PIEZONUCLEAR REACTIONS IN INERT SOLIDS: NEUTRON EMISSIONS FROM BRITTLE FRACTURE

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The results of the present paper 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], in fluids with ultrasounds and cavitation [3], as well as in solids with shock waves and fracture [4]. We are treating with inert, stable and non-radioactive elements at the beginning of the experiments (iron) [5], as well as after the experiments (aluminum). Neither radioactive wastes, nor electromagnetic emissions were recorded, but only fast neutron emissions.

Therefore, our conjecture is that the following piezonuclear fission reaction should have occurred in the compression tests on granite specimens [5]:

$$^{56}\text{Fe} \rightarrow 2\ ^{27}\text{Al} + 2n$$

The present natural abundance of aluminum (7-8% in the Earth crust), which is less favoured than iron from a nuclear point of view (it has a lower bond energy per nucleon), 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 3 billion years, we realize that iron and nickel have drastically diminished, whereas aluminum, silicon and magnesium have as much increased. It is also interesting to realize that such increases have developed mainly in the tectonic regions, where frictional phenomena between the continental plates occurred.

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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.

Experimental set-up

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 coefficients would cause catastrophic failure in granite, not in marble.

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 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 acoustical-mechanical stresses.

Neutron emission measurements

Before the loading tests

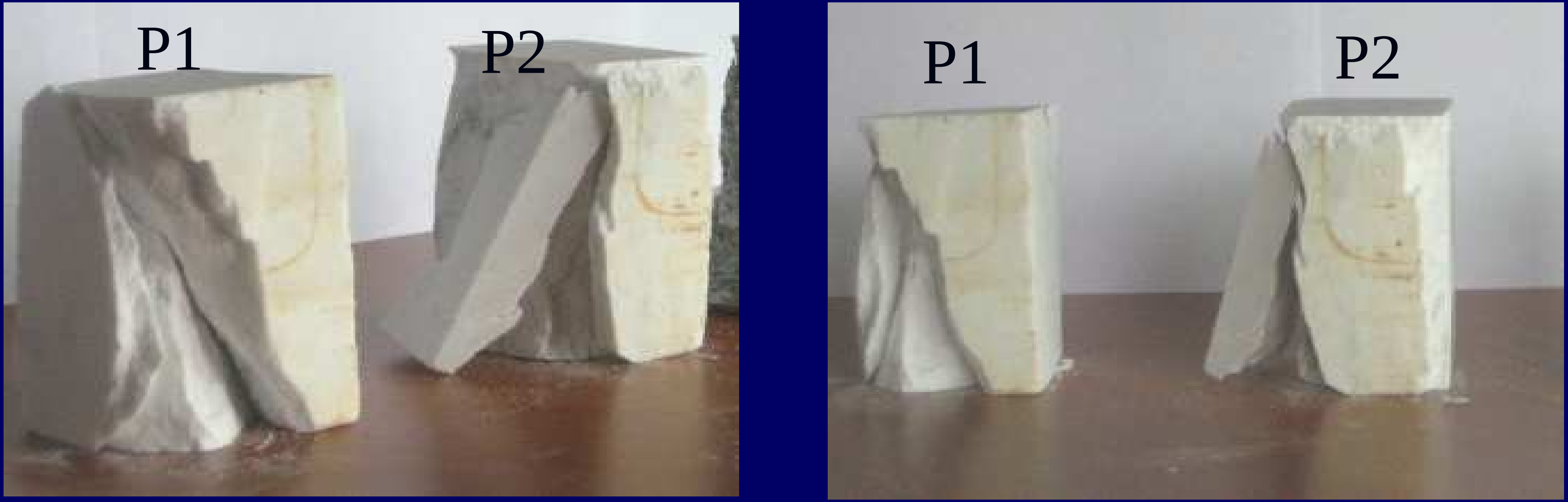
The neutron background was measured at 600 s time intervals to obtain sufficient statistical data with the detector in the position shown in the previous figure.

The average background count rate was:

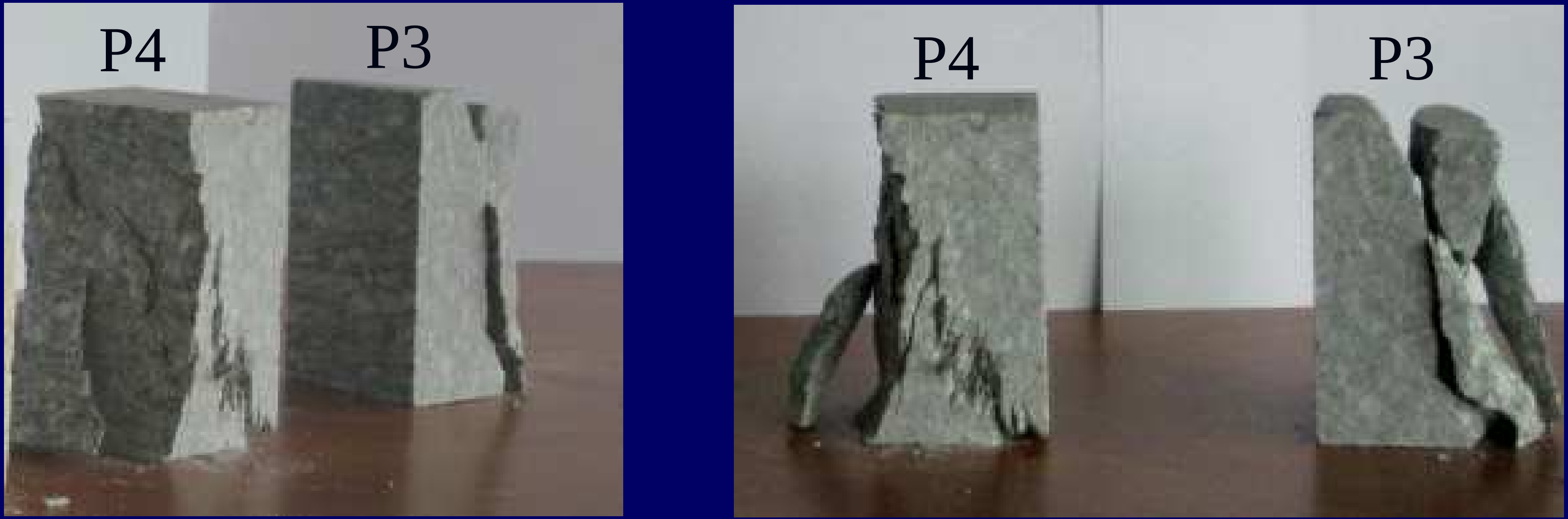
$$3.8\times10^{-2} \pm 0.2\times10^{-2} \text{ cps.}$$

During the loading tests

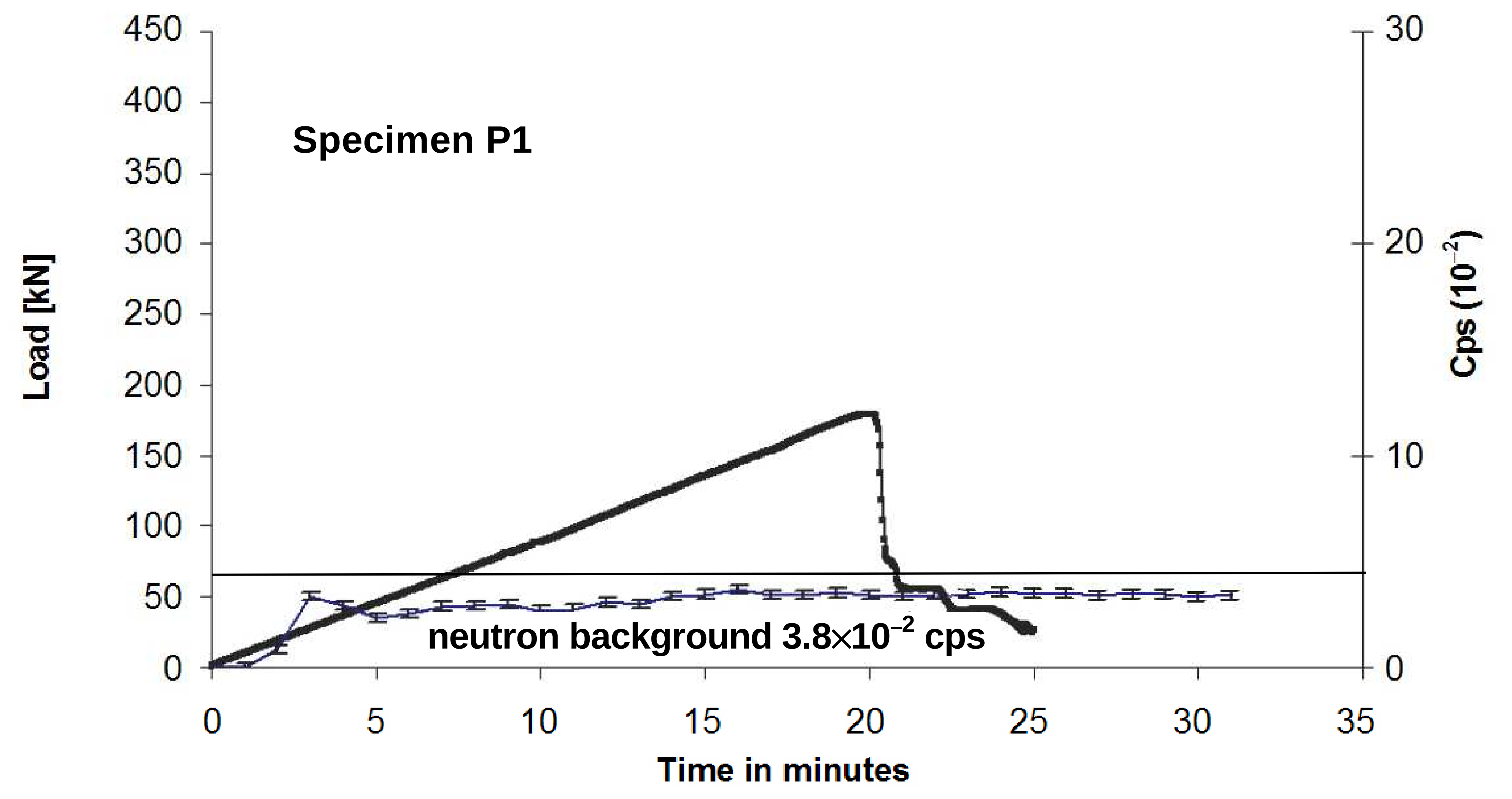
- The neutron measurements obtained on the two Carrara marble specimens yielded values comparable with the background, even at the time of test specimen failure.
- The neutron measurements obtained on the two Luserna granite specimens, instead, exceeded the background value by about one order of magnitude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



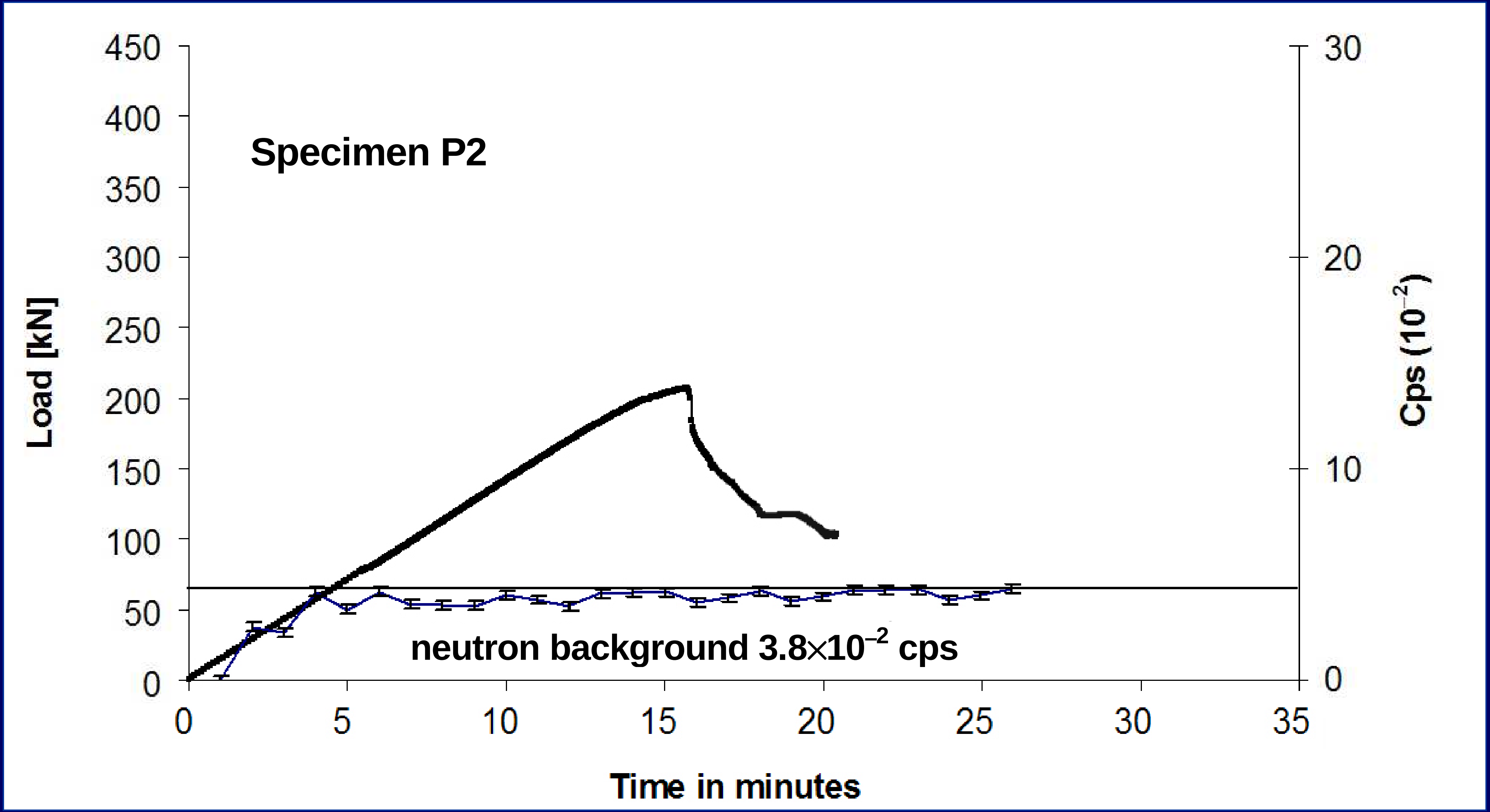
Specimens P1 and P2 in Carrara marble following compression failure.



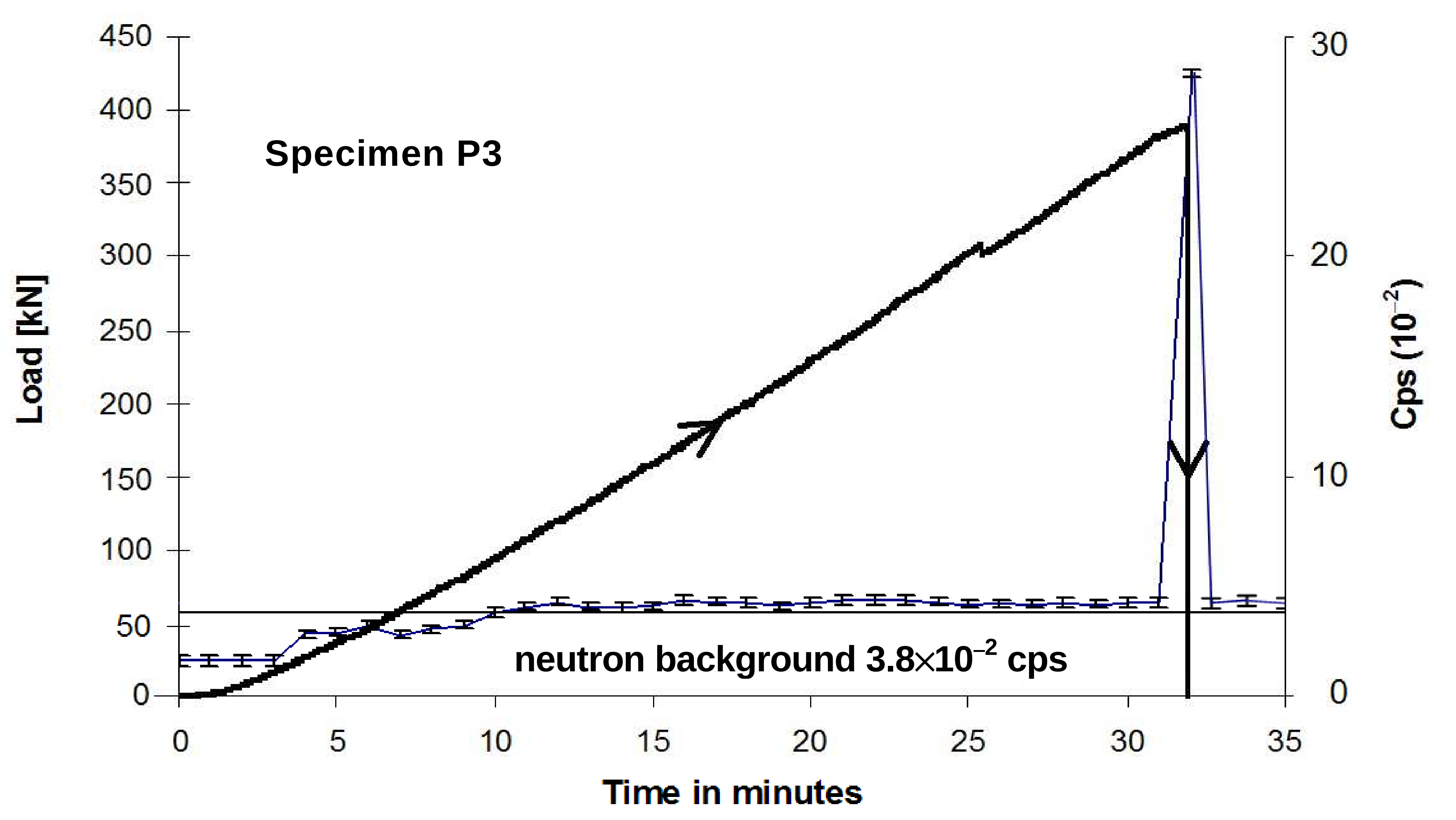
Specimens P3 e P4 in Luserna granite following compression failure.



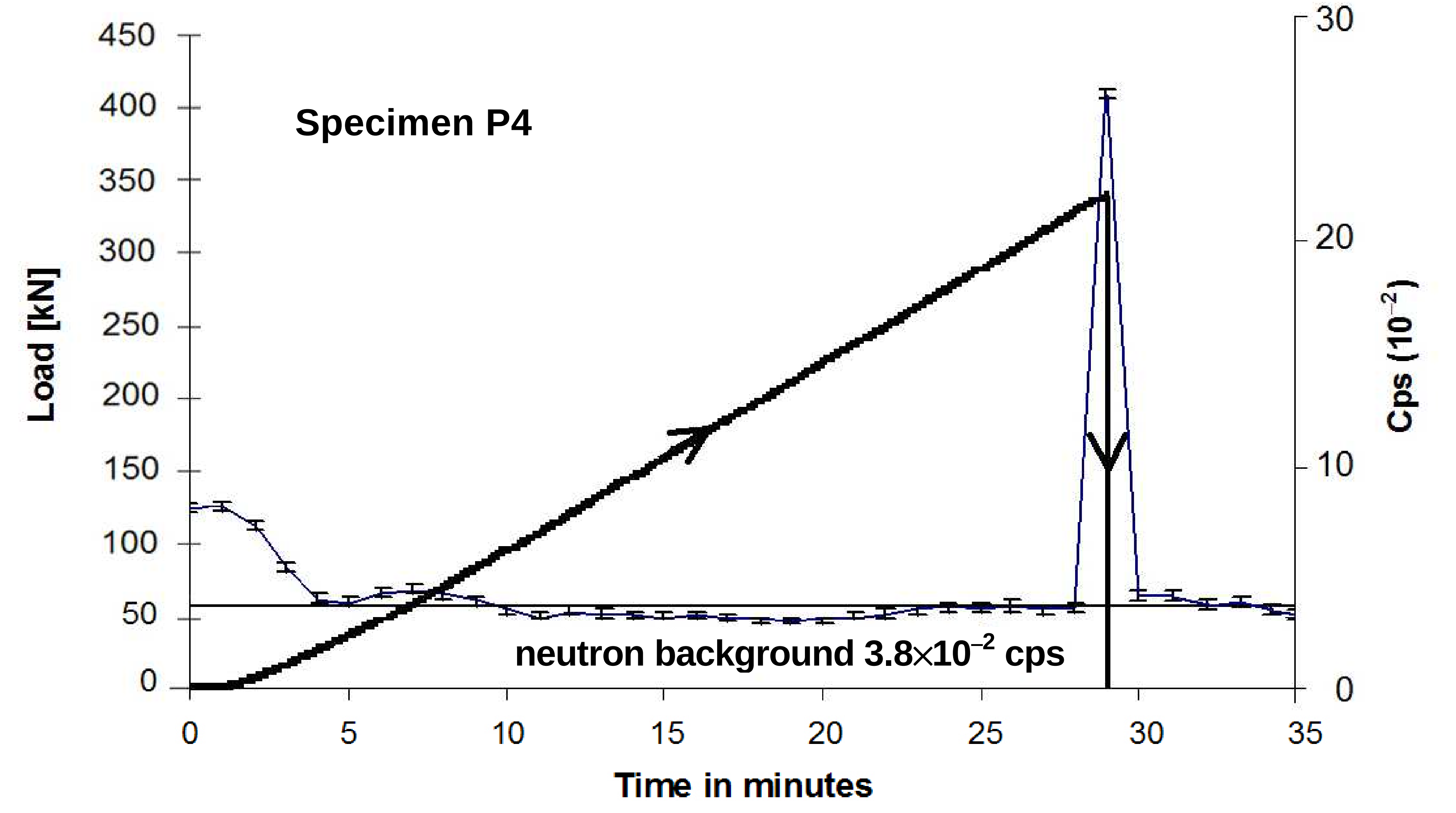
Load vs. time and cps curve for P1 test specimen in Carrara marble.



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

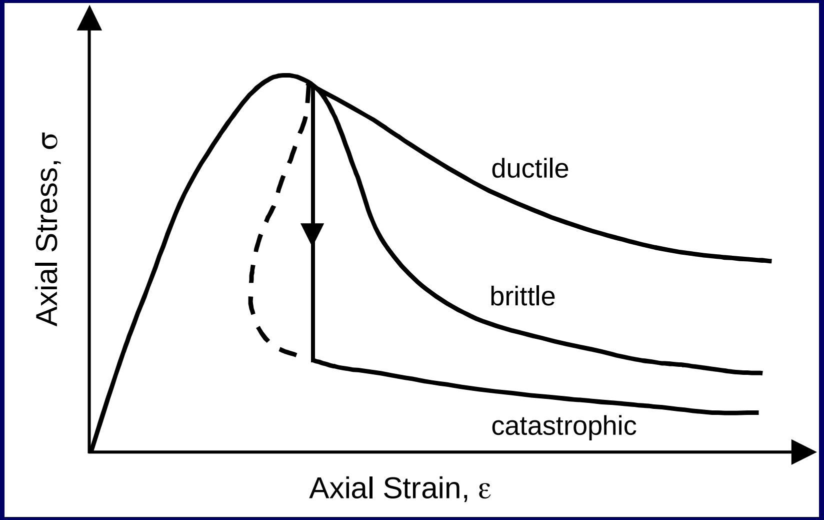


Load vs. time and cps curve for P3 test specimen in Luserna granite.

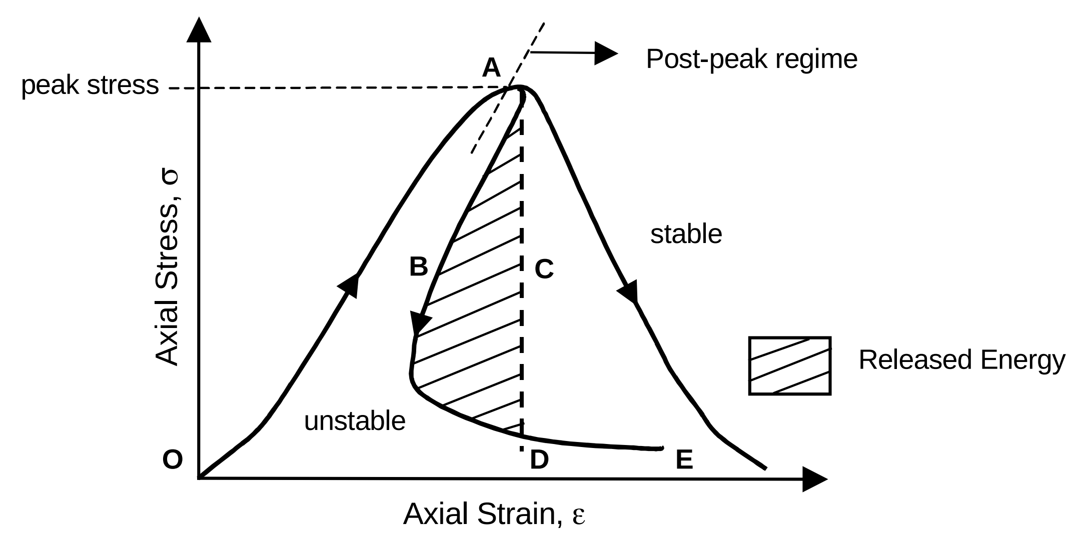


Load vs. time and cps curve for P4 test specimen in Luserna granite.

Factors involved in controlling rock failure

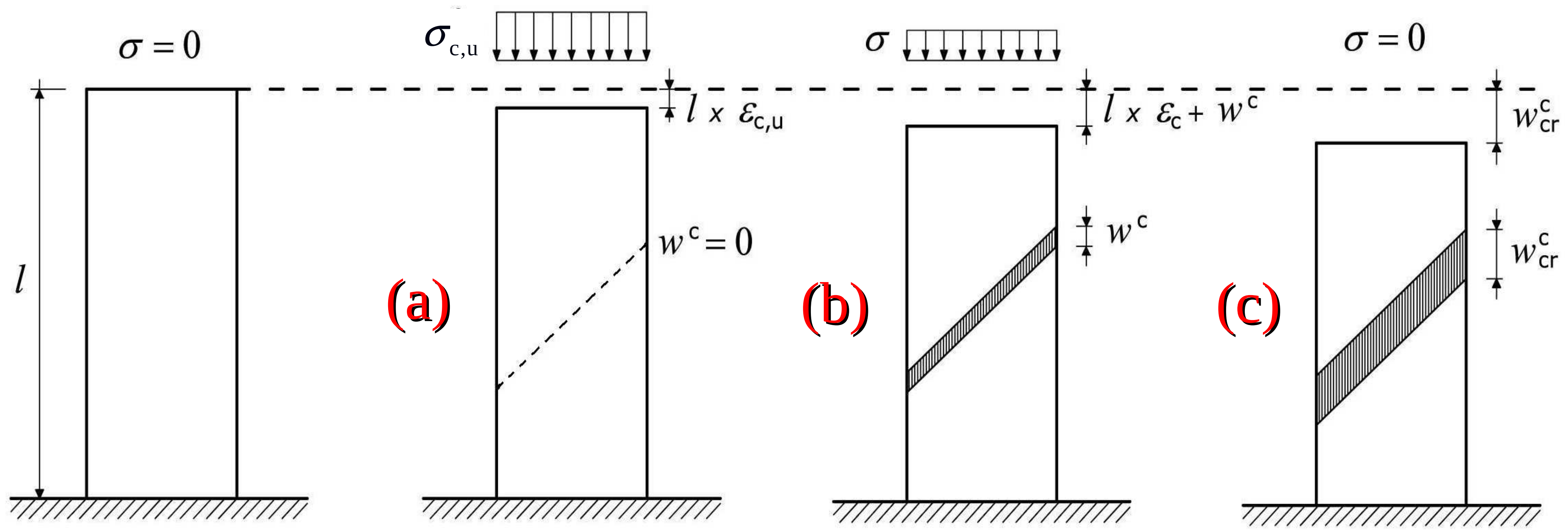


Ductile, brittle and catastrophic behaviour



Energy release and stable vs. unstable stress-strain behaviour

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



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

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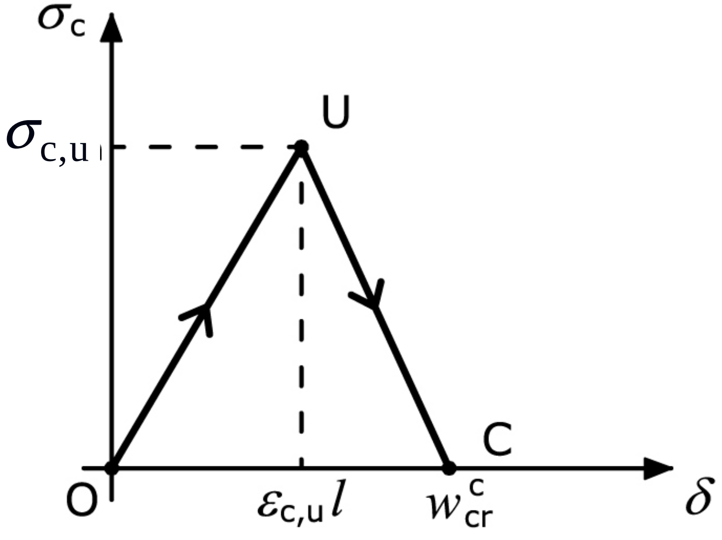
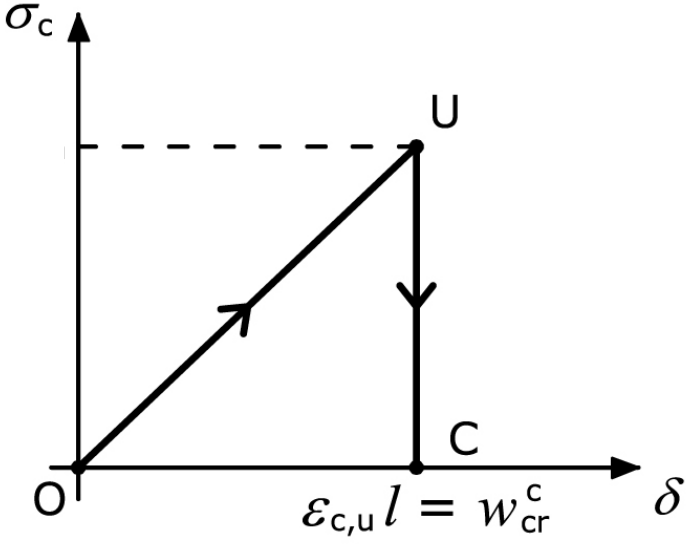
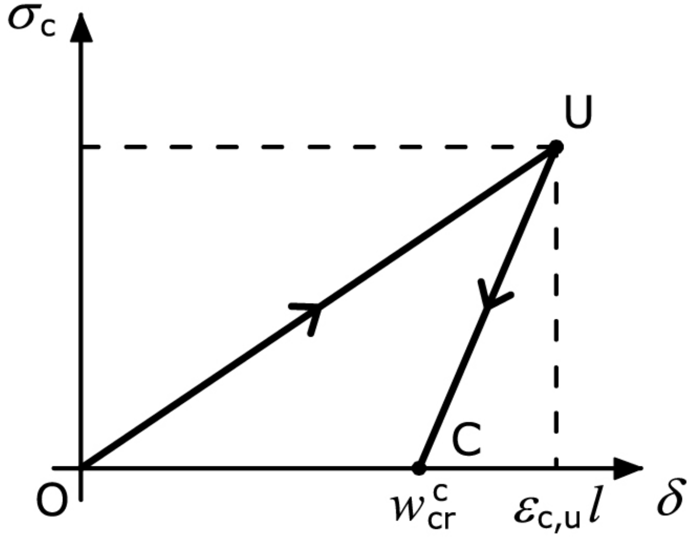
Stress vs. displacement response of a specimen in compression



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):

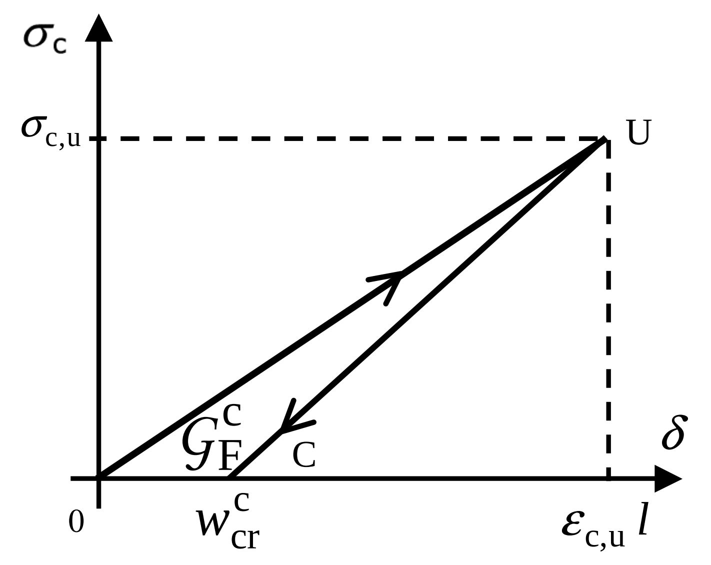
$$\frac{\Delta E}{\Delta t} \sim 7.69 \times 10^{11}\,\mathrm{W} \quad \rightarrow \quad \Delta t \sim 0.5\,\mathrm{ns}$$

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, our conjecture is that the following nucleolysis or piezonuclear “fission” reaction could have occurred:

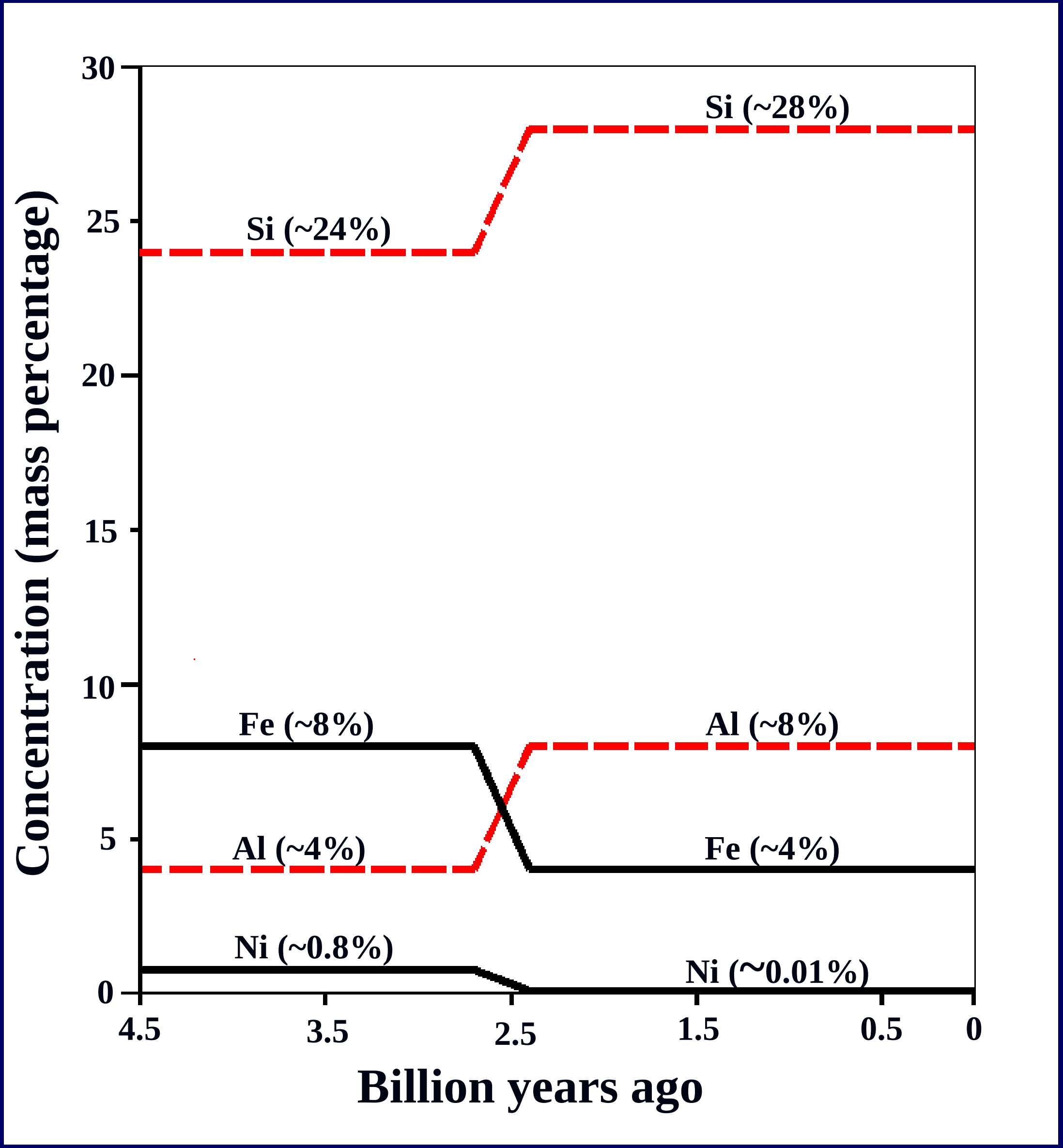
$$\mathrm{Fe}_{26}^{30} \rightarrow 2\,\mathrm{Al}_{13}^{14} + 2\ \text{neutrons.}$$

- 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.
- 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 3 billion years, we realize that iron and nickel have drastically diminished, whereas aluminum and silicon have as much increased:

$$\mathrm{Ni}_{28}^{31} \rightarrow 2\mathrm{Si}_{14}^{14} + 3\ \text{neutrons.}$$

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