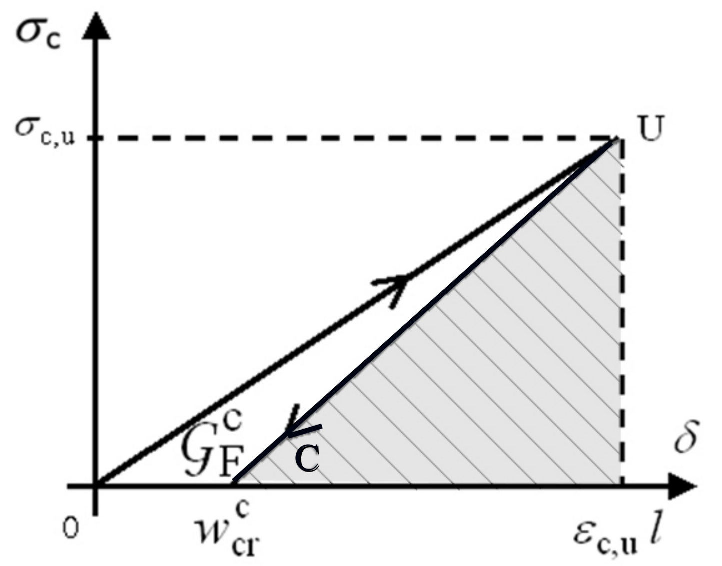
$$\frac{\Delta E}{\Delta t} \sim 7.69 \times 10^{11}\,\mathrm{W} \quad \rightarrow \quad \Delta t \sim 0.5\,\mathrm{ns}$$

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:

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

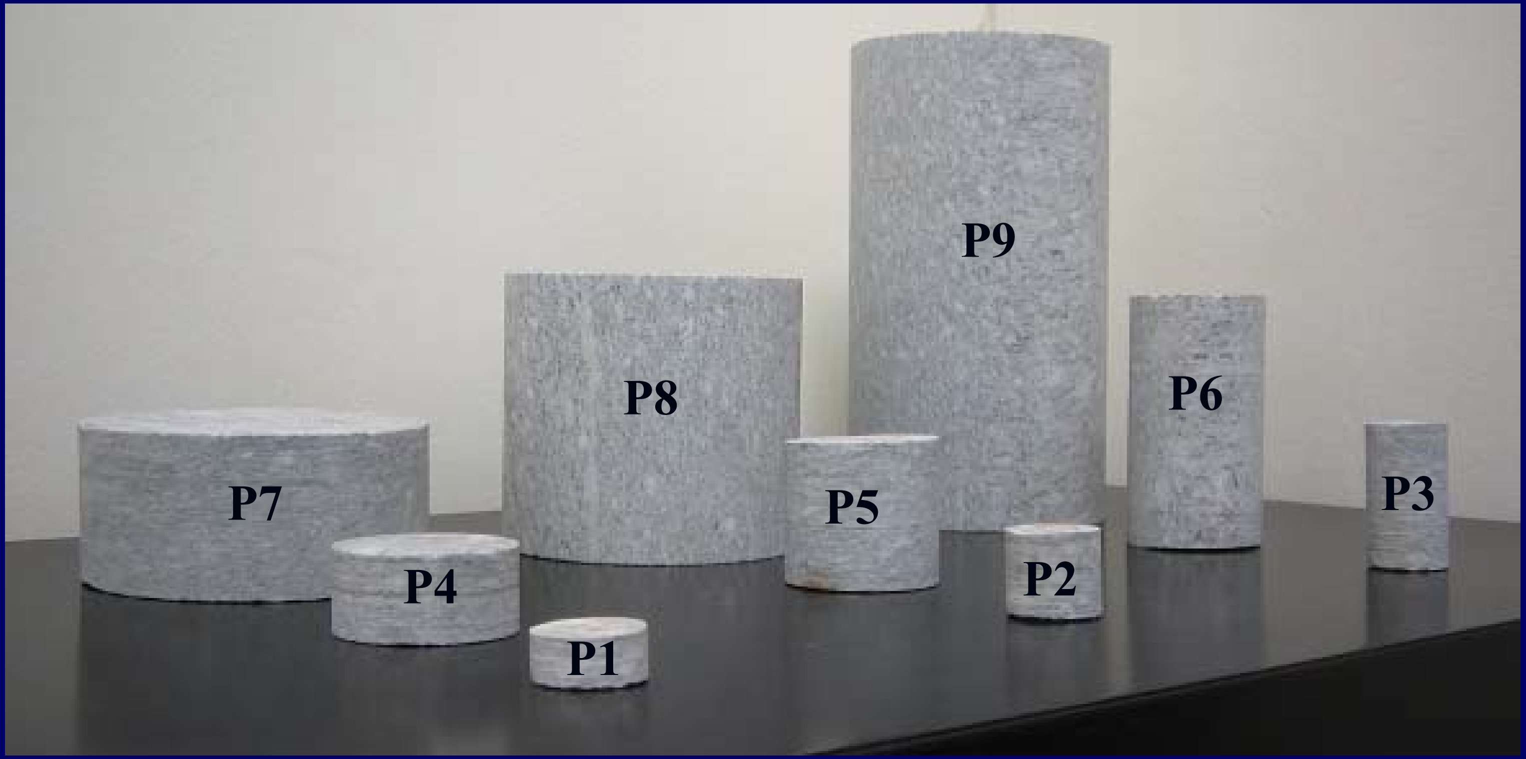


(III) Cardone, F., Mignani, R., “Piezonuclear reactions and Lorenz invariance breakdown”, *Int. J. of Modern Physics E*, *Nuclear Physics*, 15 (901), 911-924 (2006).

(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)**

Testing Machine

The tests were carried out by means of a servo-hydraulic press, with a maximum capacity of 1800 kN, working by a digital type electronic control unit.

The tests were performed under displacement control, with imposed displacement velocities 10^{-6} - 10^{-5} m/s.

Neutron Detectors

The helium-3 neutron detector was switched on at least one hour before the beginning of each compression test.

The detector was placed in front of the test specimen at a distance of 20 cm and it was enclosed in a polystyrene case of 10 cm of thickness in order to avoid “spurious” signals coming from impact and vibration.

A measurement of natural neutron background was performed. The average measured background level is ranging from $(3.17\pm0.32)\times10^{-2}$ to $(4.74\pm0.46)\times10^{-2}$ cps.

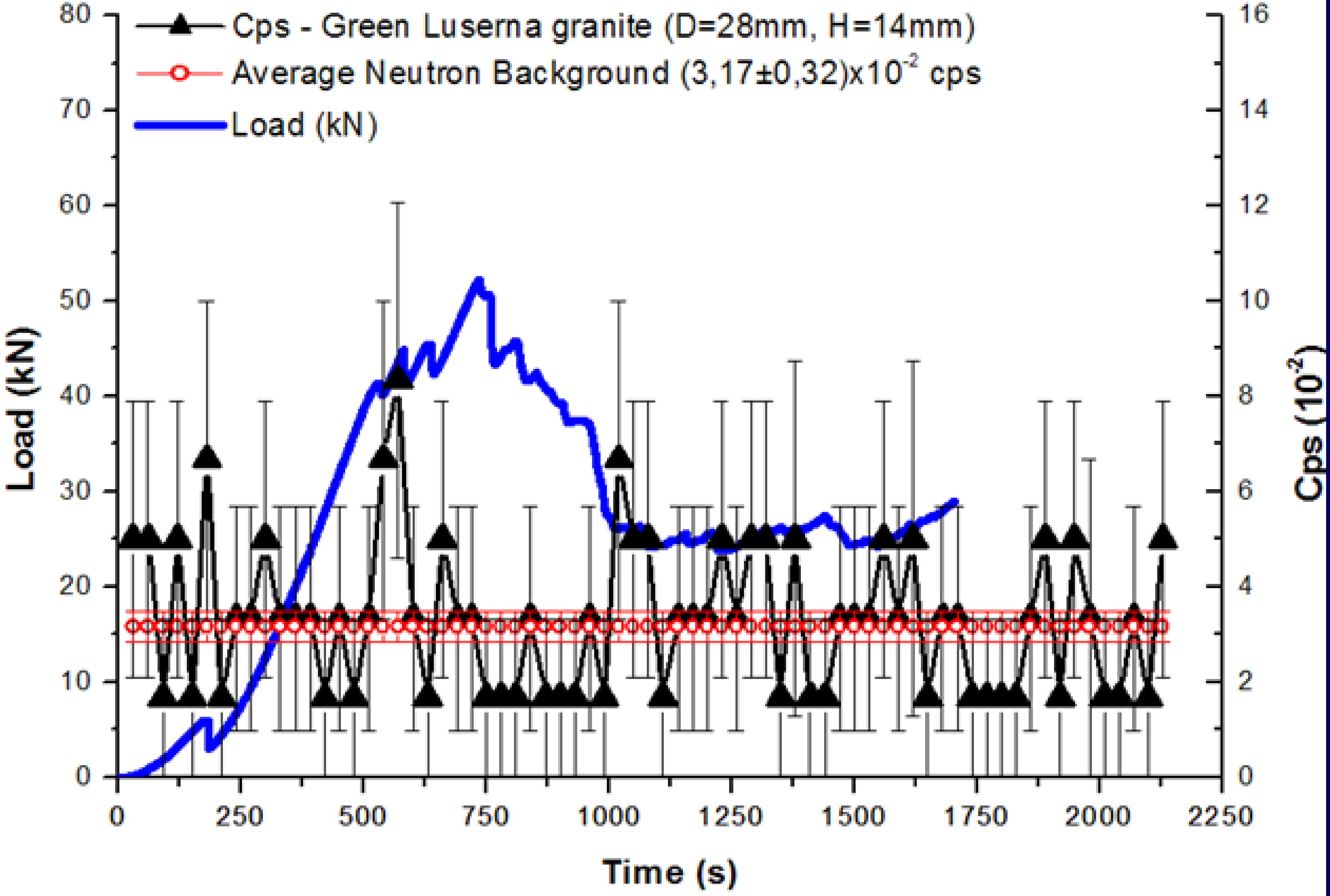
Monotonic Load: Experimental Results

Granite Specimen	D (mm)	$\lambda = H/D$	Time to neutron emission (s)	Count rate at the neutron emission (10^{-2} cps)	Corresponding thermal neutron flux ($10^{-4}cm^{-2}s^{-1}$)	Average neutron background (10^{-2} cps)
P1	28	0.5	570	8.33±3.73	12.81±5.74	3.17±0.32
P2	28	1	---	background	background	3.17±0.32
P3	28	2	---	background	background	3.17±0.32
P4	53	0.5	---	background	background	3.83±0.37
P5	53	1	2460	11.67±4.08	17.95±6.28	3.84±0.37
P6	53	2	1440	25.00±6.01	38.46±9.25	4.74±0.46
P7	112	0.5	---	background	background	4.20±0.80
P8	112	1	270	30.00±11.10	46.15±17.08	4.20±0.80
P9	112	2	225	30.00±10.00	46.15±15.38	4.20±0.80

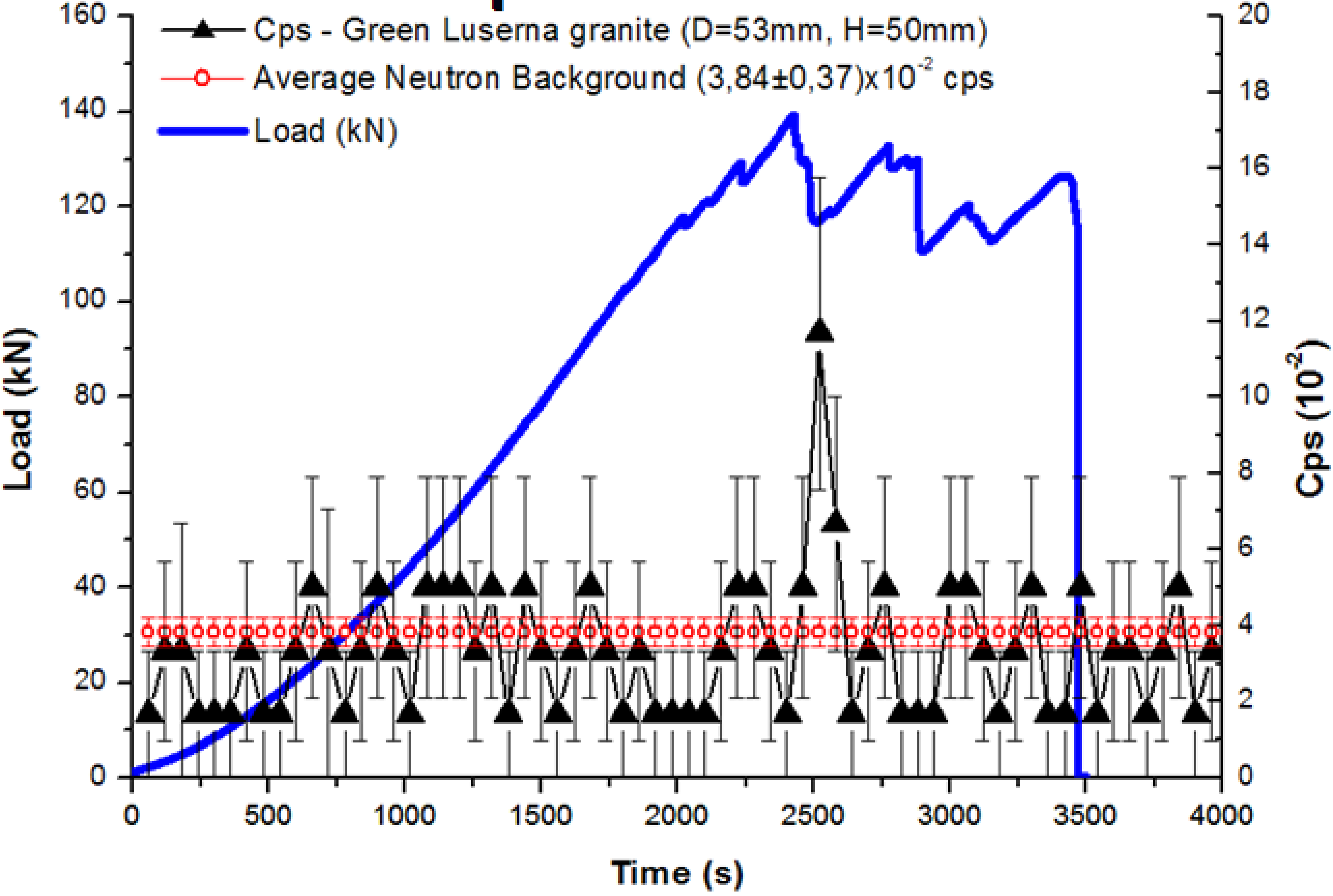
Neutron measurements of specimen P2, P3, P4, P7 yielded values comparable with the ordinary natural background.

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.

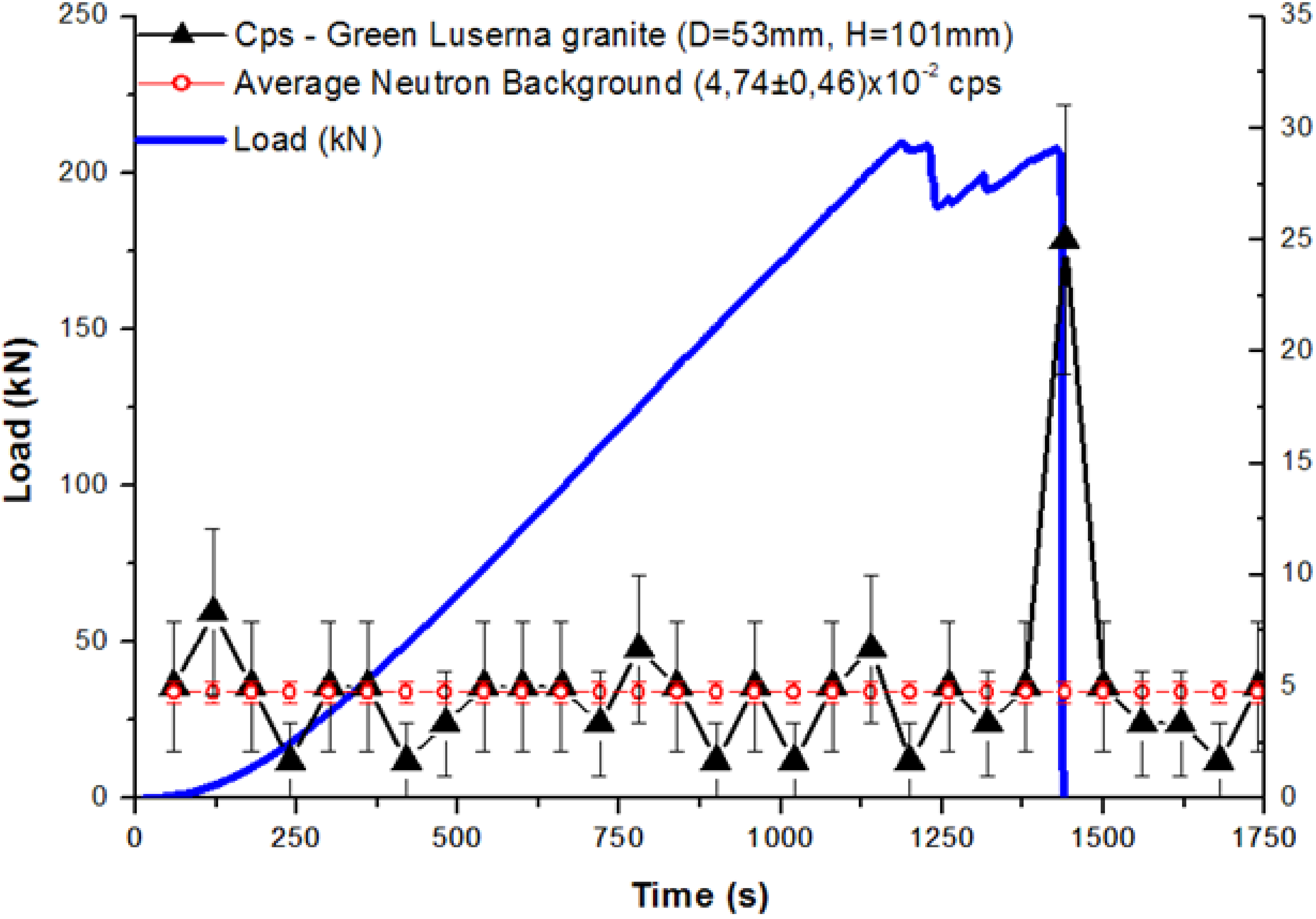
Specimen P1


Cps - Green Luserna granite (D=28mm, H=14mm)
Average Neutron Background (3,17±0,32)x10^{-2} cps
Load (kN)
Load (kN)
Cps (10^{2})
Time (s)
0
250
500
750
1000
1250
1500
1750
2000
2250
0
10
20
30
40
50
60
70
80
0
2
4
6
8
10
12
14
16

Specimen P5

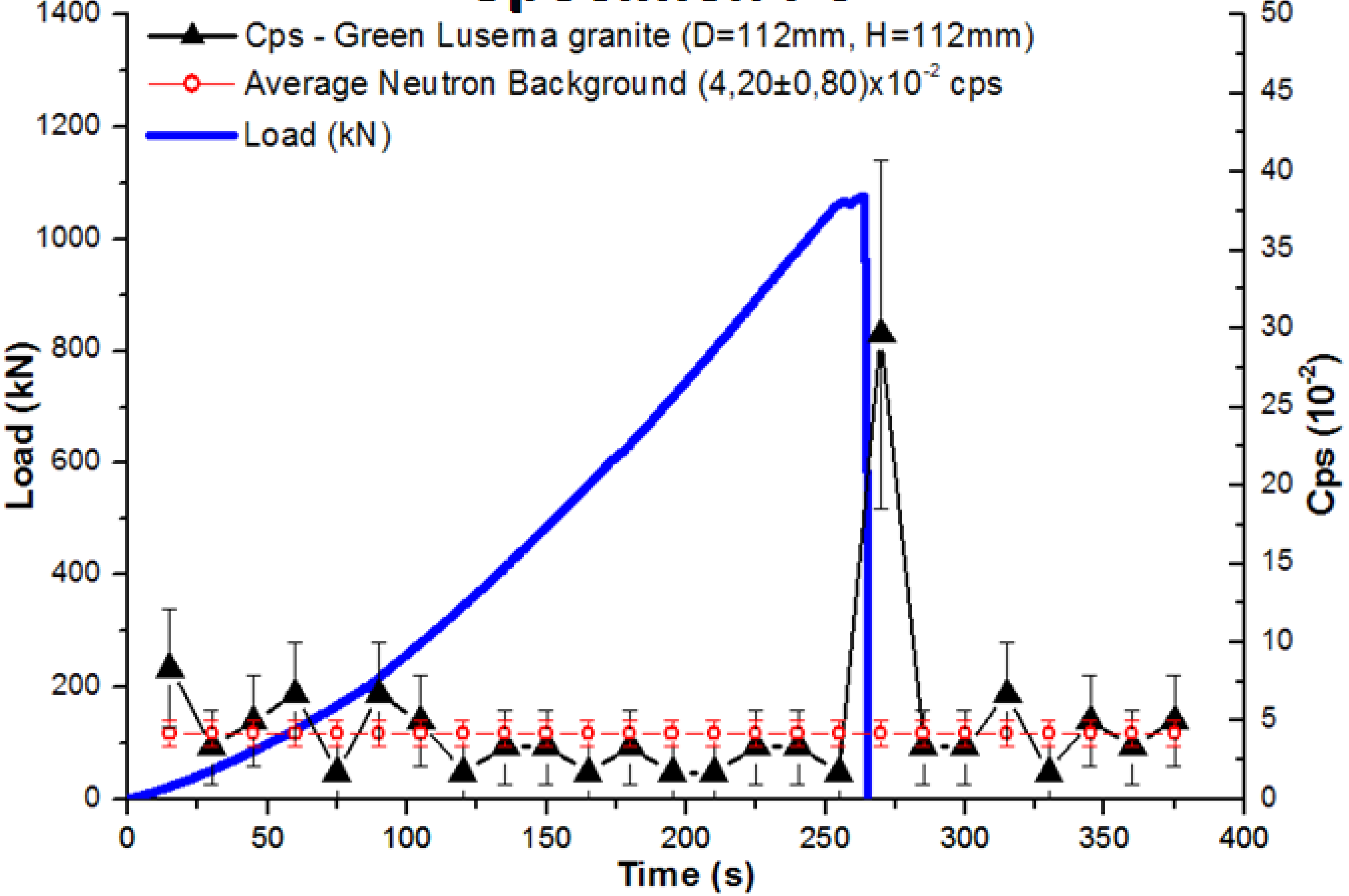

Cps - Green Luserna granite (D=53mm, H=50mm)
Average Neutron Background (3,84±0,37)x10^-2 cps
Load (kN)
Load (kN)
Cps (10^-2)
Time (s)
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10
12
14
16
18
20
0
500
1000
1500
2000
2500
3000
3500
4000

Specimen P6

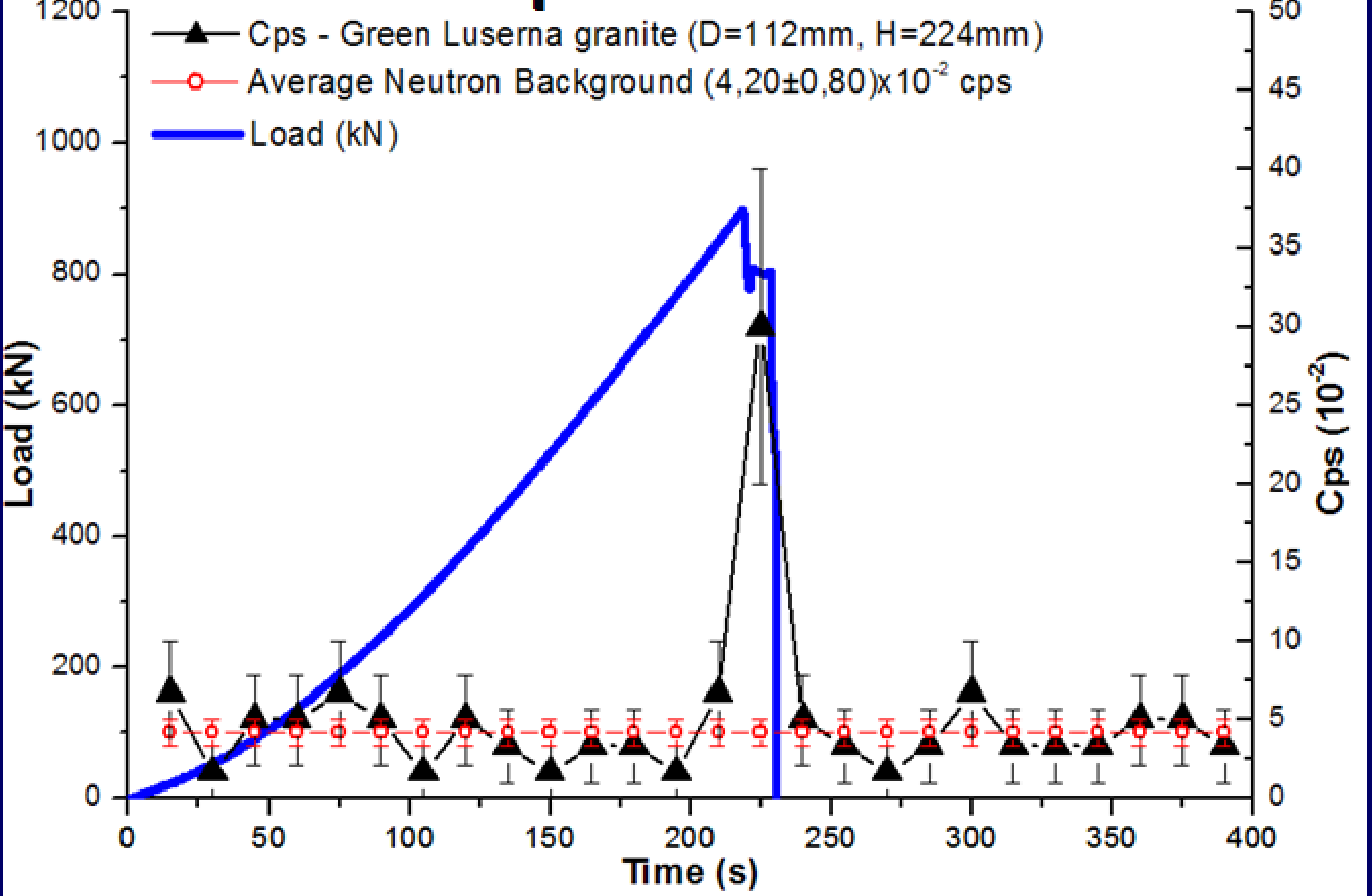


Cps - Green Luserna granite (D=53mm, H=101mm)
Average Neutron Background (4,74±0,46)x10^{-2} cps
Load (kN)
Load (kN)
0
50
100
150
200
250
Cps (10^{-2})
0
5
10
15
20
25
30
35
Time (s)
0
250
500
750
1000
1250
1500
1750

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

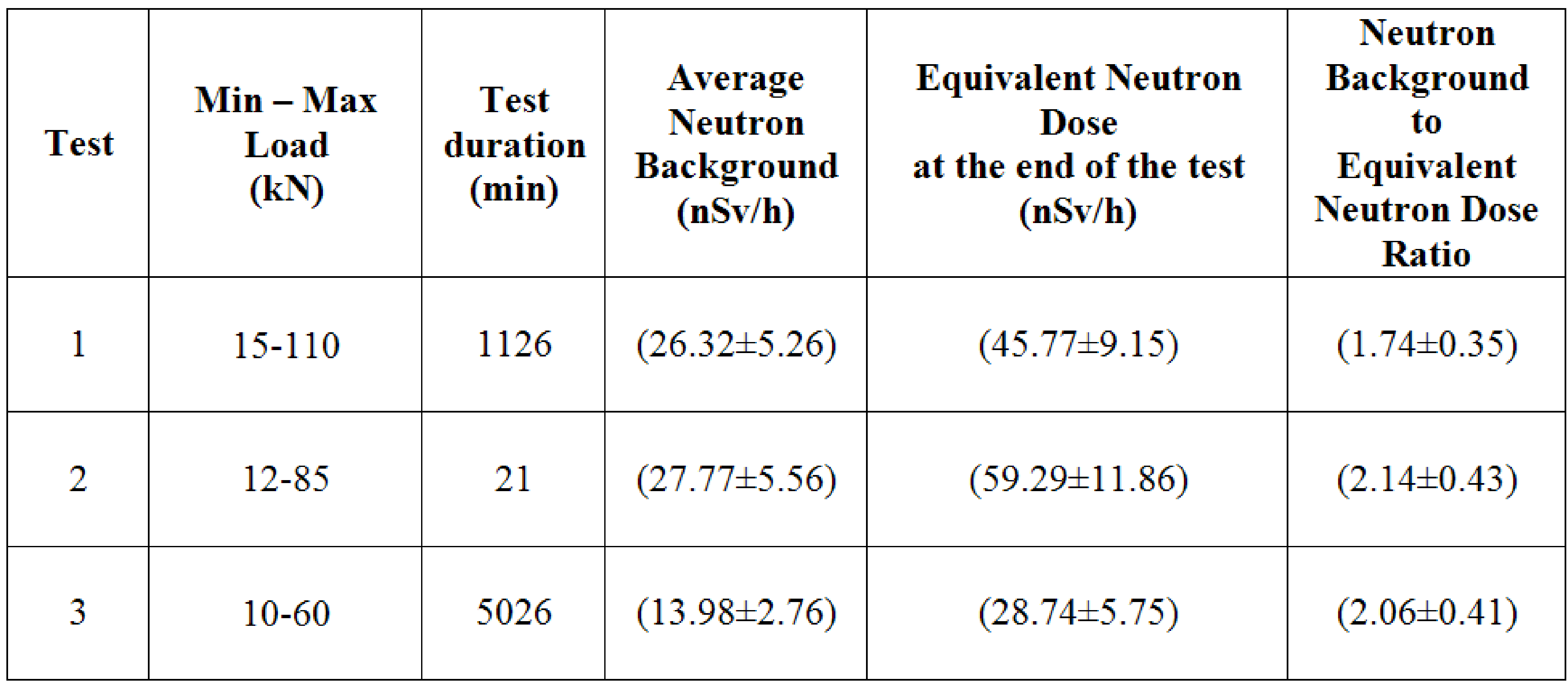
Specimen P9


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

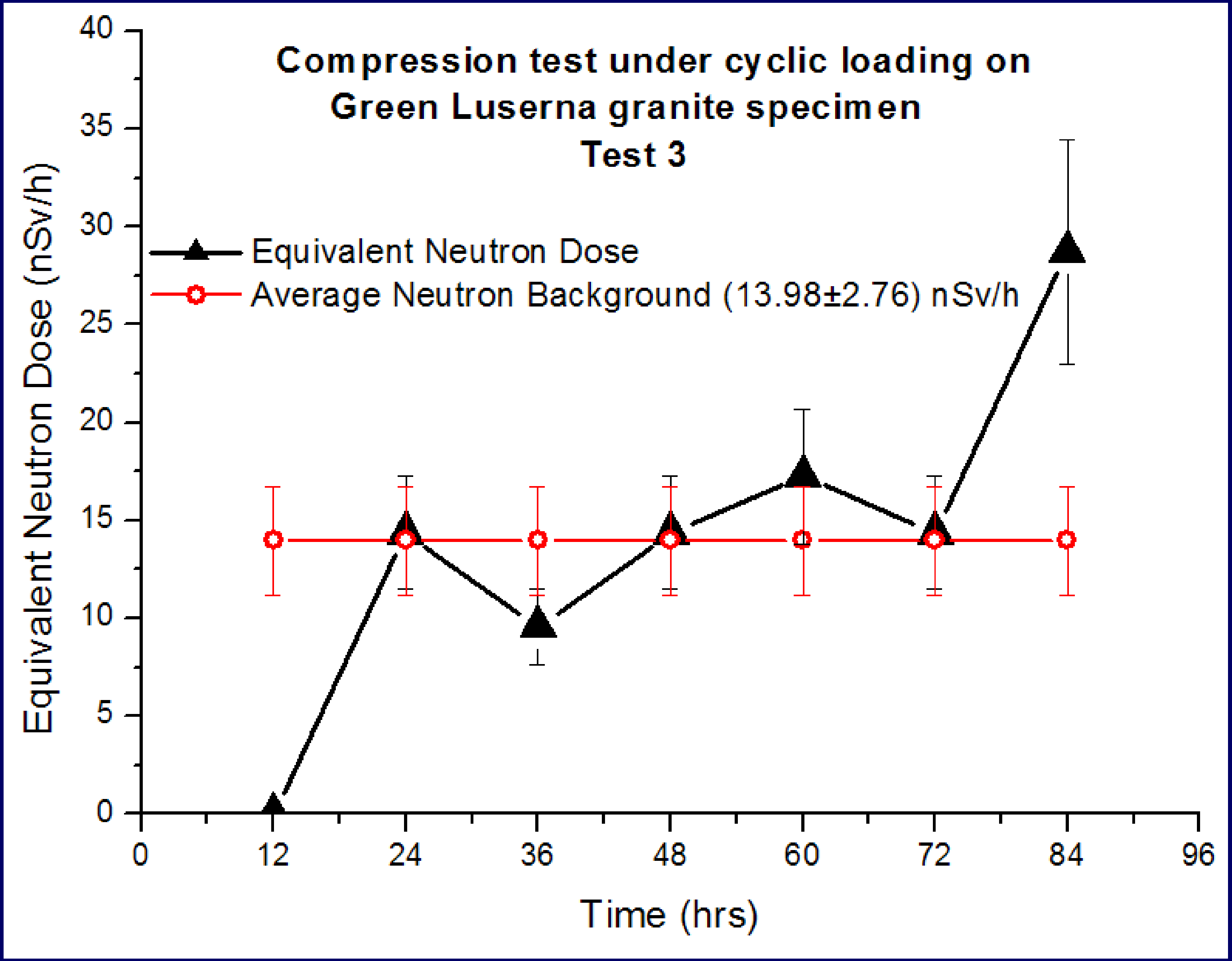
Cyclic Loading

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.

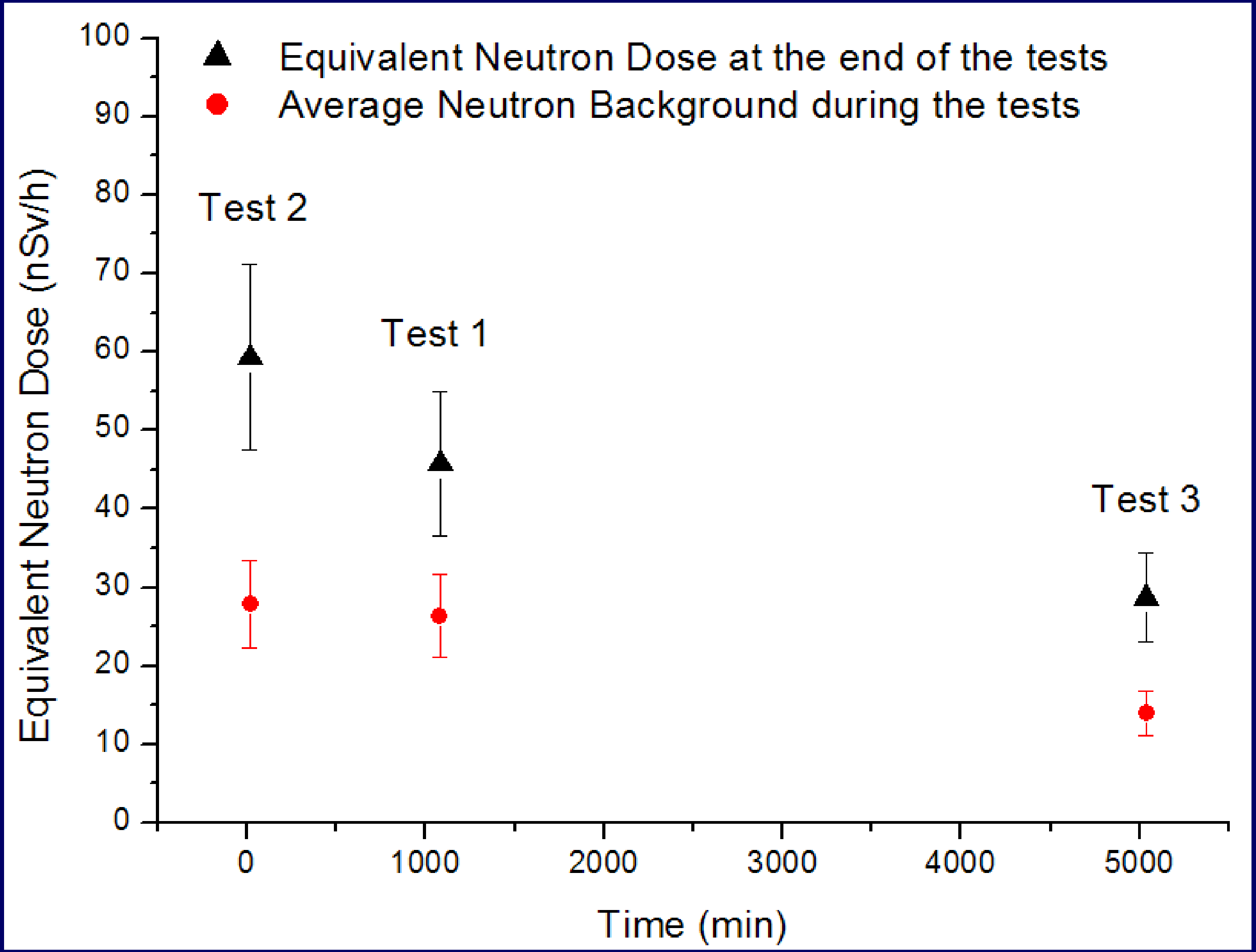
The cyclic loading was fixed at a frequency of 2 Hz for three specimens with the same shape and size (D=53mm, H=53mm, λ=1).



Test	Min – Max Load (kN)	Test duration (min)	Average Neutron Background (nSv/h)	Equivalent Neutron Dose at the end of the test (nSv/h)	Neutron Background to Equivalent Neutron Dose 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 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.

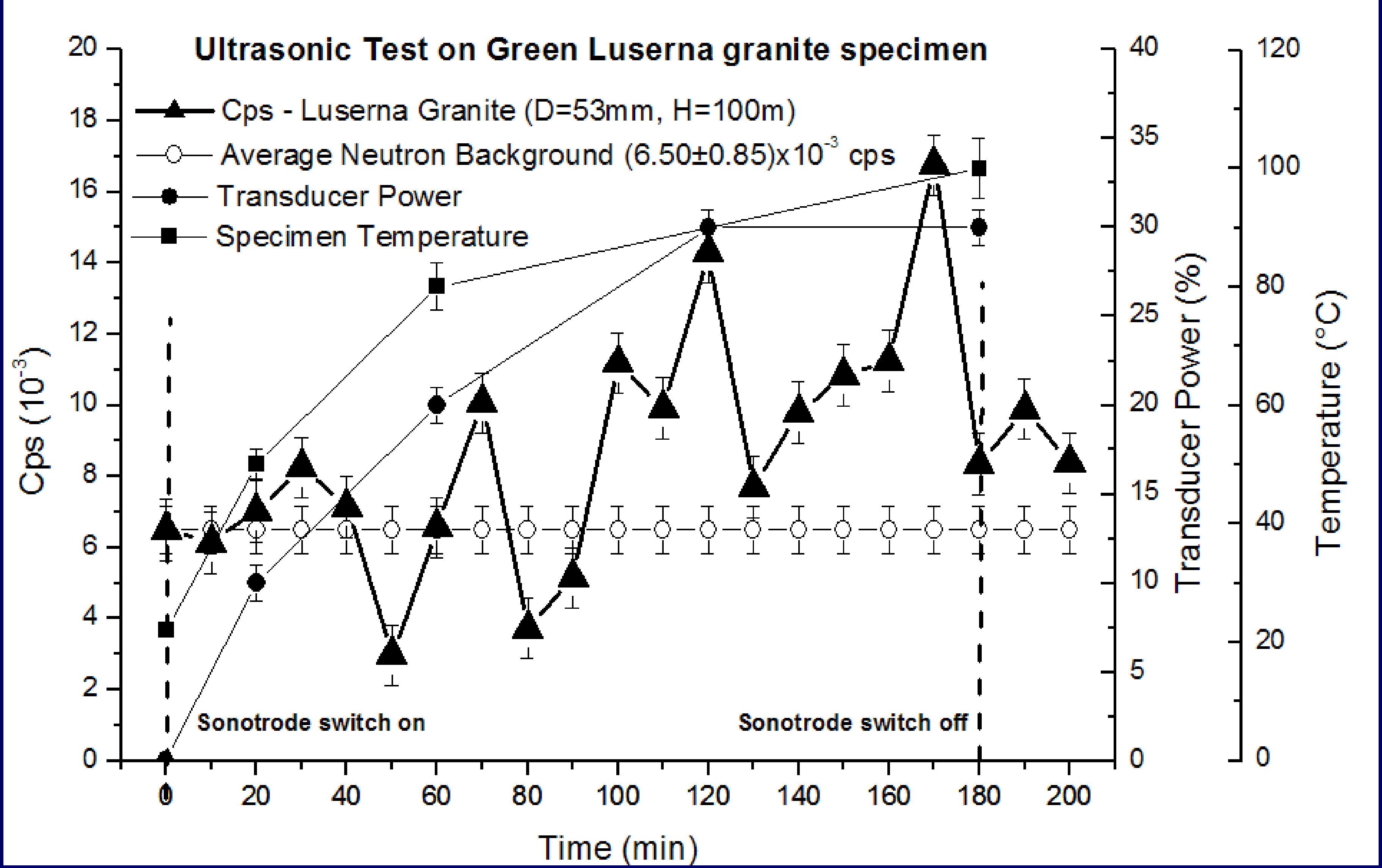


The comparison between the equivalent background neutron dose and the equivalent neutron dose at the end of the cyclic loading tests, are reported. Considering the sensitivity of bubble detectors (20%), it is possible to observe that in each test the average increment of equivalent neutron dose at failure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

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



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.

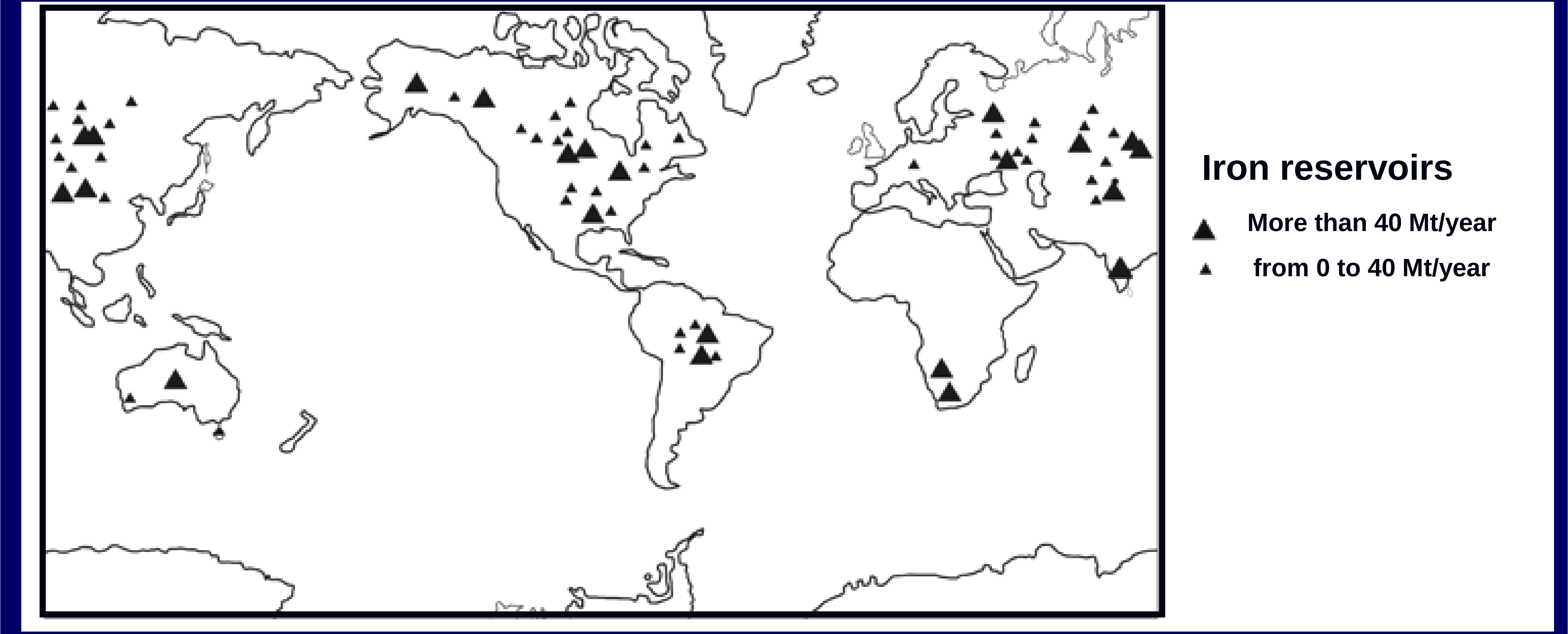
- This reaction –less infrequent than we could think– would be activated where the environment conditions (pressure and temperature) are particularly severe, and mechanical phenomena of fracture, crushing, fragmentation, comminution, erosion, friction, etc., may occur.

- 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.



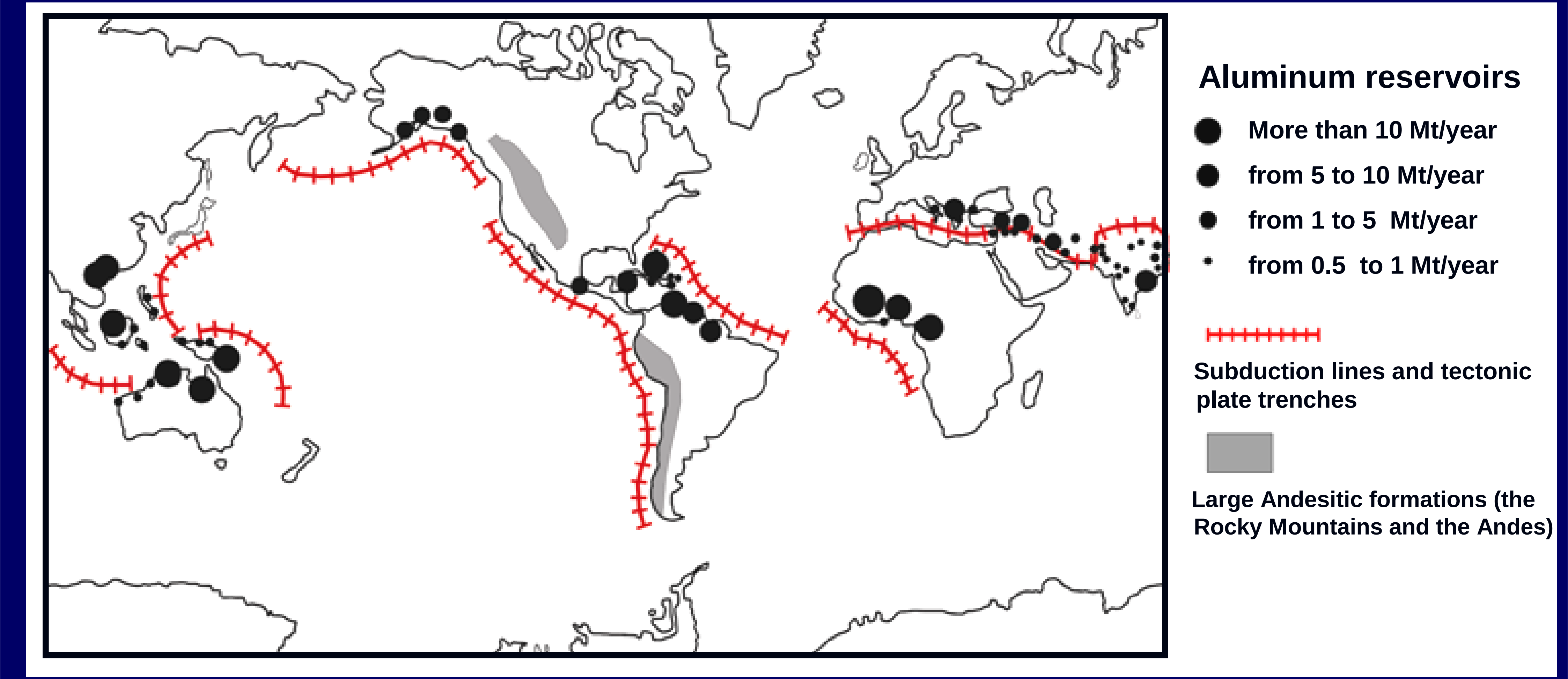
Iron reservoirs

▲ More than 40 Mt/year

▲ from 0 to 40 Mt/year

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

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



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

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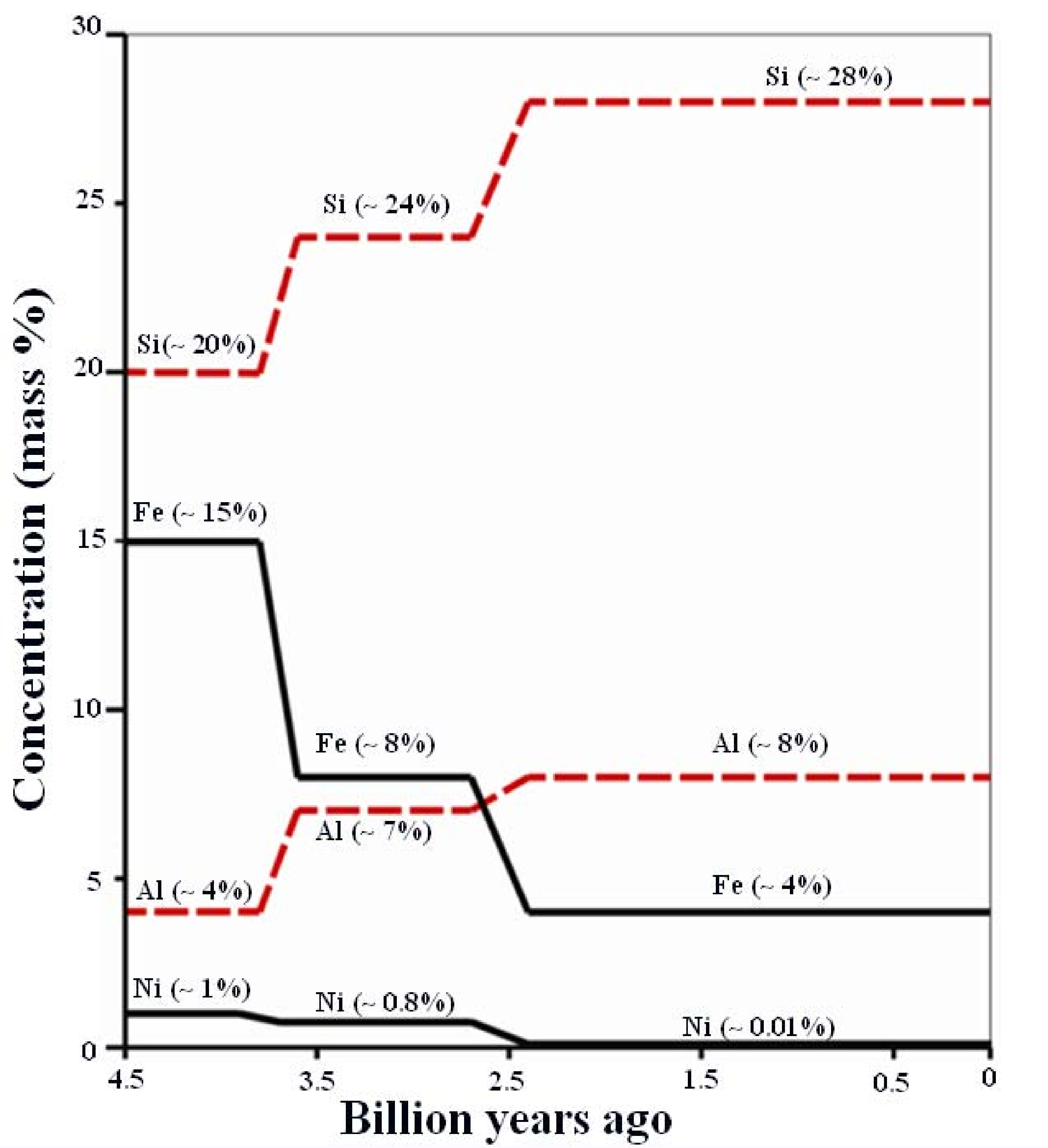
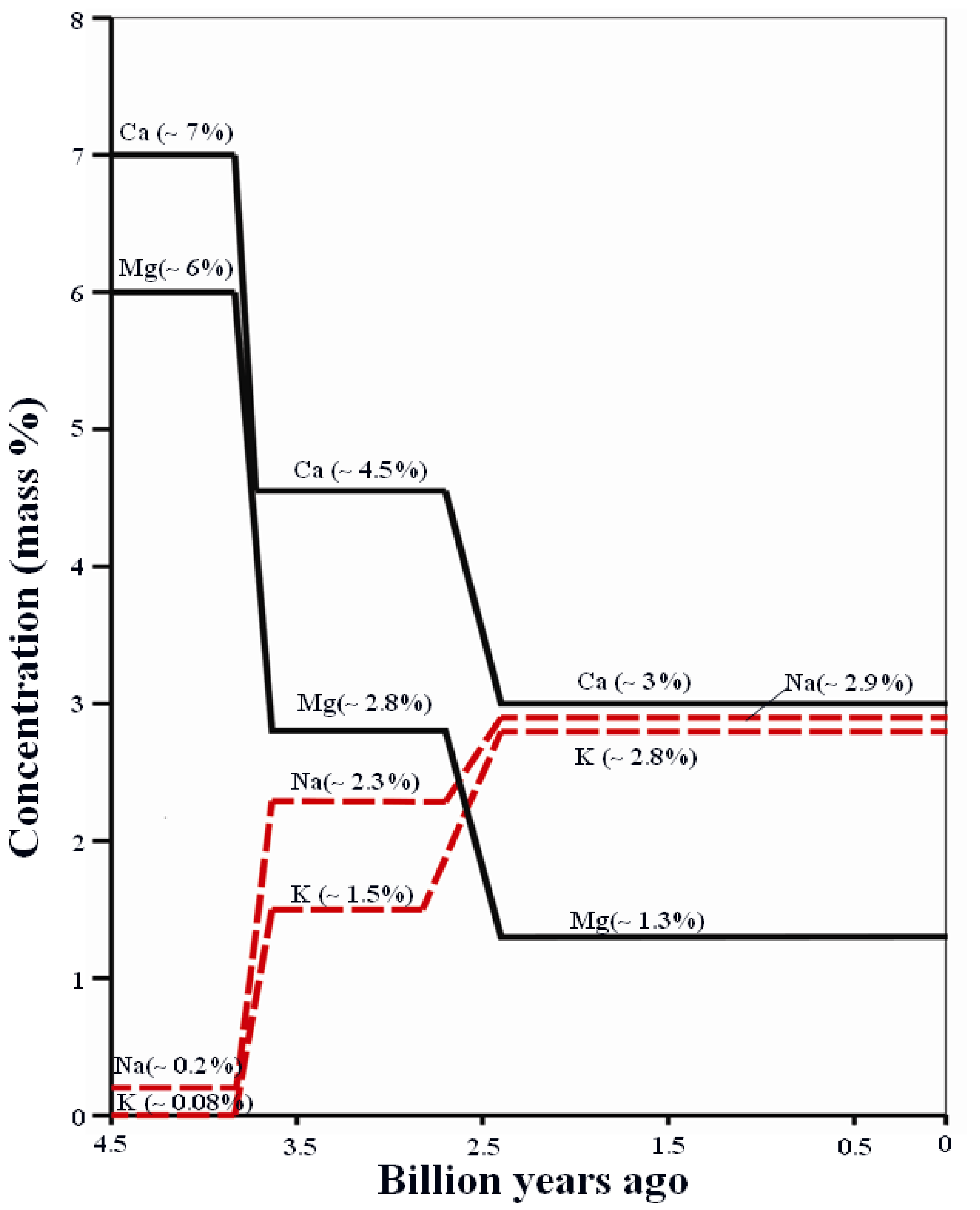
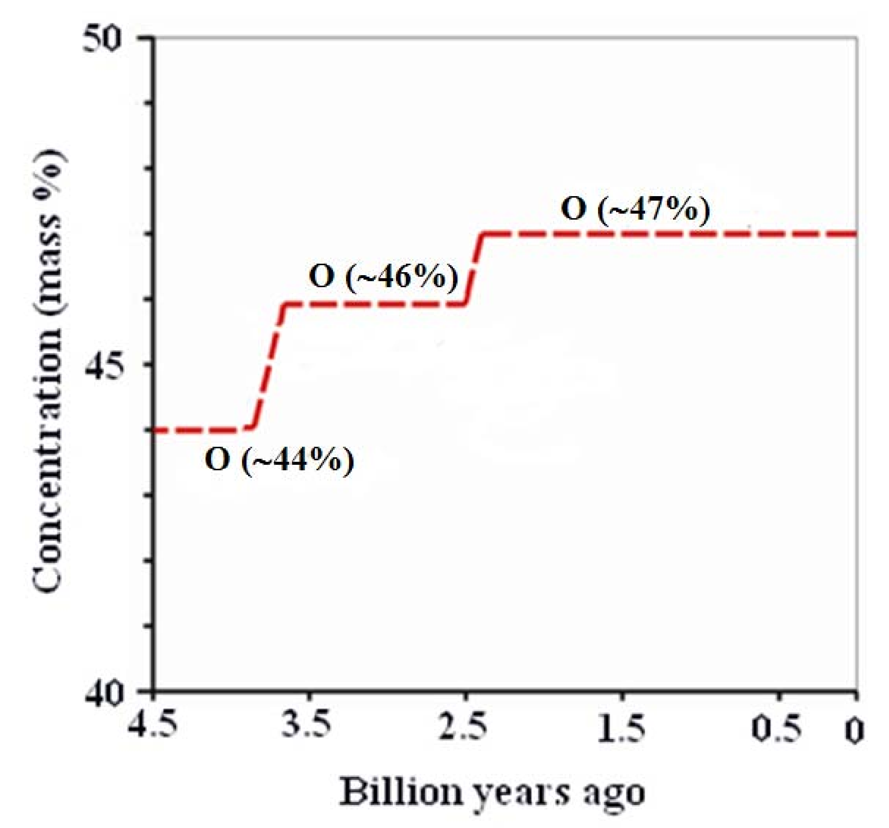


- **3.8 Billion years ago:**
  Fe (–7%) =
  =Al (+3%) + Si (+4%)

- **2.5 Billion years ago:**
  Fe (–4%)+ Ni (–1%) =
  = Al (+1%) + Si (+4%)

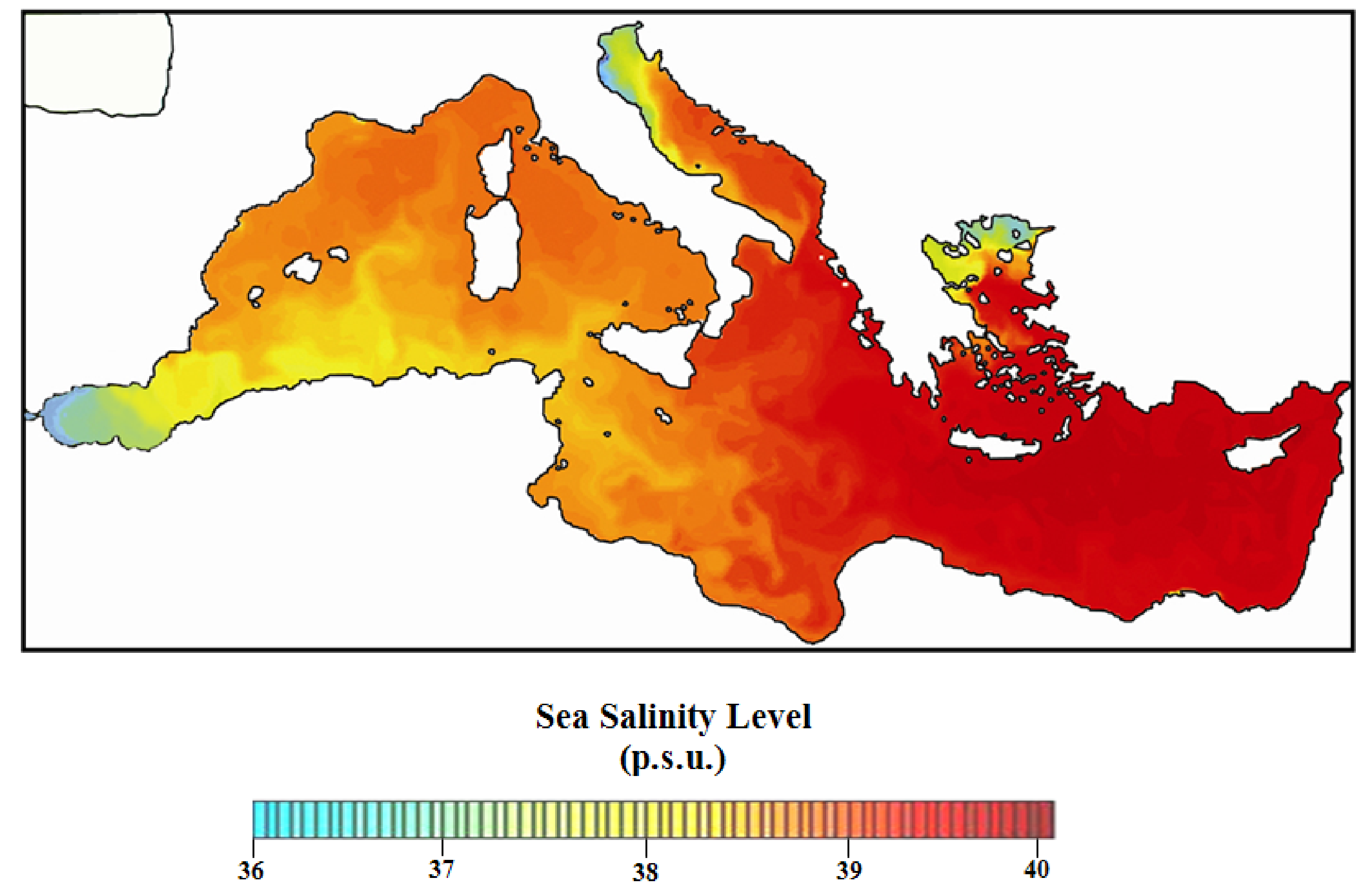




- **3.8 Billion years ago:**
  Ca (–2.5%) + Mg(–3.2%) =
  = K (+1.4%) + Na (+2.1%) + O (+2.2%)

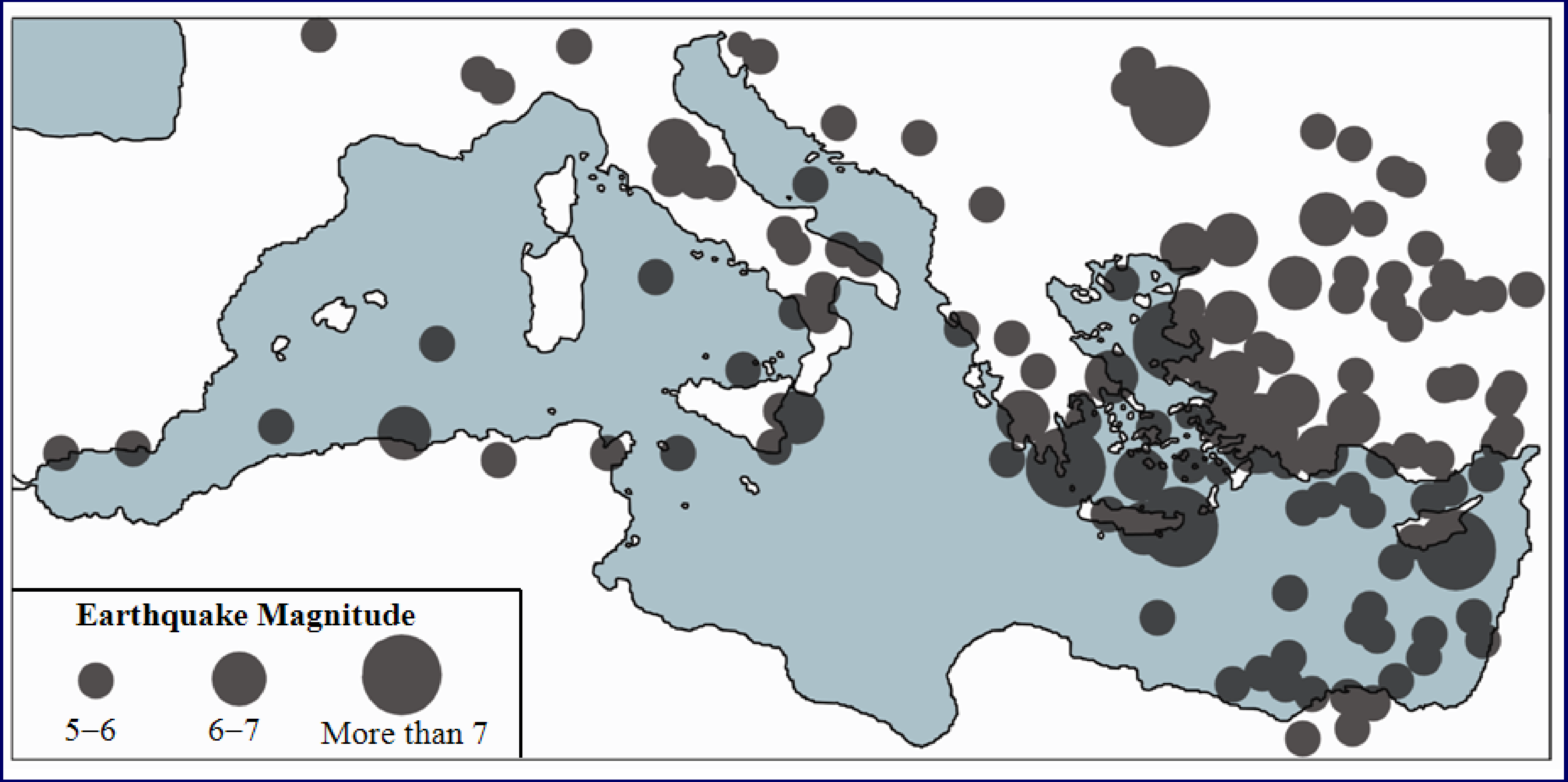
- **2.5 Billion years ago:**
  Ca (–1.5%) + Mg(–1.5%) =
  =K (+1.3%) + Na (+0.6%) + O (+1.1%)

Piezonuclear 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.



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

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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}, Mg_{12}, K_{19}, Ca_{20})
- Great Oxidation Event (2.5 Billion years ago) and origin of life
- Carbon pollution (increasing now) 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
- Production of neutrons for medical use in cancer therapy
- Disposal of radioactive wastes
- Clean nuclear energy production (?)