EPPUR SI FONDE
DALLA FUSIONE FREDDA ALLE REAZIONI PIEZONUCLEARI
NASCE UN NUOVO PARADIGMA SCIENTIFICO?

Organizzazione Nazionale Nuove Energie

Centro Congressi ed Auditorium della Provincia di Milano
Milano, 20/11/2009

Piezonuclear reactions in solids under compression

Alberto Carpinteri

Department of Structural Engineering and Geotechnics
Politecnico di Torino, Italy

Acknowledgemnts for extensive collaboration:

Fabio Cardone
ISMN – CNR Rome, Italy

Giuseppe Lacidogna
Politecnico di Torino, Italy

Amedeo Manuello
Politecnico di Torino, Italy

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

A. Carpinteri*, F. Cardone† and G. Lacidogna*

*Department of Structural Engineering and Geotechnics, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy
†ISMN – CNR Via dei Taurini 19, 00187 Rome, Italy

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

[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).

Physics Letters A 373 (2009) 4158–4163

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

Piezonuclear neutrons from fracturing of inert solids

F. Cardone [a,b], A. Carpinteri [c,*], G. Lacidogna [c]

[a] Istituto per lo Studio dei Materiali Nanostrutturati (ISMN-CNR), Via dei Taurini 19, 00185 Roma, Italy
[b] Dipartimento di Fisica "E. Amaldi", Università degli Studi "Roma Tre", Via della Vasca Navale, 84-00146 Roma, Italy
[c] Department of Structural Engineering and Geotechnics, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy

ARTICLE INFO

Article history:
Received 17 March 2009
Received in revised form 2 September 2009
Accepted 10 September 2009
Available online 16 September 2009
Communicated by F. Porcelli

Keywords:
Neutron emission
Piezonuclear reactions
Rocks crushing failure
Strain localization
Material interpenetration

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

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.

* Corresponding author. Tel.: +39 0115644850; fax: +39 0115644899.
E-mail address: alberto.carpinteri@polito.it (A. Carpinteri).

0375-9601/$ – see front matter
doi:10.1016/j.physleta.2009.09.026

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

MATERIALS

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.

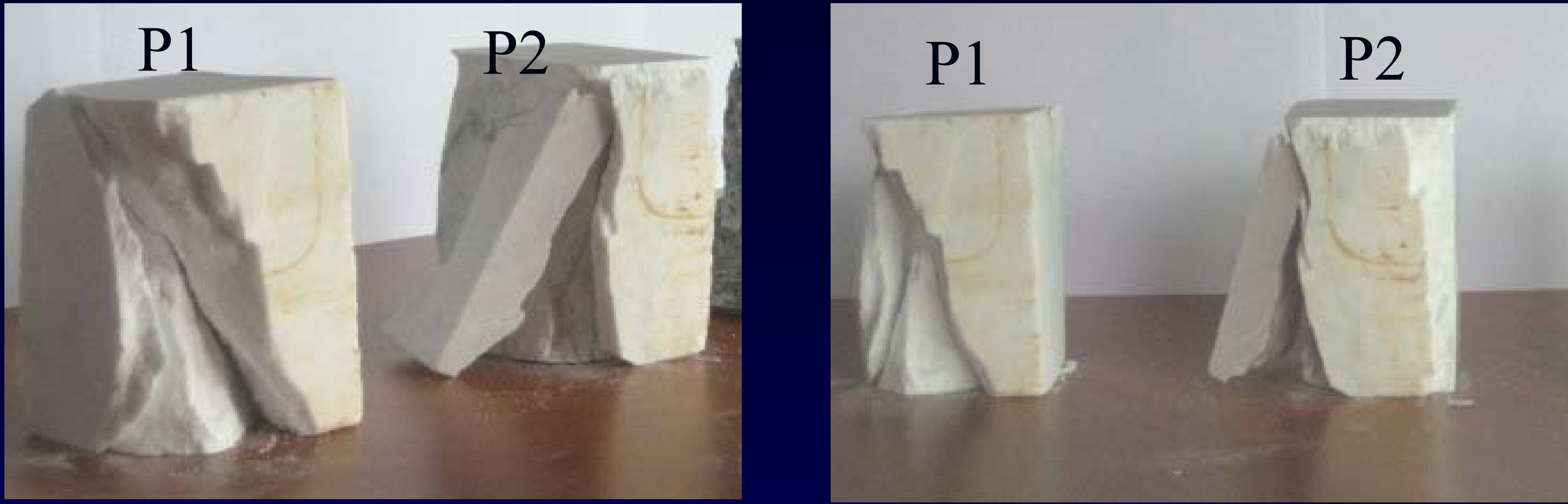
The average background count rate was:

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

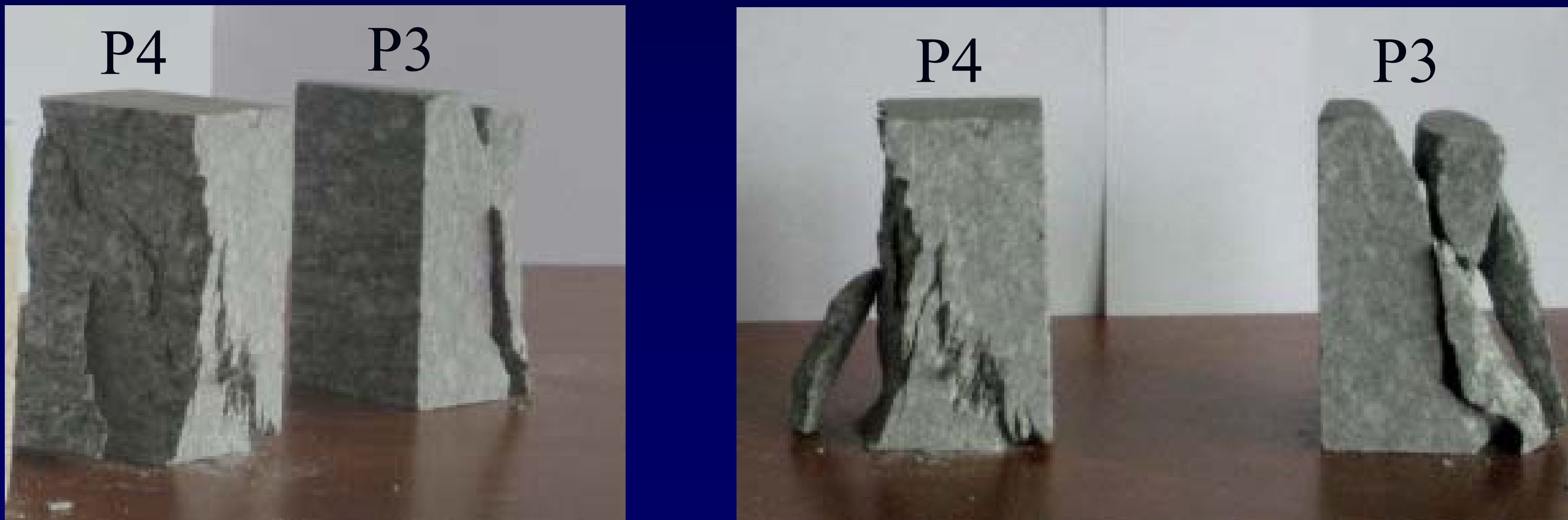
During the loading tests

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

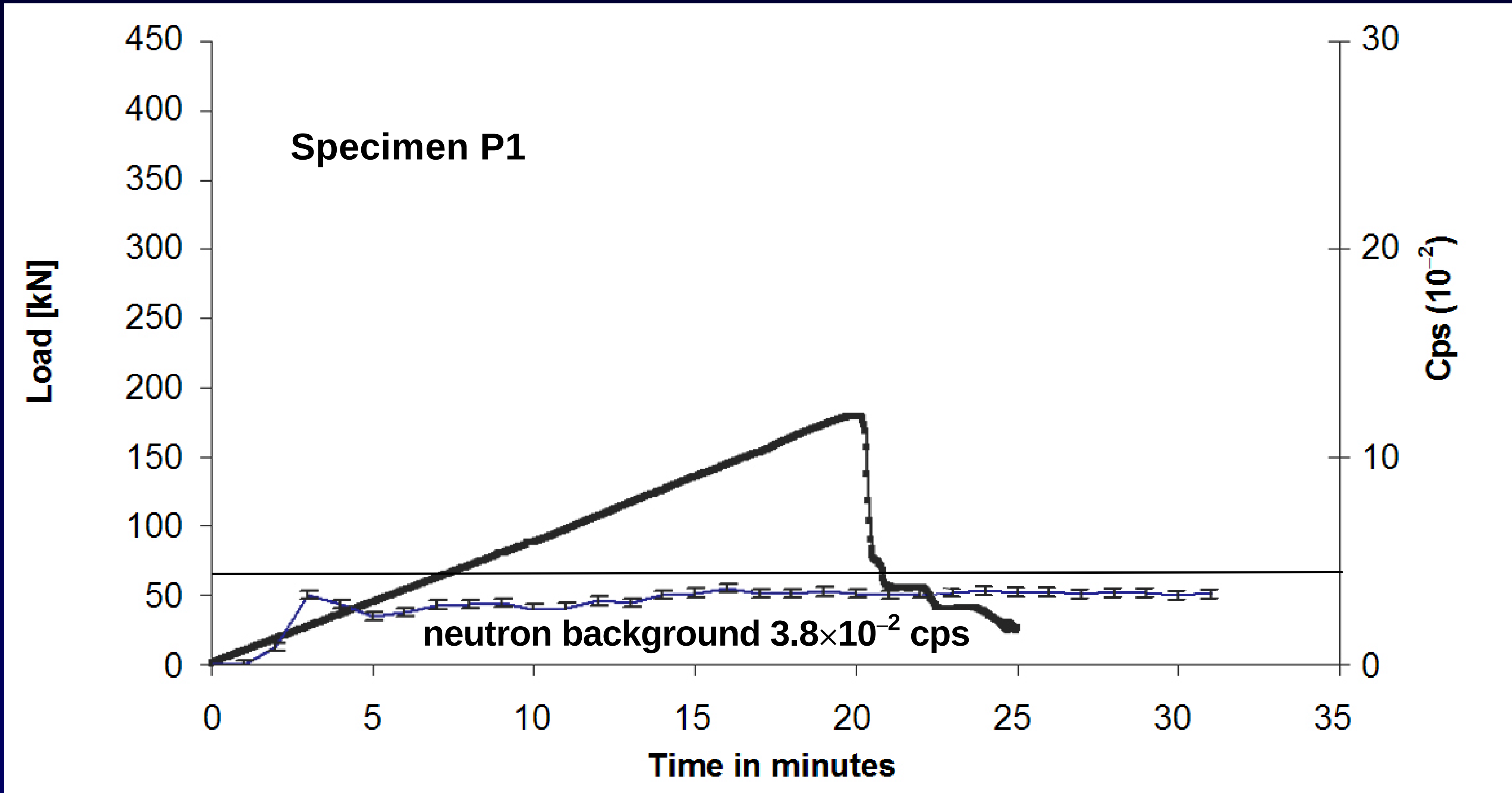
- The neutron measurements obtained on the two Luserna granite specimens, instead, exceeded the background value by about one order of magnitude at the test specimen failure.



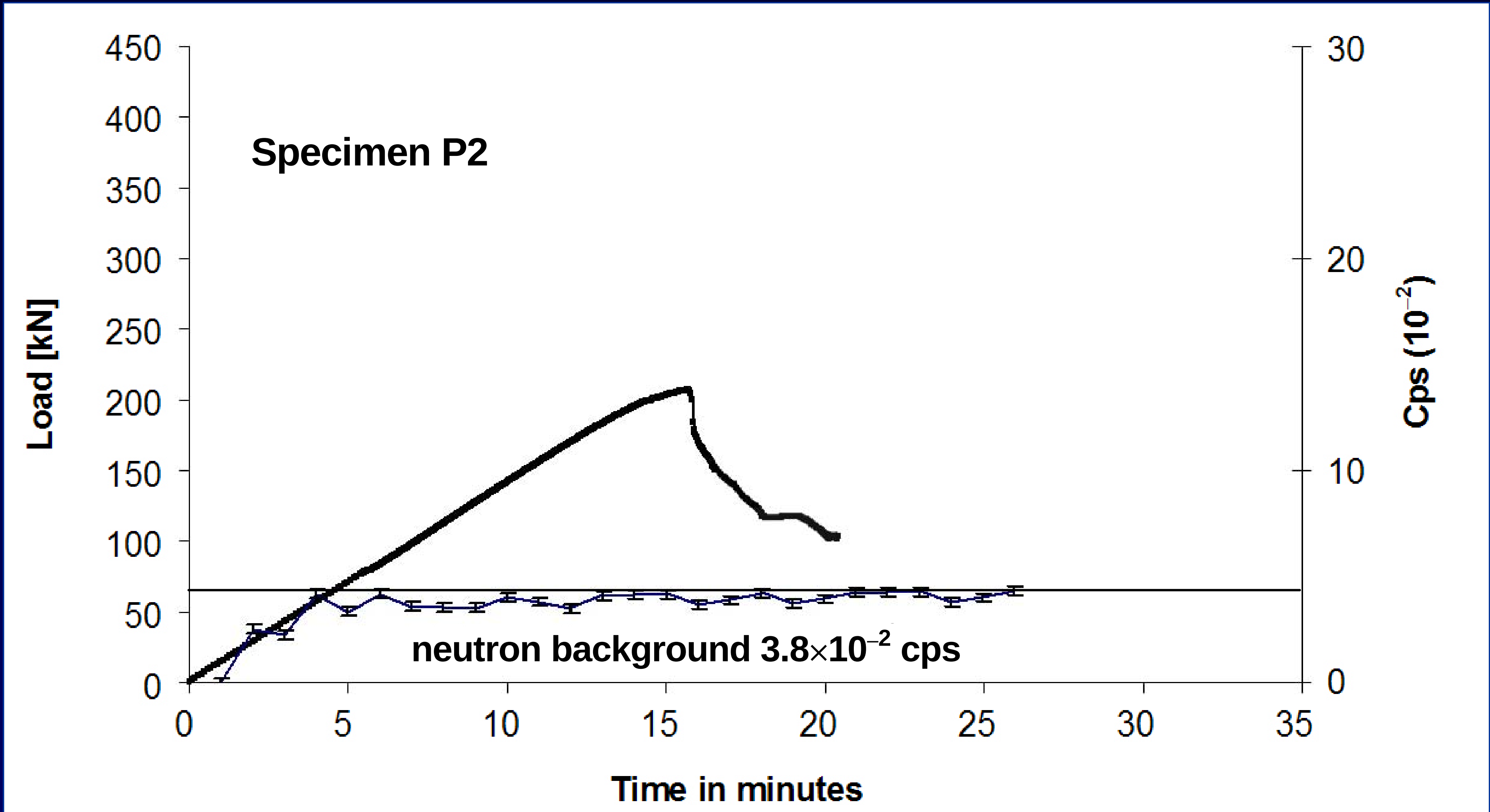
Specimens P1 and P2 in Carrara marble following compression failure.



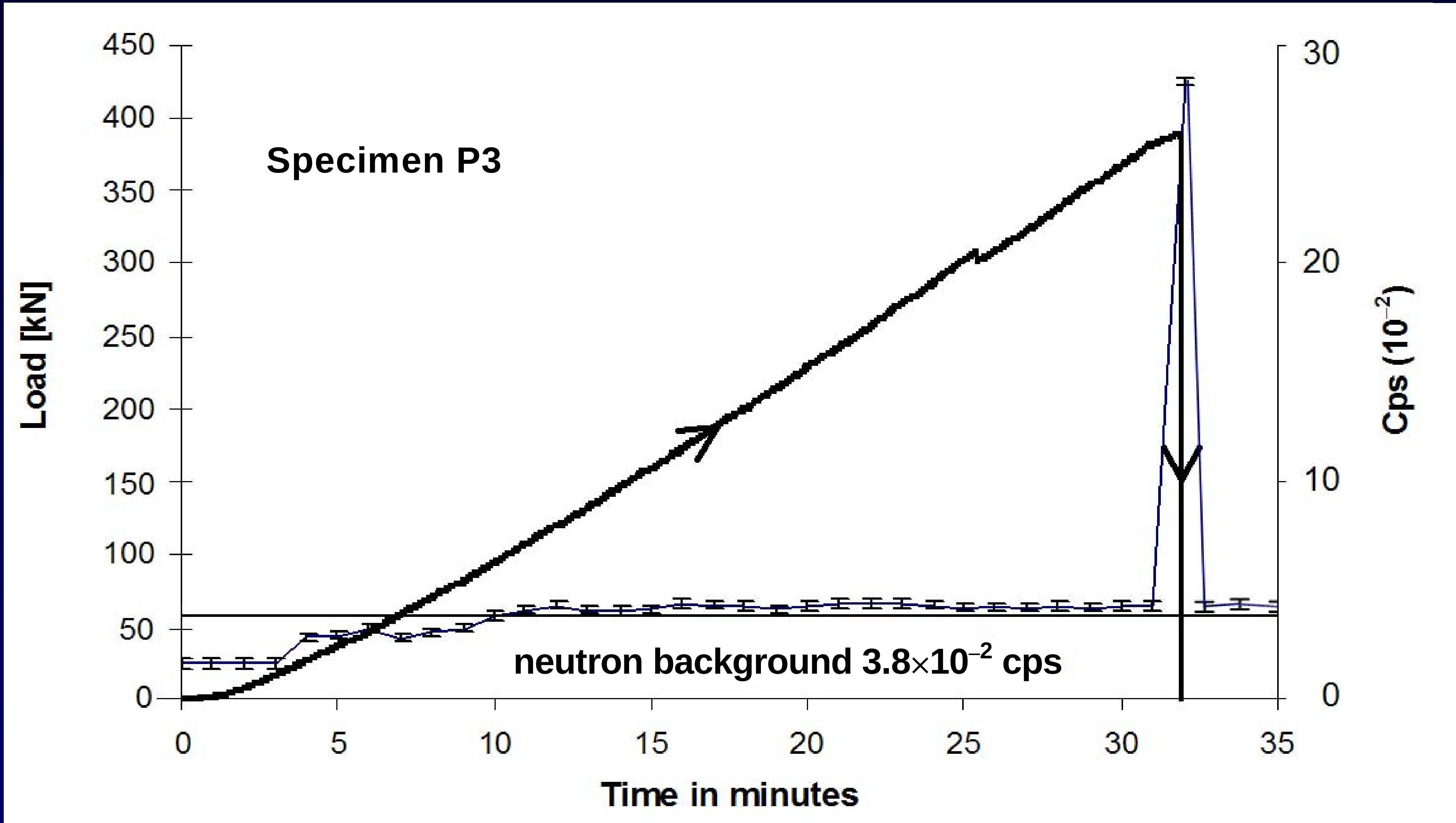
Specimens P3 e P4 in Luserna granite following compression failure.



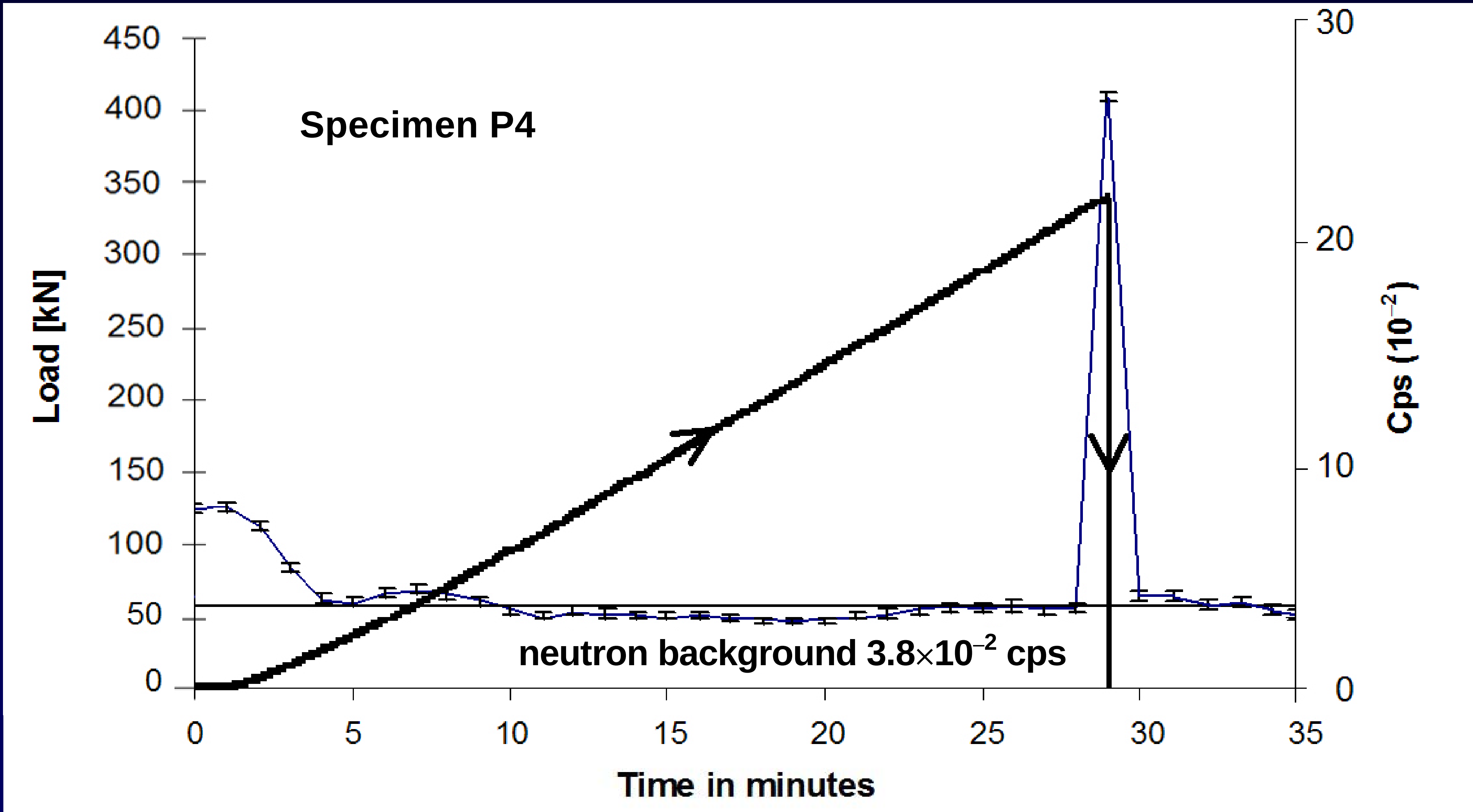
Load vs. time and cps curve for P1 test specimen in Carrara marble.



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

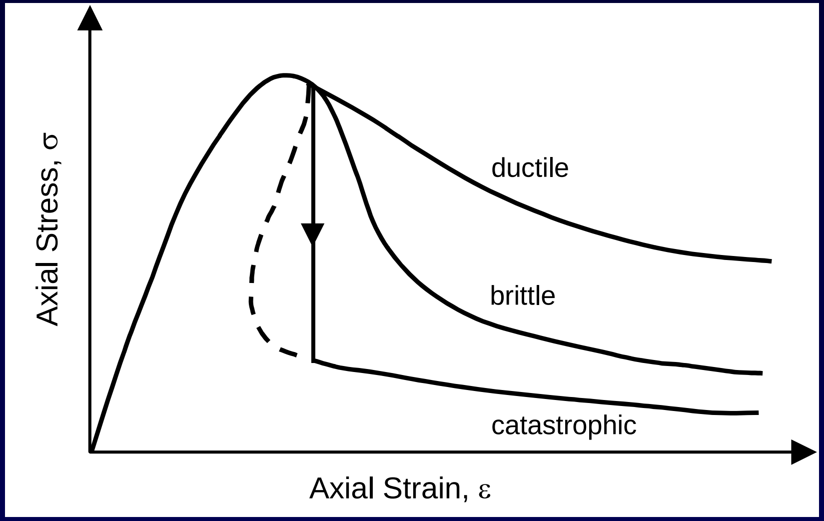


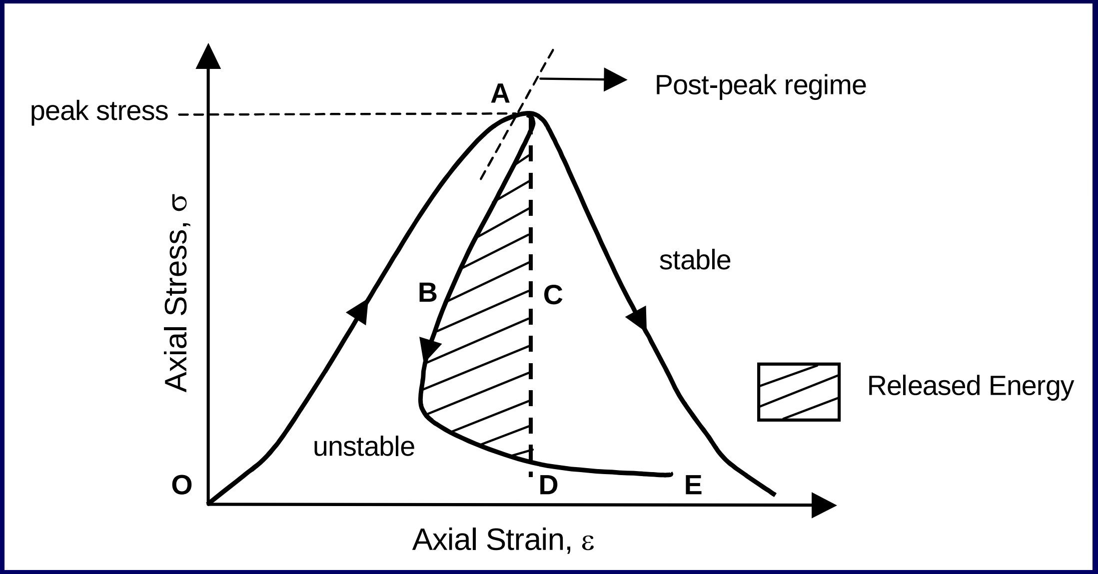
Load vs. time and cps curve for P3 test specimen in Luserna granite.



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

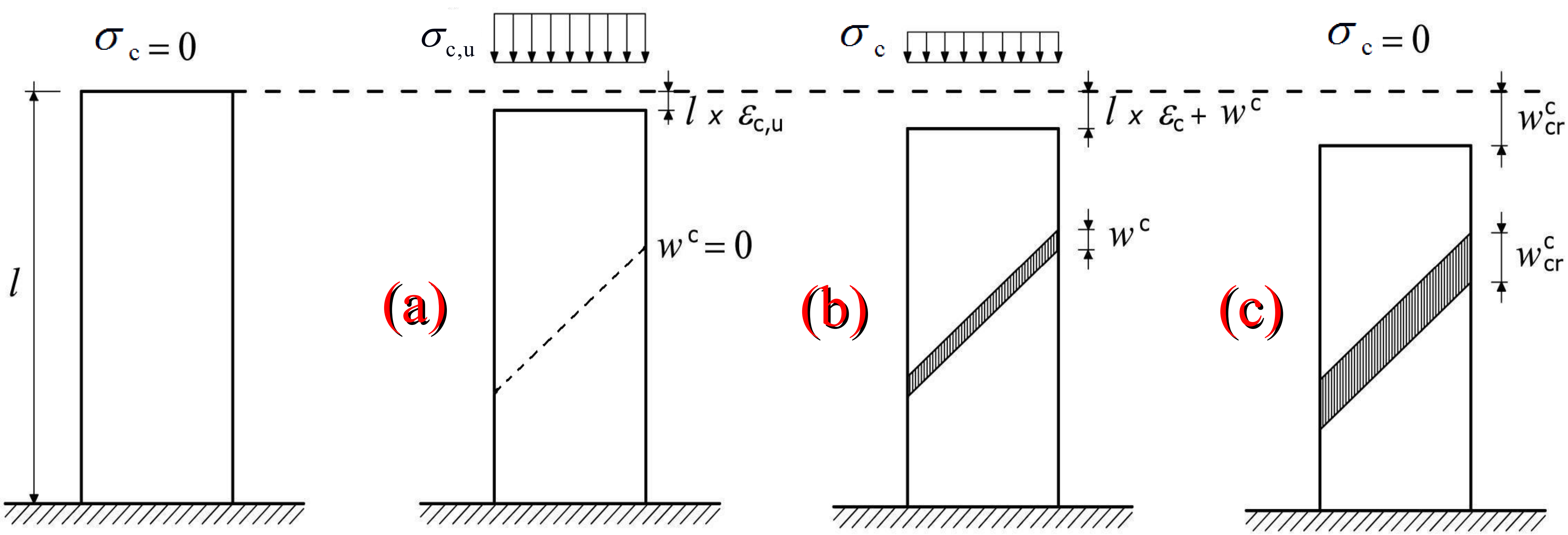
DUCTILE, BRITTLE AND CATASTROPHIC BEHAVIOUR





Energy release and stable vs. unstable stress-strain behaviour

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

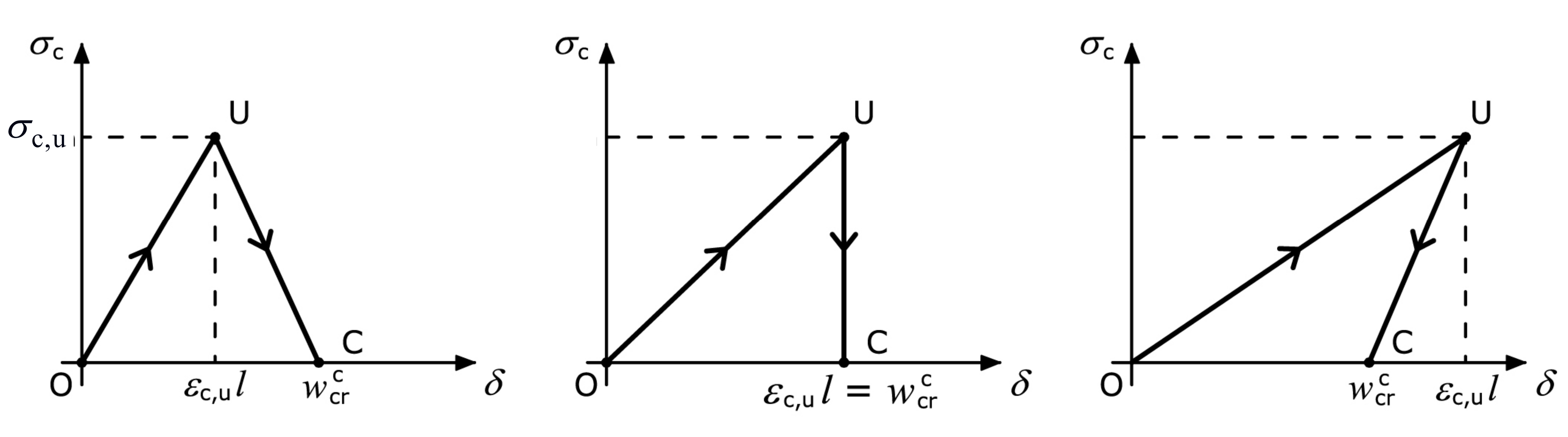


$$\delta = \varepsilon_c l = \frac{\sigma_c}{E} l; \qquad \delta = \frac{\sigma_c}{E} l + w^c; \qquad \delta \geq w^c_{cr}.$$

[(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

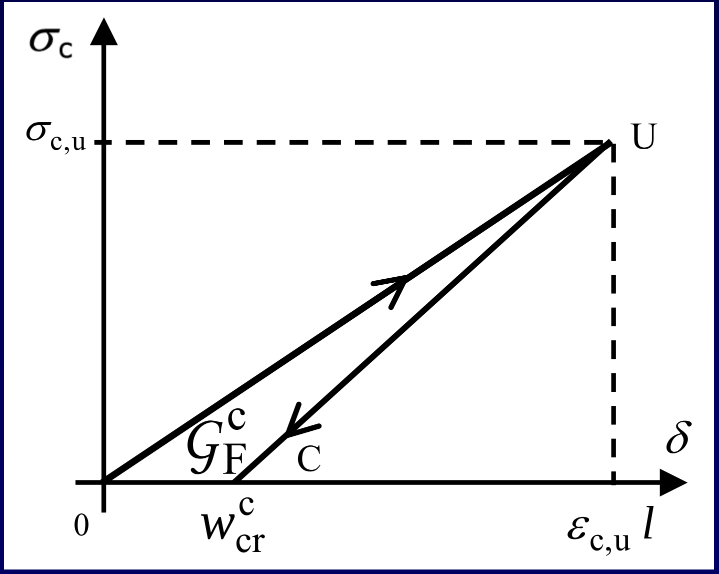
Threshold of energy rate for piezonuclear reactions (III) (IV):

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

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:



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

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EVOLUTION OF METAL ABUNDANCES IN THE EARTH CRUST

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

$$Fe_{26}^{30} \rightarrow 2\,Al_{13}^{14} + 2 \text{ neutrons.}$$

- 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.

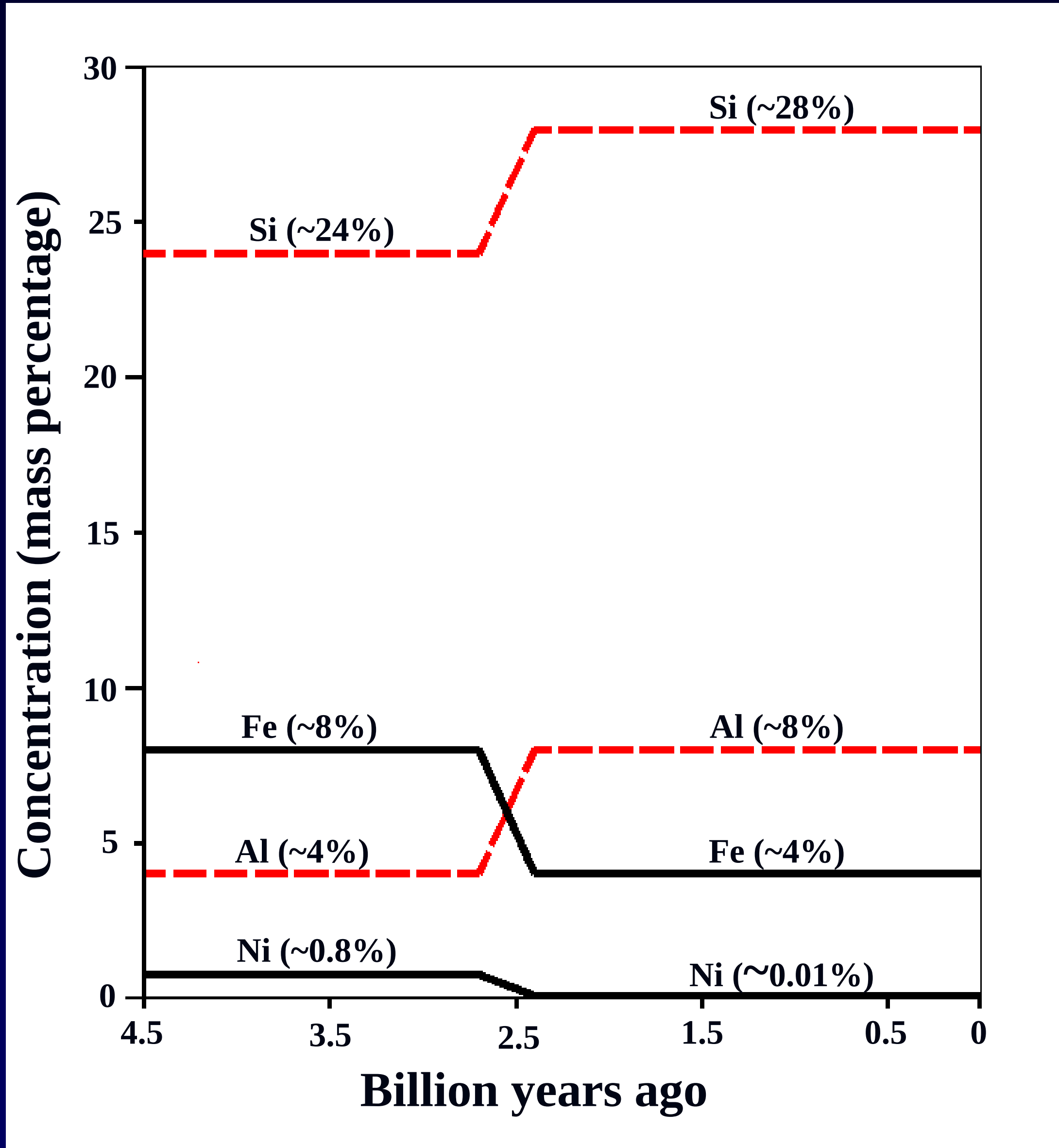
- If we consider the evolution of the percentages of the most abundant elements in the Earth crust during the last 4 billion years, we realize that iron and nickel have drastically diminished, whereas aluminum and silicon have as much increased:

$$Ni_{28}^{31} \rightarrow 2Si_{14}^{14} + 3 \text{ neutrons.}$$

$$Fe_{26}^{30} \rightarrow Si_{14}^{14} + Mg_{12}^{12} + 4 \text{ neutrons.}$$

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

- Many other clues and quantitative data could be presented in favour of the piezonuclear fission reactions, and this will be the subject of a next publication.



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CONCLUSIONS

Two piezonuclear fission reaction jumps typical of the Earth Crust:

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

Explanation for:

- Sudden variations in the most abundant elements (including Na, K, Ca)
- 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

New application fields:

- Clean nuclear energy production
- Evaluation of natural production of black carbon and CO_2 with their effects on global pollution
- Short-term prediction and monitoring of earthquakes