

Full Length Research Paper

Piezonuclear neutrons from earthquakes as a hypothesis for the image formation and the radiocarbon dating of the Turin Shroud

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Some researchers have suggested that corona discharge phenomenon or proton radiation is responsible for the Shroud body image formation, while neutron radiation is liable to a wrong radiocarbon dating. On the other hand, no plausible physical reason has been proposed to explain the radiation source origin, and its possible effects on the linen fibres. However, some recent studies, carried out by the authors at the Laboratory of Fracture Mechanics of the Politecnico di Torino, found that it is possible to generate neutron emissions from very brittle rock specimens in compression through piezonuclear reaction processes. Neutron flux variations, in correspondence to seismic activity, should be a result of piezonuclear reactions. Considering also the Earth's crust, in addition to cosmic rays, as being a relevant source of neutron flux variations, other researchers measured a neutron flux exceeding the background by three orders of magnitude in correspondence to seismic activity and rather appreciable earthquakes (4th Richter's degree). In the first part of this work, the authors consider the possibility that neutron emissions by earthquake piezonuclear reactions could have induced the image formation on Shroud linen fibres through thermal neutron capture on nitrogen nuclei, and provided a wrong radiocarbon dating due to an increment in C_6^{14} content. Then they describe their previous studies on the phenomenon of neutron emissions from brittle rocks failure through mechanical tests and microchemical analysis, as well as its relevant geological consequences.

Key words: Shroud of Turin, neutron emission, piezonuclear reactions, rocks crushing failure, plate tectonics, element evolution.

INTRODUCTION

Fanti in the paper "Can a corona discharge explain the body image of the Turin Shroud?" (Fanti, 2010) proposes the hypothesis of image formation based on corona discharge (CD). He assumes that many facts detected on the Turin Shroud body image seem in agreement with the characteristics of an energy connected to CD and related to the human body enveloped in it. According to this hypothesis, the Shroud image (Figure 1) was generated by an energy source coming from the enveloped man,

perhaps during a natural phenomenon such as lightning or earthquake. Experimental results seem to support the assumed mechanism of image formation, also in terms of anthropometrics measurements (Fanti et al., 2010a), and they also could explain the superficiality of the Shroud image (Fanti et al., 2010b).

Moreover, Morgan (1985) considers the piezoelectric effect of quartziferous rocks subjected to an earthquake as the radiation source for image formation due to CD effect. Phillips in the paper "Shroud irradiated with neutrons?" (Phillips, 1989) supposes that the Shroud may have been irradiated with neutrons which would have changed some of the nuclei to different isotopes by neutron capture. In particular, Phillips (1989) assumes

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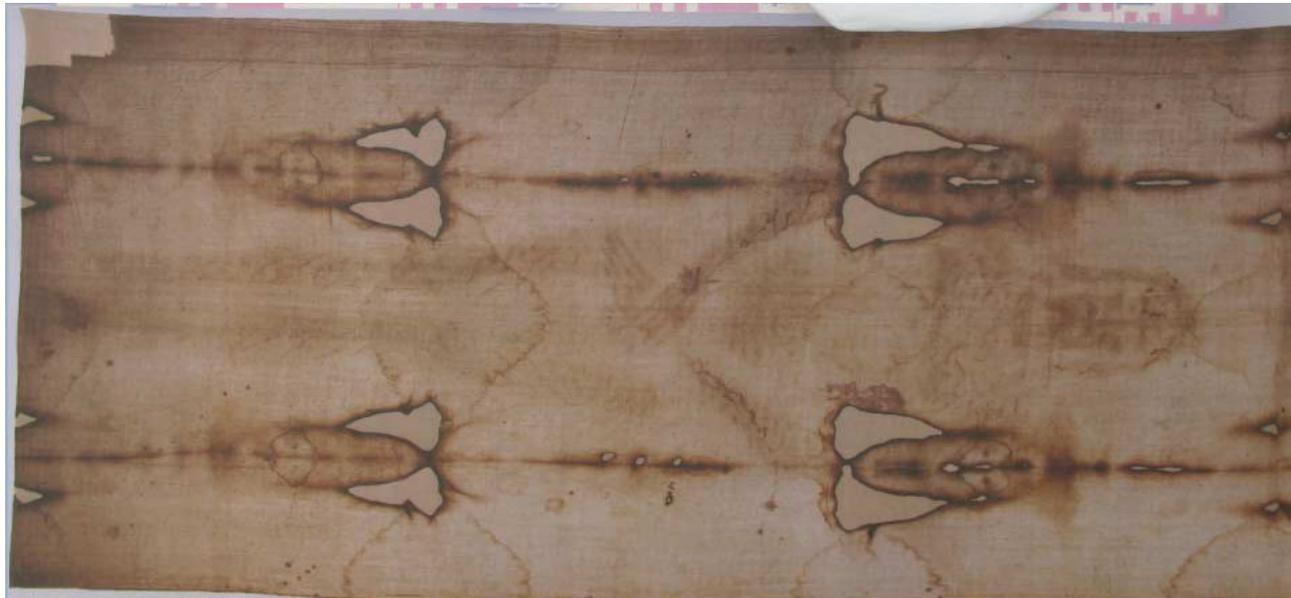


Figure 1. Semitransparent front copy of the Turin Shroud (Fanti et al., 2010a).

that some C_6^{14} nuclei could have generated from C_6^{13} , and that an integrated flux of $2 \times 10^{16} \text{ cm}^{-2}$ thermal neutrons could have produced an apparent carbon-dated age of just 670 years. However, in the reply to the same paper, Hedges (1989) asserts that the integrated flux proposed by Phillips (1989) is excessively high because he does not consider the neutron capture by nitrogen in the cloth, that would reduce the integrated neutron flux by 1000 times, down to $2 \times 10^{13} \text{ cm}^{-2}$ thermal neutrons.

Also Rinaudo (1998) evaluates that simultaneous fluxes of protons and neutrons, originated by the spontaneous disintegration of the deuterium nuclei contained in the body of the Man of the Shroud, could explain at the same time the imprint on the cloth (by protons) and the 13-century slip of time of the C_6^{14} nuclei (by neutrons). Similar assumptions on radiocarbon-dating have been formulated by Barbesino and Moroni (2009) supported also by experiments and analyses from International University and Research Institutions. Hypotheses and experimental confirmations that oxidative phenomena generated by earthquakes can provide 3D images on the linen clothes have recently been proposed by de Liso (2010).

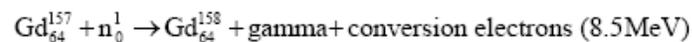
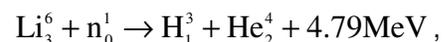
Considering the possibility that neutron flux could have induced appreciable effects on linen fibres of the Shroud, the authors have developed some hypotheses based on piezonuclear reactions. In the following, they briefly describe the process of image formation induced by neutron radiation and the effects that could be produced on linen cloths. In addition, assuming that the neutron emissions have been determined by piezonuclear reactions occurred during the earthquake in the "Old

Jerusalem" of 33 A.D., they provide experimental evidence of this phenomenon through mechanical loading and failure of brittle rock specimens. Finally, as an indirect evidence of the piezonuclear fission reactions, the anomalous chemical balances of the major events that have affected the geomechanical and geochemical evolution of the Earth's Crust are considered.

NEUTRON IMAGING

Neutron imaging is a technique which provides images similar to X-ray radiography. In simplified terms, neutrons are attenuated by matter either by scattering from the nucleus of a target atom or by absorption in the same nucleus; unlike X-rays, they interact predominantly with the outer-shell electrons. The difference between neutron and X-ray interaction mechanisms produce significantly different and often complementary information. While X-ray attenuation is gradually dependent on the atomic number, neutrons are well attenuated only by a few specific elements.

The most important detection reactions, used in neutron imaging, for both thermal and cold neutrons are:



The advantage of neutron imaging is its ability to affect very light elements (that is, with low atomic numbers) such as hydrogen, oxygen, carbon, etc. In addition, neutrons penetrate very heavy elements (that is, with high

atomic numbers) such as lead, as well as distinguish between different isotopes of the same element. For these reasons, neutrons make it possible to image some light materials (such as hydrogenous substances) with high contrast.

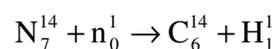
For image formation, various detector systems are employed in neutron imaging: combinations of film and neutron-sensitive converter foil, neutron sensitive imaging plates, track etch foils, or, more recently, amorphous silicon flat panel arrays.

During the irradiation, neutron imaging plates (NIP), consisting of a neutron converter material (Gd or Li) which captures neutrons and emits secondary charged particles, are used in order to reproduce the irradiated object. After the irradiation, a photostimulated luminescence (PSL) material (BaFBr:Eu²⁺ – photostimulable storage phosphor) is employed for the image formation. This material creates a colour-centre in the NIP and subsequently emits PSL light by the irradiation of a He-Ne laser. The neutron source properties, the collimator design and the detection system decide the achievable performance of image resolution.

NEUTRON EFFECTS ON LINEN FIBRES

If it is assumed the possibility of neutron induced images on linen fibres, important considerations have to be taken into account. Usually, a thermal neutron flux of intensity $10^5 \text{ cm}^{-2} \text{ s}^{-1}$ neutrons is employed, with an irradiation time of few minutes for a total integrated flux of about 10^7 to 10^8 cm^{-2} neutrons, with typical neutron imaging plates enriched for more than 20% in weight of Gd₂O₃ (Cipriani et al., 1995).

Considering the chemical composition of linen fibres (more than 80% cellulose), a nitrogen concentration of 0.3% could be supposed with a typical thermal neutron capture cross section of about 1.83 barn (by comparison Gd₆₄¹⁵⁷ ~ 254000 barn). Neglecting the different concentrations in gadolinium and nitrogen, which mainly affect the image resolution, and taking into account only their cross sections, the thermal neutron flux necessary to nitrogen nuclei neutron imaging should be approximately $\geq 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$ neutrons. Furthermore, the most important nuclear reaction of thermal neutrons on nitrogen nuclei is represented by:



That is liable of radiocarbon formation also in the atmosphere.

The hypothetical reaction induced by piezonuclear neutrons on nitrogen nuclei might have contributed on image formation also by means of proton radiation (as assumed by Rinaudo, 1998). Classically, image formation from neutron beam can be accomplished in a variety of ways

by using a suitable conversion screen. Thus, through an etching process with a chemical reagent (like KOH or NaOH) and under appropriate lighting, the image will become visible. Similarly, in the case of linen, neutrons could have interacted with nitrogen nuclei, and the protons, produced as secondary particles, may have assumed the function of the reagent, triggering oxidation processes or chemical combustion and making the image visible. Moreover, a further relevant effect could have been provided by a wrong radiocarbon dating due to an increment in C_6^{14} nuclei in the linen fibres.

EARTHQUAKES AND NEUTRON EMISSIONS FROM THE EARTH'S CRUST

The neutron emissions involved in piezonuclear reactions can be detected not only in the laboratory experiments, as shown in Carpinteri et al. (2009, 2010b) and Cardone et al. (2009) but also at the Earth's crust scale (Carpinteri et al., 2011a; Carpinteri and Manuello, 2011). Recent neutron emission detections by Volodichev et al. (1999), Kuzhevskij et al. (2003a, b) and Antonova et al. (2009) have led to the consideration also of the Earth's crust, in addition to cosmic rays, as a relevant source of neutron flux variations.

Neutron emissions measured in seismic areas of the Pamir region (4200 m asl) exceeded the usual neutron background (up to two orders of magnitude in correspondence to seismic activity and rather appreciable earthquakes, greater than or equal to the 4th degree in the Richter scale magnitude) (Volodichev et al., 1999). Considering the Pftotzer profile on the altitude dependence of neutron radiation (Pftotzer and Regener, 1935), values of about 10 times higher than natural background at sea level are generally detected at 5000 m altitude. Therefore, the same earthquake occurring at sea level should produce a neutron flux up to 1000 times higher than the natural background. More recent neutron emission observations have been performed before the Sumatra earthquake of December 2004 (Sigaeva et al., 2006). Variations in thermal neutron measures were observed in different areas (Crimea, Kamchatka) a few days before that earthquake.

If we assign the image imprinted on the Shroud to the man who died during the Passover of 33 A.D., there are at least two documents in the literature attesting the occurrence of disastrous earthquakes during that event. Matthew wrote that there was a strong earthquake at the moment of Christ's death: "When the centurion and those who were with him, keeping watch over Jesus, saw the earthquake and what took place, they were filled with awe and said, "Truly this was the Son of God!". (Matthew 27: 54). On the other hand, he wrote that there was another even bigger earthquake at the time of his resurrection: "And behold, there was a great earthquake, for an angel of the Lord descended from heaven and came and rolled back the stone and sat on it. His appear-

ance was like lightning and his clothing white as snow. And for fear of him the guards trembled and became like dead men". (Matthew 28: 2-4).

There is also the narrative of Joseph of Arimathea: "And, behold, after He had said this, Jesus gave up the ghost, on the day of the preparation, at the ninth hour. And there was darkness over all the earth; and from a great earthquake that happened, the sanctuary fell down, and the wing of the temple" (The Narrative of Joseph of Arimathea, Chapter 3, The good robber, 5).

That event is also mentioned by Dante Alighieri, XXI Canto, Inferno, as the most violent earthquake that had ever shaken the Earth: «Then said to us: "You can no farther go Forward upon this crag, because is lying All shattered, at the bottom, the sixth arch. And if it still doth please you to go onward, Pursue your way along upon this rock; Near is another crag that yields a path. Yesterday, five hours later than this hour, One thousand and two hundred sixty-six Years were complete, that here the way was broken"» (Inferno, XXI Canto:106-114) (Dante Alighieri). Since most scholars believe that the journey of Dante began on the anniversary of the Christ's death, during the Jubilee of 1300, the chronology goes back to 33 A.D., on the Friday when, according to tradition, Christ was put to death. Therefore, it was the earthquake after Christ's death that caused disasters and crashes, including the Sanctuary of Jerusalem, and the wing of the Solomon's Temple (The Narrative of Joseph of Arimathea).

A thorough scientific and historiographic study of the earthquake in Jerusalem is also described in Ambraseys (2005). In this article the author suggests that the earthquakes are not mentioned by three out of the four Evangelists, because they have given a greater emphasis to the supernatural phenomenon rather than to the seismic event. Moreover, the interpretation of Matthew suggests that the earthquake at the time of the Resurrection was associated with the opening up of the rock beneath the Chapel of the Exaltation of the Cross, possibly as a result of surface faulting. These cracks in the bedrock are said to be still visible. It is interesting also that the open structure of the rock in the vicinity of the Holy Sepulchre was noticed after its restoration and it is reported by Soewulf in 1102, who says that the ground was ". . . much cracked near the fosse of the Cross. . ." (Ambraseys, 2005).

Nevertheless, the results from historical studies have value for Earth scientist only when the information is converted into data representing epicentral location and magnitude of the events. Some modern writers say that Jerusalem is situated relatively close to the active Dead Sea Fault zone. They accept the occurrence of the Resurrection earthquake, to which they assign the magnitude of a catastrophic event, characterized by a local magnitude $M_L = 8.2$, as well as of another earthquake that took place in Bithynia, during the same period, that would have had even a greater magnitude (Ambraseys,

2005).

As regards the recurrence of the historical earthquakes, determined in terms of Richter scale magnitude, we can refer to the recent paleoseismic studies. A challenge in resolving this question is that the rates of small earthquakes are typically determined from the seismologically recorded earthquake history, whereas the rates of large earthquakes with intensity close to the 9th degree in the Richter scale magnitude are inferred from paleoseismic observations.

Based on a detailed analysis of paleoearthquakes along the major active faults in the Earth, some studies give evidence of their temporal and spatial distribution, as well as of their regional recurrent behaviour (Min et al., 2000). From these studies, it can be argued that a hypothetical earthquake of the 11th degree in the Richter scale magnitude may have a recurrence time of about 1000 years, as well as of about 100 years one of the 10th degree, and of about 10 years one of the 9th degree.

Considering that, in the active faults of the Mediterranean basin and of the Middle East region, about one-hundredth of the earthquakes recorded during long periods over the entire surface of the Earth take place, and that their historical maximum intensity should be close to the 9th degree in the Richter scale magnitude (Ambraseys, 2005), then in this case an earthquake of the 9th degree may have a recurrence time of about 1000 years, as well as of about 100 years one of the 8th degree, and so on.

This last observation would give further scientific value, as well as historical and archaeological importance, to the hypothesis that, in the "Old Jerusalem", there was a strong earthquake very close to the 9th degree in the Richter scale magnitude.

EARTHQUAKE AND NEUTRON EFFECTS ON THE SHROUD

Considering the historical sources attesting the occurrence of a disastrous earthquake in 33 A.D., and assuming an hypothetical magnitude between the 8th and the 9th degree in the Richter scale (Ambraseys, 2005), it is possible to provide an evaluation of the consequent neutron flux.

The Richter scale is logarithmic (base 10). This means that, for each degree increasing on the Richter scale, the amplitude and the acceleration of the ground motion recorded by a seismograph increase by 10 times. From a displacement or acceleration viewpoint, the seismic event which occurred in 33 A.D. may have been 10^4 to 10^5 times more intense than an event of the 4th degree. On the other hand, from the energy viewpoint, it should have been 10^8 to 10^{10} times more intense than the same reference event.

Assuming a typical environmental thermal neutron flux background of about $10^{-3} \text{ cm}^{-2} \text{ s}^{-1}$ at the sea level, in correspondence of appreciable earthquakes with a

magnitude of the 4th degree, an average thermal neutron flux up to $10^0 \text{ cm}^{-2} \text{ s}^{-1}$ should be detected, that is, 1000 times higher than the natural background (Volodichev et al., 1999; Pfozter and Regener, 1935), as previously calculated.

Thus, an earthquake of the 8th to 9th degree in the Richter scale could provide a thermal neutron flux ranging from 10^8 to $10^{10} \text{ cm}^{-2} \text{ s}^{-1}$, if proportionality between released energy and neutron flux holds. A similar event could have produced chemical and/or nuclear reactions, contributing both to the image formation and to C_6^{14} increment in the linen fibres of the Shroud, if only it had lasted for at least 15 min. In this way, an appropriate integrated thermal neutron flux of about 1×10^{13} neutrons cm^{-2} , is obtained, as assumed by Hedges (1989).

In confirmation of this assumption, one of the most powerful earthquakes, the so called "Greatest Chile Earthquake" occurred in Valdivia on May 22, 1960, had a complicated seismogram that lasted at least 15 min (Barrientos and Ward, 1990). Further information about the intensity and duration of this earthquake are reported in Kanamori and Cipar (1974).

PIEZONUCLEAR REACTIONS IN THE EARTH'S CRUST

Original experimental tests on neutron emissions, performed on brittle rock specimens in compression, have been recently performed by the authors (Carpinteri et al., 2009, 2010a, b, 2011b; Cardone et al., 2009). The tests have been carried out by using suitable He^3 and bubble type BD thermodynamic neutron detectors.

The materials employed for the tests are non-radioactive Luserna stone, a metamorphic rock deriving from a granitoid protolith, and Carrara Marble. While the measurements of neutron emissions obtained on marble yielded values comparable with the natural background, for the Luserna stone neutron emissions, produced without gamma rays, were found to be of about one order of magnitude higher than the ordinary natural background level at the time of the catastrophic failure.

Since the granite contains iron, it was supposed that piezonuclear reactions involving fission of iron into aluminum, or into magnesium and silicon, should have occurred during compression of the specimens (Carpinteri et al., 2009, 2010a, b, 2011b; Cardone et al., 2009). The assumed fissions of iron into aluminium, or into magnesium and silicon, are supported by spectroscopical analyses of the fracture surfaces and by consistent geological data (Carpinteri et al., 2011a; Carpinteri and Manuello, 2011). The results of energy dispersive X-ray spectroscopy (EDS) are performed on samples carefully chosen to investigate and compare the same crystalline phases both before and after the crushing failure. In particular, two crystalline phases, phengite and biotite, were considered due to their high

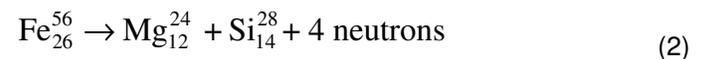
iron content and their relative abundances in the Luserna stone, 20 and 2% respectively (Vola and Marchi, 2009).

The present natural abundances of aluminum (~8%), and silicon (28%) and scarcity of iron (~4%) in the continental Earth's crust are possibly due to the piezo-nuclear fission reactions considered above (Carpinteri et al., 2011a). These reactions 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 4.5 billion years, we realize that iron and nickel have drastically diminished, whereas aluminum, and silicon 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 (Ambar, 2008; Carpinteri and Manuello, 2011; Favero and Jobstraibizer, 1996; Konhauser, et al., 2009). In particular, the samples coming from the Luserna stone specimens used in the preliminary experiments (Carpinteri et al., 2009, 2010a, b, 2011b; Cardone et al., 2009) show that, on the fracture surfaces, a considerable reduction in the iron content (~25%) is very consistently counterbalanced by an increase in Al, Si, and Mg concentrations (Carpinteri et al., 2011a).

From the EDS results on fracture samples mentioned above, the evidences of Fe and Al variations in phengite lead to the conclusion that the piezonuclear reaction:



should have occurred (Carpinteri et al., 2009, 2010a, b, c, 2011b; Cardone et al., 2009). Moreover, considering the evidences for the biotite content variations in Fe, Al, Si and Mg, it is possible to conjecture that another piezonuclear reaction, in addition to Equation 1, should have occurred during the compression tests (Carpinteri et al., 2009, 2010a, c, 2011b):



Taking into account that granite is a common and widely occurring type of intrusive, sialic, igneous rock, and that it is characterized by an extensive concentration in the rocks that make up the Earth's crust (~60% of the Earth's crust), the piezonuclear fission reactions expressed above can be generalized from the laboratory to the Earth's crust scale, where mechanical phenomena of brittle fracture, due to fault collision and subduction, take place continuously in the most seismic areas. This hypothesis seems to find surprising evidence and confirmation from both the geomechanical and the geochemical points of view (Carpinteri and Manuello, 2011). The neutron emissions involved in piezonuclear

reactions have therefore been detected not only in laboratory experiments, as shown in Carpinteri et al., (2009; 2010a, b, c; 2011b) and Cardone et al. (2009), but also at the Earth's crust scale as previously described (Antonova et al., 2009; Kuzhevskij et al., 2003a, b; Volodichev et al., 1999).

The present natural abundances of aluminum (~8%), silicon (28%) and magnesium (1.3%), and scarcity of iron (~4%) in the continental Earth's crust (Favero and Jobstraibizer, 1996; Taylor and McLennan, 1995, 2009) are possibly due to the piezonuclear fission reactions (Equations 1 and 2) expressed above (Carpinteri and Manuello, 2011). In addition, considering the mass percentage concentrations of other chemical elements, such as Na (~2.9%), Ni (~0.01%), and Co (0.003%), in the continental crust (Anbar, 2008; Doglioni, 2007; Favero and Jobstraibizer, 1996; Fowler, 2005; Taylor and McLennan, 1995, 2009; Rudnick and Fountain, 1995), it is possible to conjecture additional piezonuclear fission reactions that could have taken place in correspondence to plate collision and subduction (Carpinteri and Manuello, 2011).



The large concentrations of granite minerals, such as quartz and feldspar (SiO_2 and Al_2O_3) in the Earth's crust, and to a lesser extent of magnesite, halite, and zeolite (MgO , Na_2O and Cl_2O_3), and the low concentrations of magnetite, hematite, bunsenite and cobaltite (composed predominantly of Fe, Co, and Ni minerals), could be ascribed to piezonuclear reactions (Equations 1 to 5) produced by tectonic and subduction phenomena (Carpinteri and Manuello, 2011).

HETEROGENEITY IN THE COMPOSITION OF THE EARTH'S CRUST: Fe AND Al RESERVOIR LOCALIZATIONS

The localization of Al and Fe mineral reservoirs seems to be closely connected to the geological periods when different continental zones were formed (Anbar, 2008; Favero and Jobstraibizer, 1996; Fowler, 2005; Roy et al., 2001; Taylor and McLennan, 1995, 2009; Key Iron Deposits of the World, 2012; World Iron Ore Producers, 2012; World Mineral Resources Map, 2012). This fact would seem to suggest that our planet has undergone a continuous evolution from the most ancient geological regions, which currently reflect the continental cores rich in Fe reservoirs, to more recent or contemporary areas of

the Earth's crust where the concentrations of Si and Al oxides present very high mass percentages (Favero and Jobstraibizer, 1996). The main iron reservoir locations (Magnetite and Hematite mines) are reported in Figure 2a. The main concentrations of Al-oxides and rocky andesitic formations (the Rocky Mountains and the Andes, with a strong concentration of Al_2O_3 minerals) are shown in Figure 2b, together with the most important subduction lines, plate tectonic trenches and rifts (Favero and Jobstraibizer, 1996; Roy et al., 2001). The geographical locations of the main bauxite mines show that the largest concentrations of Al reservoirs can be found in correspondence to the most seismic areas of the Earth (Figure 2b). The main iron mines are instead exclusively located in the oldest and interior parts of continents (formed through the eruptive activity of the proto-Earth), in geographic areas with a reduced seismic risk and always far from the main fault lines. From this point of view, the close correlation between bauxite and andesitic reservoirs and the subduction and most seismic areas of the Earth's crust provides a very impressive evidence of piezonuclear effects at the planetary scale.

GEOCHEMICAL EVIDENCE OF PIEZONUCLEAR REACTIONS IN THE EVOLUTION OF THE EARTH'S CRUST ELEMENTS

Evidence of piezonuclear reactions can be also recognized considering the Earth's composition and its way of evolving throughout the geologic eras. Plate tectonics and the connected plate collision and subduction phenomena are useful to understand not only the morphology of our planet, but also its compositional evolution (Carpinteri and Manuello, 2011).

The most abrupt changes in element concentrations shown in Figure 3 appear to be intimately connected to the tectonic activity of the Earth. The vertical drops in the concentrations of Fe and Ni, as well as the vertical jumps in the concentrations of Si and Al, 3.8 Gyrs ago, coincide with the time that many scientists have pointed out as the beginning of tectonic activity on the Earth. The subsequent abrupt transitions 2.5 Gyrs ago coincide with the period of the Earth's largest and most intense tectonic activity (Taylor and McLennan, 1995, 2009).

In particular, piezonuclear reactions (Equations 1, 2 and 4) seem to be the cause of the abrupt variations shown in Figure 3. Piezonuclear reaction (Equation 2) implies that not only the Si mass percentage should increase overall by about 4.0% but also that of Mg. However, the latter increase, due to piezonuclear reaction (Equation 2), cannot be revealed from geological data of sediments in the Earth's continental crust. The most probable explanation is that Mg is not only a resulting element, as shown by piezonuclear reaction (Equation 2), but can also be considered as a starting element of other possible piezonuclear reactions, for example (Carpinteri and Manuello, 2011):

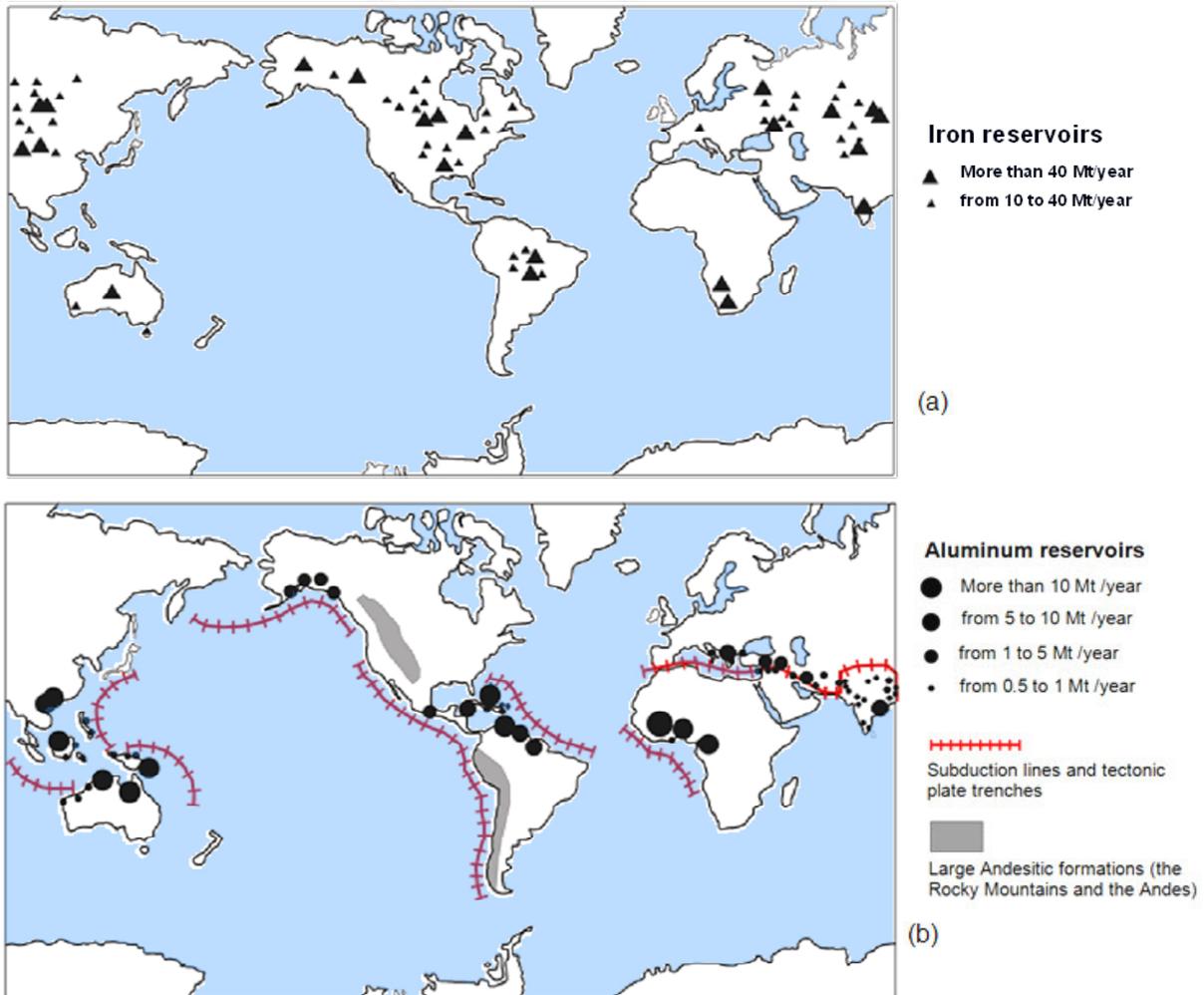


Figure 2. (a) Locations of the largest iron mines in the world (Roy et al., 2001; Key Iron Deposits of the World, 2012; World iron ore producers, 2012; World Mineral Resources Map, 2012). Iron ore reservoirs (Magnetite and Hematite mines) are located in geographic areas with reduced seismic risks and always far from fault lines. (b) The largest aluminum (bauxite) reservoirs are reported together with the main andesitic formations and most important subduction lines and plate tectonic trenches (Favero and Jobstraibizer, 1996).



Reaction (Equation 6) could be very important for the evolution of both the Earth's crust and atmosphere, and considered as a valid explanation for the high level of CO_2 concentration (~15%) in the Archean Earth's atmosphere (Liu, 2004). In addition, the large amount of C produced by Mg transformation (~4.0% of the Earth's crust) has undergone a slow but continuous diminishing in the CO_2 composition of the Earth's atmosphere, as a result of the escape which also involves other atmospheric gases like, O, He and H (Catling and Zahnle, 2009).

Piezonuclear reaction (Equation 6) can also be put into correlation with the increase in seismic activity that has occurred over the last century (Aki, 1983). Very recent

evidence has shown CO_2 emissions in correspondence to seismic activity (Padron et al., 2008): significant increase in the emission of carbon dioxide was recorded in a geochemical station at El Hierro, in the Canary Islands, before the occurrence of several seismic events during the year 2004. Appreciable precursory CO_2 emissions were observed to start before seismic events of relevant magnitude, and to reach their maximum values some days before the earthquakes (Padron et al., 2008). Finally, it is interesting to note that, as also reported in Carpinteri and Manuello (2011), taking into account a density of 3600 kg m^{-3} and a thickness of 60 km for the Hadean and Archean crusts, it is possible to estimate the mass of the early Earth's proto-crust as $\sim 1.08 \times 10^{23} \text{ kg}$. Considering this value, the decrease in Ca concentration, 1.3% of the Hadean and Archean proto-crust ($\sim 1.41 \times 10^{21} \text{ kg}$), corresponds very closely to the mass of water in

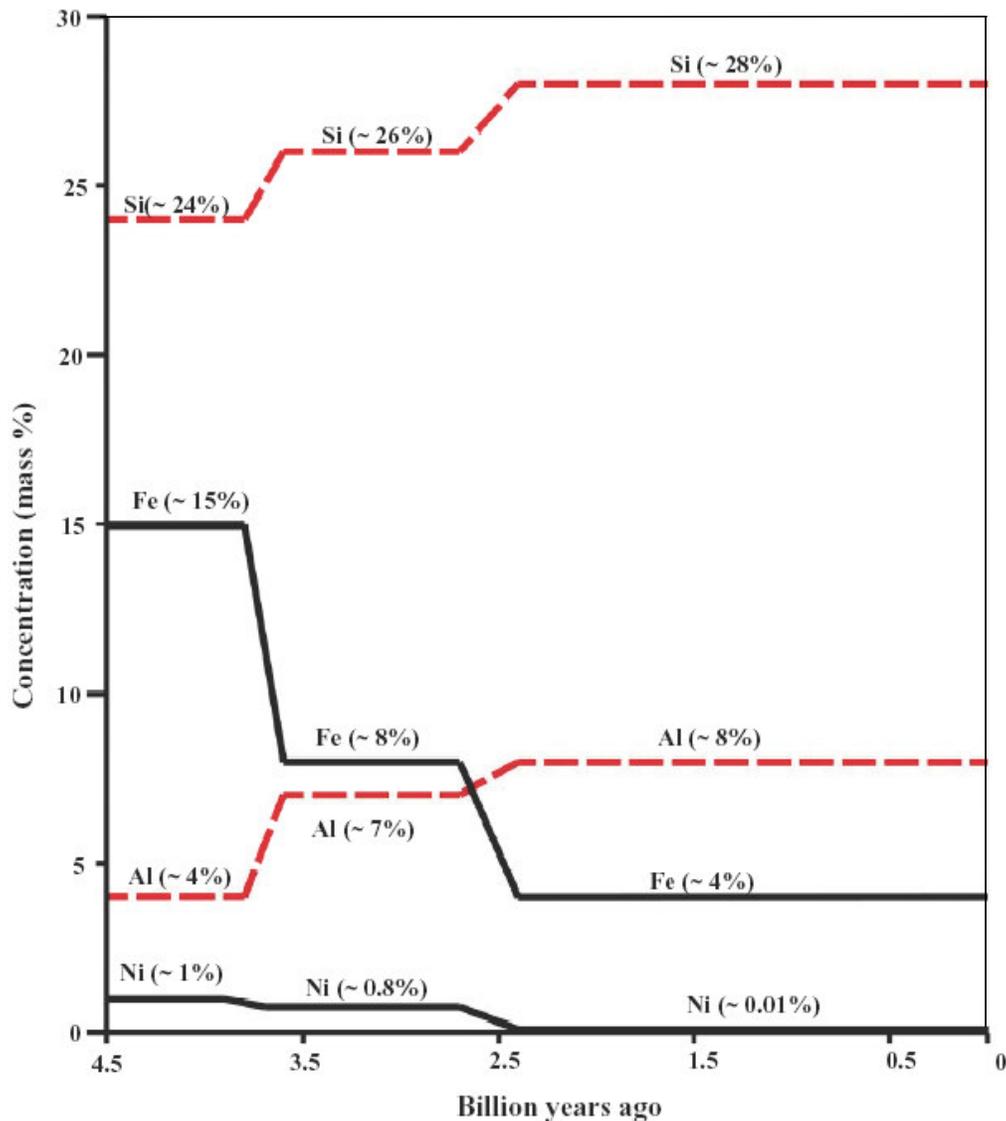


Figure 3. The estimated concentrations of Fe, Ni, Al, and Si in the Hadean and Archean Earth's protocrust and in the Earth's continental crust. The Archean Earth's protocrust (3.8–2.5 Gyrs ago) had a less basaltic composition (Fe, ~8%; Ni, ~0.8%; Al, ~7%; Si, ~26%) compared to the previous period (Hadean Era, 4.5–3.8 Gyrs ago), and a less sialic composition compared to the concentrations in the Earth's continental crust today: Fe, ~4%; Ni, ~0.01%; Al, ~8%; Si, ~28% (Carpinteri and Manuello, 2011). Considering piezonuclear reactions (Equations 1, 2 and 4), the overall 12% decrease in the heavier elements (Fe and Ni) is balanced by the Al and Si increases and assuming an increase in Mg, according to reaction (Equation 2), equal to that of Si over the last 4.5 billion years.

oceans ($\sim 1.35 \times 10^{21}$ kg). In this way, piezonuclear reaction (Equation 7) could be considered as responsible for the formation of oceans during the Earth's life time.



CONCLUSIONS

Some recent studies, performed by the authors at the

Laboratory of Fracture Mechanics of the Politecnico di Torino, found that it is possible to produce a neutron flux from very brittle rock specimens under mechanical loadings. The authors have considered the hypothesis that neutron emissions by earthquake piezonuclear reactions have led to appreciable effects on Shroud linen fibres. Considering the historical documents attesting the occurrence in the "Old Jerusalem" of a disastrous earthquake in 33 A.D., the authors assume that a seismic event with magnitude ranging from the 8th to the 9th

degree in the Richter scale could have produced a thermal neutron flux of up to $10^{10} \text{ cm}^{-2} \text{ s}^{-1}$. Through thermal neutron capture by nitrogen nuclei, this event may have contributed both to the image formation, and to the increment in C_6^{14} on linen fibres of the Shroud.

In the second part of this work the authors, referring to the original experimental tests performed on brittle rock specimens, give experimental evidences that piezonuclear reactions are possible in inert non-radioactive solids under pressure loading. In particular, during compression tests of specimens in Luserna stone of sufficiently large size, the neutron flux was found to be of about one order of magnitude higher than the background level at the time of the catastrophic failure.

The proposed conjecture, also confirmed by the EDS tests, is that piezonuclear reactions, produced without gamma emission, and involving fission of iron into aluminum, or into magnesium and silicon, should have occurred during compression of the specimens.

The hypothesis of piezonuclear reactions seems to find surprising evidence and confirmation at the Earth crust scale from both geomechanical and geochemical points of view. The piezonuclear reactions have thus been considered in order to interpret the most significant geophysical and geological transformations, today still unexplained.

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