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Reply to "Comments on 'Geomechanical and Geochemical Evidence of Piezonuclear Fission Reactions in the Earth's Crust' by A. Carpinteri and A. Manuello" by U. Bardi and G. Comoretto

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ABSTRACT: In the paper entitled "Comments on 'Geomechanical and Geochemical Evidence of Piezonuclear Fission Reactions in the Earth's Crust' by A. Carpinteri and Manuello" by U. Bardi and G. Comoretto, the authors criticise the hypothesis based on piezonuclear reactions for the interpretation of the compositional evolution of the Earth's crust. We report a detailed reply of how the traditional theories, used by the authors of the comments, are obviously inadequate to describe this new kind of nuclear phenomena. Only very recently, independent authors proposed a theoretical model explaining the anomalous energy emissions in the form of neutrons, involved in piezonuclear reactions, during fracture of nonradioactive rocks. It is also known how the evidences that Bardi and Comoretto claim to be non-existent could be found in many independent works that appeared in most important journals about unexplained questions of the Earth's crust and environment. The data reported in the original work and the details included in this reply show that it is incorrect to consider impossible or simply to ignore the existence of unexplained phenomena only because they cannot be described by traditional models and conventional theories.

KEY WORDS: *Earth's crust evolution, element evolution, great oxidation event, neutron emissions, piezonuclear reactions, plate tectonics, rocks crushing*

Reply to the Principal Criticisms of the Comments

In their introduction and in the first sections of their comments, Bardi and Comoretto state that the quantity of energy required for the nuclear reactions conjectured in the article by Carpinteri and Manuello would be too high. For this reason, they conclude that such reactions cannot be responsible for the compositional variations reported in the article. They seem to deliberately ignore the fact that in the article they comment on, as well as in all other works published by Carpinteri and coauthors about the argument, these fission reactions, referred to as piezonuclear, are acknowledged to be anomalous nuclear phenomena [1–11].

Only very recently, independent authors provided a theoretical explanation for the experimental evidence that fracturing piezoelectric rocks produces neutrons [12]. As reported in all papers published by Carpinteri and co-workers on this argument, anomalous neutron emissions represent the first evidence of the piezonuclear reactions taking place in nonradioactive or inert rocks during fracture [1–11]. Furthermore, whether these reactions should be regarded as exoenergetic or endoenergetic is still an open question. Bardi and Comoretto presuppose in their comments that these reactions are endoenergetic and must be interpreted through the rules of classical nuclear physics. But, as stated before, how can phenomena, which are anomalous be explained with a classical approach?

It is also evident that the theory of the nuclear models is extremely fragmented [13–17], and several questions remain unresolved [13]. In fact, there is not a unique model that is able to describe the various phenomena and behaviours that have recently been observed in the context of the so-called low-energy nuclear reactions [18–21].

Moreover, the concept of average binding energy per nucleon seems very simplistic and inadequate to describe the phenomena recently observed by Carpinteri and co-workers in their investigations. Assuming a non-uniform distribution of the binding energy between nucleons, it is possible to consider the presence of weak planes of fracture along which the fission is privileged [14–16]. The result is represented by an energy required for fission lower than that which can be calculated via the classical models of the atomic nucleus used by Bardi and Comoretto for their energy balances.

In their comments, the authors referred that the experimental evidence proposed by Carpinteri and co-workers in several publications has been strongly criticised. It is difficult to understand, in the context of a correct scientific debate, why the authors of the comments forgot to report also all the replies published by Carpinteri *et al*. and by independent authors to each comment and criticisms. These replies showed how these criticisms are incorrect, extremely forced and not sufficiently supported [22, 23].

In the sections of the comments entitled "Compared Composition of the Earth's Crust and the Oceanic Crust" and "Heterogeneity of the Earth's Crust", the authors affirm that the phenomena associated with the formation of the continental crust and the reasons explaining the difference between the oceanic and the continental crust compositions are well-known. It is difficult to understand

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how the scientific debate can be ignored on this subject that has filled the pages of the major journals in the field for years and especially today [24–28]. In which manner can the authors of the comments may explain the unsolved questions emerging from the papers recently published in the journal Science by Anbar [24] and Buesseler [25] and related to the element evolution and the iron depletion? At the same time, it is very hard to understand how the mechanism underlying the nickel depletion and the inexplicable increase in Oxygen reported in the papers by Konhauser *et al*. and Saito in the journal Nature [26, 27] are 'well-known'.

The model cited by Bardi and Comoretto, which is based on the concept of differentiation whereby the composition of the continental crust is the result of simple 'distillation', is an extremely simplistic and dated way of explaining the complicated phenomena involving the subduction of the oceanic crust and the consequent formation of the continental crust. This approach is in no way capable of explaining how an oceanic crust that is not made up of light elements such as those found on the continents can be arisen from the upper layers of the mantle. In other words, if the mechanism was univocally that proposed by Bardi and Comoretto, the oceanic crust would be sialic as is the continental one. And yet, innumerable scientific data show it to be basaltic, with high percentages of Fe and Mg.

As for the criticisms advanced by the authors of the comments in the section entitled 'Oceanic Salinity and Nickel Depletion' regarding the evidence provided for reaction (5) in the original paper by Carpinteri and Manuello, the authors of the comments indicate that the Pacific's salinity is much lower than that of the Mediterranean, although the tectonic activity in this area is at the same time very high. This, they say, is at odds with the high salinity associated with high tectonic activity in the Mediterranean area. It is sufficiently clear that the salinity in an area as extensive as the portion of the Pacific around the so-called 'Ring of Fire' is more likely to be lower in view of the volume of water, where sodium chloride has been diffused and diluted.

In the last section of the comments, the authors speak alleged errors reported in the original paper. They start with the temporal location of the emergence of life on the planet, maintaining that the time given by Carpinteri and Manuello is incorrect. It should be obvious, as is in any case indicated in many specific papers on this topic that Carpinteri and Manuello are referring to the appearance of living creatures having an O_2-based metabolism such as aerobic bacteria and the first eukaryotic cells. The timeframe of 3.5 billion years ago, mentioned by Bardi and Comoretto refers to the appearance of the first anaerobic bacteria (Fe, Mg metabolism). As for the large emission of C involved in the formation of the Earth's atmosphere, the authors cite a number of sources, including the work of [29, 30], while as for the comment concerning Ni^{59}, reactions (4) and (5) given by Carpinteri and Manuello remain valid if the isotopes Ni^{58} (NA = 68%, stable isotopes) is considered. The only change here regards the neutron emission involved in these reactions.

Eventually, in the section entitled 'Evolution of the Earth's Crust', Bardi and Comoretto claim that it is impossible to find a correspondence between the data shown in Figures 4 and 5 of the original article and the references given in the bibliography. The sources of all data provided in the disputed graphs and figures are indicated in the following. For the period between 2.5 billion years ago and the present (data reported in Figure 4), we can observe that Table 11.3 on page 284 of Taylor and McLennan [31] presents values for silicon oxide in the different layers of the Earth's crust. Given the molecular weight of SiO_2, an Si concentration of ~28% can be assumed. Likewise, as the average value for Si oxide indicated in Table 1, page 380, by Favero and Jobstraibizer [32] is 59.3, the mass percentage concentration of Si is 27.7% or ~28%. Table 3, page 248 in Taylor and McLennan [33] gives an Si concentration in the crust of around 27.7%, while Doglioni also indicates a value of 27.7% on page 596 [34]. For the same period, the ~4% indicated for Fe concentration was based on the iron oxide concentration of 4.52% given in Table 11.3, page 284 by Taylor and McLennan [31] and the 5.8% FeO concentration shown in Table 1, page 380 by Favero and Jobstraibizer [32]. Also for the same period, the ~8% Al concentration shown is based on the 15.2% Al oxide concentration given in Table 11.3, page 284, by Taylor and McLennan [31] and the 16.3% given for Al_2O_3 in Table 1, page 380 by Favero and Jobstraibizer [32]. Considering that the Al_2O_3 molecule has an atomic weight of 102, the mass percentage concentration of Al is approximately 7.9% and 8.4% for the values expressed above in oxides. In addition, Table 3, page 248 of [33] indicates an 8.04% Al concentration in the continental crust. This was the basis for assuming an average Al value of about 8% for the continental crust in the considered period. For Ni, the ~0.01% concentration was assumed considering the value given on page 2 of the text entitled: Medical and Biological Effects of Environmental Pollutants: Nickel, 1975.

For the Archean period, 3.8−2.5 billion years ago (data reported in Figure 4). The ~26% Si concentration was assumed on the basis of the value shown for silicon oxide SiO_2 presented in Table 10.1, page 256 (Archean Bulk Crust) of Taylor and McLennan [31]. The ~8% Fe concentration was assumed on the basis of the 11.3% concentration of Fe oxide in the Archean period (3.8–2.5 billion years ago) shown in Table 6, page 294 of Rudnick and Fountain [35]. The ~7% Al concentration was derived from an aluminium oxide (Al_2O_3) concentration of 14.7% based on values presented in the literature: 14.9% (Tab. 10.1 page 256) for [31] and 14.5% (Tab. 6 page 294) for [35]. The concentration

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of Ni in the Archean period was addressed in recent studies by Saito and Konhauser *et al.* [26, 27]. The data given by [26] on page 750 and in Figure 3 on page 752 were the basis for estimating that there has been an approximately 80-fold drop in nickel concentrations since the Archean period [36]. This figure for the oceans can also be assumed to apply to the terrestrial crust. As the current concentration of Ni in the crust is ~0.01 [37], it was assumed that the concentration of Ni between 3.8 and 2.5 billion years ago was 80 times higher than it is at present, ~0.8%.

For the Hadean period, 4.5–3.8 billion years ago (data reported in Figure 4). The ~24% of Si concentration was assumed from the data given for SiO_2 in Tables 8.1, page 212 and Tab. 5.3, page 118 in Taylor and McLennan [31]. The ~15% Fe concentration was assumed from the data given for iron oxide in Table 3.1, page 65 in [31]. The average value is 19.4%. As the atomic weight of the FeO molecule is 72, the mass percentage concentration of Fe is 15.3% or ~15%. The ~4% Al concentration results from averaging the data given for aluminium oxide Al_2O_3 in Table 3.1, page 65 in [31]. As the average value is 8.9%, the mass percentage concentration of Al is 4.4% or ~4%. The ~1% Ni concentration was taken from the values given in Table 1.1, page 9 in [31]. Table 1.1 expresses the Ni value in mass percentage for the different types of chondrites (1.08% and 1.1%) in proto-planets during the Hadean period (4.5–3.8 billion years ago). For the data reported in Figure 5 of the paper published by Carpinteri and Manuello, the values of Ca, Mg, K and Na in the different periods of the Earth's evolution are reported according to the data presented in Tab. 3.1 page 65, Tab. 10.1 page 256 and Tab.11.3 page 284 of [31].

Conclusions

The arguments put forward by the authors of the comments and used to refuse the hypotheses proposed in the original work of Carpinteri and Manuello ignore the assumptions declared by Carpinteri and co-workers [1–11] and the theoretical explanation to anomalous neutron emissions from rock fracture recently proposed by Widom *et al.* [12]. The discussers of the comments argue that all the unresolved questions and various unexplained problems of Geophysics and Geology are already clarified and explained. It is difficult not to consider the large number of works that appeared in most important journals (Nature, Science, etc.) in recent years about the unexplained questions of the Earth's crust evolution. Beyond the errors that have been highlighted in this reply about the comments, it should be noted that the reported assertion by Bardi and Comoretto at the beginning of the section entitled 'Evolution of the Earth's Crust' of their comments and precisely'…stepped diagrams for this evolution (Figures 4 and 5 of Paper 1) for which we cannot find the corresponding data in the scientific literature, not even in the references cited by the authors themselves'. is false. In the last part of this reply, we have shown that each value referred to the figures has a precise origin from the scientific literature and the related citations are reported. In addition, it is believed that the interests of scientific progress would be better served by the collaboration in determining the repeatability of the experiments that are the basis of the conjectures proposed in the original paper. Further investigations, even if performed independently by other research groups, could lead to significant advances in understanding this new physical phenomena and the large number of unresolved questions that still remain in Earth Sciences.

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