Chapter 13
Chemical Evolution in the Earth's Mantle and Its Explanation Based on Piezonuclear Fission Reactions

Alberto Carpinteri, Amedeo Manuello, and Luca Negri

Abstract The anomalous chemical balances at the major events in the geomechanical and geochemical evolution of the Earth's crust should be considered as indirect evidences of piezonuclear fission reactions. Recent results observed at the scale of the Earth's crust and reproduced at the scale of the laboratory during quasi-static and repeated loading experiments may be extended to the different layers of the planet like the atmosphere and the bulk Earth (mantle and external core). The mantle of our planet is characterized by very high pressures and temperatures (~150 GPa and ~4000 °C) that could favour this kind of reactions. In the present paper, it is shown that the most important chemical changes in the Earth's crust evolution may be recognized also at the internal Earth's layers. Recent investigations have shown that also the mantle is characterized by significant compositional time variations. This evolution may be interpreted in the light of the same nuclear reactions recently proposed to explain the chemical changes in the Earth's continental crust and atmosphere through the entire life of our planet.

Keywords Earth's mantle • Chemical evolution • Piezonuclear fission reactions

13.1 Introduction

Recent geophysical and geochemical studies of our planet present a rich array of large-scale processes and phenomena that are not fully understood [1]. These range from the subducted slabs to the nature of the core – mantle boundary; from the mechanisms forming the present-day crust, mantle, and core to the distribution of Earth's crust elements and the uptake and recycling of volatiles throughout Earth's history [1]. It is only recently that pressures similar to those prevailing inside the Earth can be produced in the laboratory, as well as the materials can be tested by the necessary tools, in order to study the interior Earth's composition. The experiments

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have demonstrated that, under such extreme conditions, the physical behavior of materials can be profoundly altered, causing new and unforeseen reactions and giving rise to electromagnetic and nuclear transitions in rocks and minerals [1]. Similar results have been recently observed also in the rocks of near-surface environment. During the last few years, in fact, surprising results have been reported considering the chemical changes that characterized the Earth's crust and atmosphere evolution, together with the ocean formation, during the last 4.57 Billion years [2–9]. These evidences are related to the depletions of elements such as iron and nickel and the increment in lighter ones just in correspondence to tectonic activities in our planet [3–5]. The chemical changes observed at the scale of the Earth's crust have been interpreted by innovative experiments conducted on non-radioactive rocks subjected to different mechanical loading conditions [10–13]. These rocks are natural materials that represent the composition of the Earth's near-surface environment, such as granite, basalt, magnetite, and calcareous rocks. All these results provided evidence concerning a new kind of nuclear reactions that may take place during static or cyclic-fatigue tests [10]. The phenomena observed at the laboratory scale suggested that pressure waves of very high frequency, suitably exerted on inert and stable nuclides, generate nuclear reactions of a new type accompanied by evident and reproducible chemical changes localized on the fracture surfaces of rock fragments [10–16].

The catalysing factor producing these new kind of nuclear reactions, with so important geological and geophysical effects, is pressure. In particular, 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 [8–14]. It is evident that the physical conditions characterising the microseismic and seismic activity of an impending earthquake may be sufficient to produce these nuclear reactions at the scale of the Earth's crust. Even more severe conditions regard the bulk of our planet [1]. The mantle, presenting huge pressures and temperatures reaching ~150 GPa and ~4000 °C, respectively, is characterized by significant compositional time variations, similar to those observed in the Earth' s crust [1, 3, 17–20]. As will be reported in the present paper, the chemical evolution of the Mantle may be interpreted in the light of the same low energy nuclear reactions recently discovered and firstly proposed to explain the chemical evolution of the Earth's lithosphere.

13.2   Earth's Crust and Atmosphere Evolution

A transition from a mafic to a sialic composition of the Earth's Crust was observed by different authors [2, 3, 8, 9]. Recent studies advanced the hypothesis that the changes in Ni, Fe, Si, and Al compositions can be interpreted by the so-called piezonuclear fission reactions [8–13, 15, 16]. During the first Earth's geological period, when the planet's tectonic activity began (3.8 Gyr ago), the decrease in Fe

Table 13.1 Quantitative data for the "first piezonuclear jump" in the Earth's crust

Geological period	Decrease of Fe and increase of Al, Si and Mg				Decrease of Ni and increase in Si and NaCl		
	Fe (%)	Al (%)	Si (%)	Mg (%)	Ni (%)	Si (%)	(NaCl) (%)
Beginning of Earth's tectonic activity 3.8 Gyr ago	−7	+3	+2.2	+1.8	−0.2	+0.2	+0
Greatest tectonic activity 2.5 Gyr ago	−4	+1	+1.6	+1.4	−0.8	+0.75	+0.05
Total per element	−11	+4	+3.8	+3.2	−1	+0.95	+0.05

amounted to 7 % of the mass of the Hadean protocrust, and through the symmetric piezonuclear reaction [8–13] (see also Table 13.1):

$$Fe_{26}^{56} \rightarrow 2 \ Al_{13}^{27} + 2 \, \text{neutrons} \tag{13.1}$$

this was partially counterbalanced by a 3 % increase in Al. The remaining 4 % can be explained considering the asymmetric fission reaction (see also Table 13.1).

$$Fe_{26}^{56} \rightarrow Mg_{12}^{24} + Si_{14}^{28} + 4 \ \text{neutrons}. \tag{13.2}$$
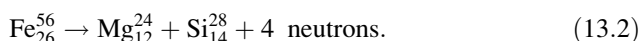
In evaluating the effect of this reaction, we can consider a 2.2 % increase in Si and an increase in Mg of 1.8 % (see Table 13.1). In the same period, the decrease in Ni appears to be 0.2 %. The latter reduction can be interpreted in the light of the following reaction:

$$Ni_{28}^{59} \rightarrow 2 \ Si_{14}^{28} + 3 \ \text{neutrons} \tag{13.3}$$

which was balanced by an identical 0.2 % increase in Si. From these reactions, the overall increase in Si for this period is thus around 2.4 % (see Table 13.1).

In the second geological period of the Earth's history, at the most intense tectonic activity (2.5 Gyr ago), Fe decreased by 4 %, and this can be balanced by a 1 % increase in Al through reaction (13.1). With regard to reaction (13.2), the remaining 3 % can be balanced by an increase in Si (+1.6 %) and in Mg (+1.4 %). In the same period, 0.8 % decrease in Ni can, by taking reaction (13.3) into account, be balanced by an increase in Si of the same percentage. Nickel can also be involved in the following piezonuclear reaction in addition to the reaction presented above:

$$Ni_{28}^{59} \rightarrow Na_{11}^{23} + Cl_{17}^{35} + 1 \ \text{neutron} \tag{13.4}$$
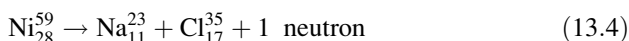
The recent studies cited above [8–15] also illustrate the compositional changes in the Earth's crust that have taken place for Ca, Mg, K, Na, and O. In the first geological critical period (3.8 Gyr ago), the decrease in Ca amounts to 2.5 %, through the reaction:

$$Ca_{20}^{40} \rightarrow K_{19}^{39} + H_1^1 \tag{13.5}$$

Table 13.2 Quantitative data for the "second piezonuclear jump" in the Earth's crust

Geological period	Decrease of Ca and increase of K and H$_2$O			Decrease of Mg and increase of Na, O and H		
	Ca (%)	K (%)	H$_2$O (%)	Mg (%)	Na (%)	O + H (%)
Beginning of Earth's tectonic activity 3.8 Gyr ago	−2.5	+1.4	+1.1	−3.2	+2.1	+1.1
Greatest tectonic activity 2.5 Gyr ago	−1.5	+1.3	+0.2	−1.5	+0.6	+0.9
Total per element	−4.0	+2.7	+1.3	−4.7	+2.7	+2.0

This decrease is balanced by a 1.4 % increase in K. The remaining 1.1 % may be balanced by the following reaction (see also Table 13.2):

$$Ca_{20}^{40} \rightarrow 2O_8^{16} + 4H_1^1 + 4\text{neutrons} \tag{13.6}$$

This reaction may be considered to explain the formation of H$_2$O, which was firstly concentrated in the primordial atmosphere and then condensed to form the oceans (see Table 13.2). In the same critical period, there was a 3.2 % reduction in Mg:

$$Mg_{12}^{24} \rightarrow Na_{11}^{23} + H_1^1 \tag{13.7}$$

which can be balanced by a 2.1 % increase in Na and by a total increase in O and H of 1.1 % (see Table 13.2). In the second critical geological period (2.5 Gyr ago), the decrease in Ca is 1.5 %, which, considering reaction (13.5), is balanced by a 1.3 % increase in K. Taking reaction (13.6) into account, the remaining 0.2 % is balanced by the formation of H$_2$O (see Table 13.2). The 1.5 % decrease in Mg for the same period, see reaction (13.7), can be balanced by a 0.6 % increase in Na and by a total increase in O and H of 0.9 % (see Table 13.2). In both critical periods of compositional step-wise transition (3.8 and 2.5 Gyr ago), the reduction in Ca that is not balanced by an increase in K can be balanced by the formation of H$_2$O molecules, see reaction (13.6) (see Table 13.2).

13.2.1 Atmosphere Evolution and Climate Change

Recent studies have demonstrated that the Earth's atmosphere, as well as its crust, has undergone significant changes in its major constituent elements over the last 4.5 billion years [17–26].

The findings presented here stem from studies of the evolution of the individual gases in the early atmosphere and considerations regarding the variations in the atmospheric pressure exerted on Earth's primordial crust. These analyses make it possible to formulate hypotheses about both the constitution of the atmosphere and

the early tectonic phenomena that took place during the Hadean (4.5–3.8 billion years ago) and Archean (3.8–2.5 billion years ago) periods.

In the early stages of Earth's formation, our planet underwent complex phenomena of differentiation, that slowly led to the stratigraphic division into Crust (continental and oceanic), Mantle (upper and lower), and Core (inner and outer) [27–31].

There can be no doubt that one of the basic characteristics of the early stages of the proto-Earth's formation was the presence of an atmosphere very different from today's. The origin of atmosphere and the formation of oceans are still being intensively investigated, with studies that continue to fuel scientific debate [17–19].

As can be seen from the specific literature [32–34], the most common elements are now nitrogen ($N_2 \sim 78$ %) and oxygen ($O_2 \sim 20$ %). During the planet's primordial epoch, the main constituents were H_2O and CO_2, while the accessory constituents, as is the case for the atmosphere now found on Mars and Venus, were N, CH_4 and O. What were the reasons for this relevant change? How was it possible to pass from an atmosphere that was highly toxic for present-day forms of life to one compatible with mankind's appearance on the Earth? Though these are still unanswered questions, the literature can provide us with data that suggest a number of intriguing assumptions.

First, it is interesting to note that having a primordial atmosphere saturated with CO_2 and H_2O could mean that atmospheric pressure amounted to some hundred bar, as several authors have affirmed [23–25]. In particular, the hypotheses regarding the concentrations of the various elements making up the primordial atmosphere make it possible to evaluate the effect exerted by each gas in terms of atmospheric pressure on the surface of the protocrust. These considerations are particularly important in the light of the first tectonic movements affecting Earth's life.

On the basis of the findings presented in [8, 9] and the data given in Table 13.2, reaction (13.2) would result in an overall increase in Mg of 3.2 %. This increase in Mg, however, was involved in a further piezonuclear reaction in which Mg is the starting element and C the resultant:

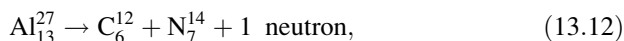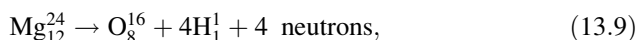$$Mg_{12}^{24} \rightarrow 2C_6^{12}. \tag{13.8}$$

This hypothesis is borne out by the idea that Earth's atmosphere in the Hadean and Archean periods was very different than it is today, the concentration of C in the form of CO_2 and CH_4 being particularly high.

Different quantitative considerations can be advanced. Today, Earth's atmosphere consists of a 40 km layer, while its mass is 5×10^{18} kg with a density γ of around 1.250 kg/m^3. Given this mass and a terrestrial surface area of 5.10×10^{14} m^2, we thus have an atmospheric pressure of 96,060 Pa or 0.96 atm (~1 atm).

A similar calculation can be made for the primordial atmosphere with high concentration of Carbon. In this case, the mass to be considered will be that resulting from the piezonuclear reaction (13.8) and corresponding to 3.2 % of the

mass of the protocrust involved in the reaction, $(3.4 \times 10^{21}$ kg). Considering the same gravitational acceleration for the proto-Earth, we obtain an atmospheric pressure of 666.70 atm. Although this value is very high in comparison with the current conditions of the planet's atmosphere, it can be regarded as plausible and consistent with the conditions prevailing between 3.8 and 2.5 billion years ago. In addition, it is corroborated by the studies of a number of authors who present models of a CO_2 and CH_4-rich early atmosphere with a pressures of some hundred atm, as was the case for the ground level atmospheric pressure of 660 atm indicated by Liu [17].

The large increase in light molecular composites such as O_2, CO_2, CH_4, and N_2 can be explained by the piezonuclear reactions discussed in recent papers by Carpinteri et al. [8–16]. In particular, the reactions involving Mg, Si and Al as starting elements and C, N, O, and H as resultants [8, 9]:

$$Mg_{12}^{24} \rightarrow O_8^{16} + 4H_1^1 + 4 \ \text{neutrons}, \tag{13.9}$$

$$Si_{14}^{28} \rightarrow 2N_7^{14}, \tag{13.10}$$

$$Si_{14}^{28} \rightarrow C_6^{12} + O_8^{16}, \tag{13.11}$$

$$Al_{13}^{27} \rightarrow C_6^{12} + N_7^{14} + 1 \ \text{neutron}, \tag{13.12}$$

can be considered to obtain a new explanation revealing the composition of the primordial atmosphere. Recent data have shown that CO_2 and H_2O concentrations increased dramatically between 3.8 and 2.5 Gyr ago (Fig. 13.1) in correspondence to sporadic seismic activity and the subduction of the primordial plates. Successively, between 2.5 and 2.0 Gyr ago, the rapid increase in N and O concentrations may be considered to be closely related to the most relevant formation of the Earth's continental crust (Fig. 13.1). The oxygen level, in fact, was very low during the Hadean and Archean eras (4.5–2.7 Gyr ago), whereas it increased sharply (Great Oxidation Event) between 2.7 and 2.4 billion years ago, until the present concentration ~21 % of the Earth's atmosphere was reached, a 10^5-fold higher value than that of the oxygen concentration in the earlier atmospheres (Fig. 13.1).

During the same period (from 2.7 to 2.4 Gyr ago), which represents 6 % of the entire Earth's lifetime (4.57 Gyr), 50 % of the continental crustal volume formed in concomitance to the most intense tectonic and continental subduction activities. Considering the scenario of approximately 2.0 Gyr ago, it is also possible to justify the origin of the first aerobic bacteria and multicellular eukaryotic organisms, ancestors of animals and human beings. Based on the composition time variations in the Earth's atmosphere shown in Fig. 13.1, and the piezonuclear fission reactions (13.6, 13.8, 13.9, 13.10, and 13.11), it can be observed that the intense tectonic activity caused a sudden increase in CO_2 and later in the O and N levels of the Earth's atmosphere. While the O and N levels remained constant, the high CO_2 concentration, principally due to piezonuclear reaction (13.8), started to decrease after 2.5 Gyr ago (Fig. 13.1). This fact can be explained considering the planetary air leak of gaseous elements and molecules, such as H, He, and CO_2, that has
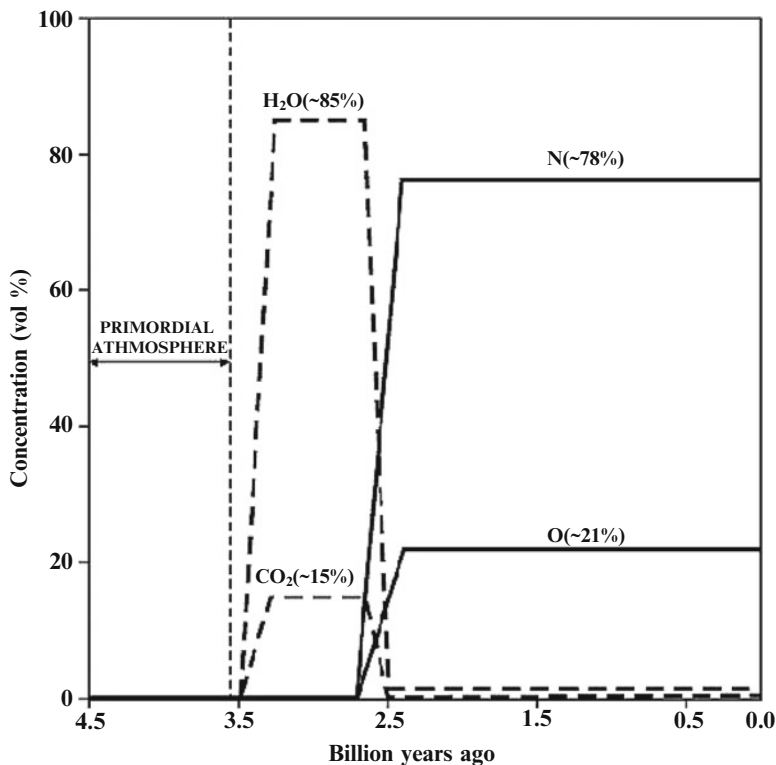
Fig. 13.1 Variation in the athmospheric composition over the Earth's life time. During the Achean era, about 15 % of the Earth's athmosphere was constituted by CO_2, and remaining part was mainly composed of H_2O. The Earth's athmospherical composition is dominated by nitrogen (N ~78 %) and oxygen (O ~21 %) [17]

affected the atmosphere during the Earth's lifetime [35]. The continuous decrease in CO_2 concentration over the last 3.5 Gyr has recently been contrasted by the well-known Carbon pollution.

The carbon dioxide (CO_2) variations over the last 500 million years (Phanerozoic period) are reported in Fig. 13.2a. The trend shown in the plot is determined considering Royer's database [36] together with the results of several specific geochemical models [37–39]. The present CO_2 concentration in the Earth's atmosphere is about 400 ppm, whereas 500 million years ago it was about 6000 ppm. Observing the phenomenon at that time scale, the increase that has occurred over the last 100 years, and which has been ascribed to Carbon emissions from the industrial revolution, seems to be negligible. In Fig. 13.2b, it is possible to observe the carbon dioxide (CO_2) variations over the last 4×10^5 years [31, 40, 41, 44, 46]. Today, some scientists sustain that, throughout the Twentieth Century, new forms of carbon pollution and the reactive nitrogen released into terrestrial environment by human activities (synthetic fertilisers, industrial use of ammonia) have

a

b
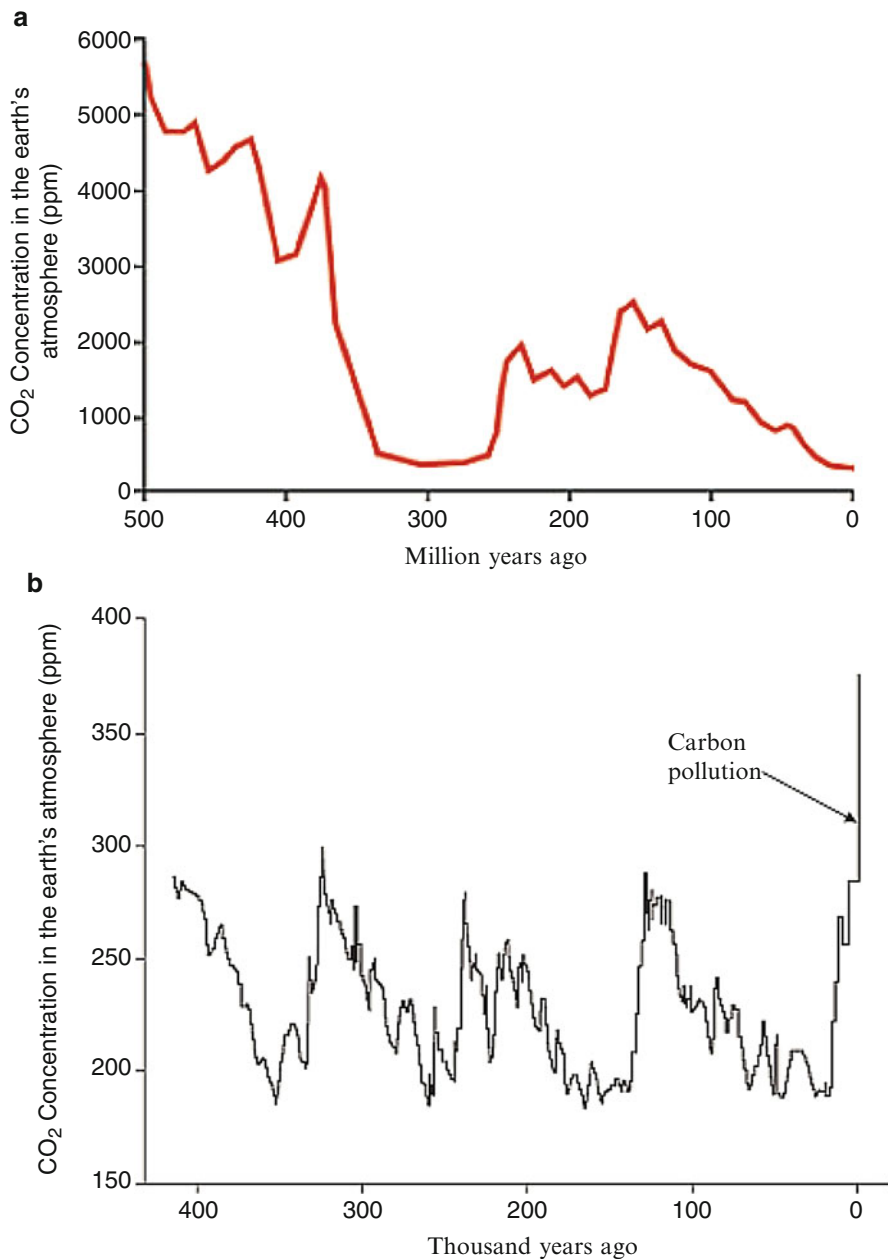
Fig. 13.2 CO_2 concentration in the Earth's atmosphere over the last 500 million years (**a**). The trend shown in the plot has been determined considering the database reported by Royer [36] together with the results of some geochemical models developed between 2001 and 2004 [38–40]. CO_2 concentration in the Earth's atmosphere over the last 4×10^5 years (**b**) [38, 39]

been the only responsible for the dramatic increase in CO_2 and N of the contemporary Earth's atmosphere [42–44]. However, a strong doubt remains whether much of these CO_2 (about 3/4 of the total) and N (about 2/3 of the total) are provided by the same causes that have produced the previous cycles of carbon dioxide concentrations (Fig. 13.2b) and the nitrogen increase in the Archean atmosphere (Fig. 13.1) [18, 32].

This hypothesis would appear to be supported by the evidence presented recently for the Earth's Crust [19, 20], together with the usually accepted idea that the early atmosphere's composition derived from Mantle degassing [31, 32, 45–47].

13.3 Compositional Evolution of the Earth Convective Mantle

Studies of the mantle's compositional evolution [32, 34, 48–50] have made it possible to analyze changes in the mass percentage concentrations of its main chemical elements and compare them with those that have been recently determined for the Earth's Crust by Carpinteri et al. [8–11].

These analyses are the basis for the graph reported in Fig. 13.3 and dealing with the changes in the mass concentrations of Fe, Mg, Si, Al, and Ca over the Earth's Mantle evolution. They lead to a number of considerations concerning the tectonic and convective events that occurred in the late Archean and their contributions to the chemical evolution of the terrestrial Mantle.

As has been observed for the Earth's Crust [8, 9], major changes in mass concentrations took place at the time of the great tectonic events, transforming heavier (Fe) into lighter (Al, Si, Mg) elements. The data presented in the literature indicate that the Earth's Mantle, like the continental crust [8, 9], saw two abrupt transitions in the concentrations of its constituent elements [32]. Specifically, these periods date between 4.0 and 3.8 billion years ago, and between 2.8 and 2.5 billion years ago. As shown in Fig. 13.3, the Mantle's decrease in Fe is balanced by the increase in other elements such as Si, Mg, Al, and Ca, which may have been involved in piezonuclear reactions like those observed for the Earth's Crust.

The data for FeO and Fe_2O_3 given in [32] indicate that Iron dropped by about 6 % at the first piezonuclear jump, and that the piezonuclear reactions (13.1 and 13.2) and a further reaction:

$$Fe_{26}^{56} \rightarrow Ca_{20}^{40} + C_6^{12} + 4 \text{ neutrons} \tag{13.13}$$
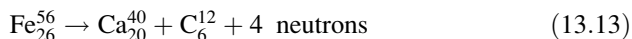
can explain the increase of ~2.8 % in Si, ~2.4 % in Mg, ~0.3 % in Al, and ~0.35 % in Ca. These contributions are surprisingly precise in balancing the reduction in Fe in terms of mass at the Mantle. A similar situation occurred in the second critical period. Between 2.8 and 2.5 billion years ago, the decrease in Fe is again around 6 %, while the increases of ~2.3 % in Si, ~3.0 % in Mg, ~0.5 % in Al, and ~0.35 %
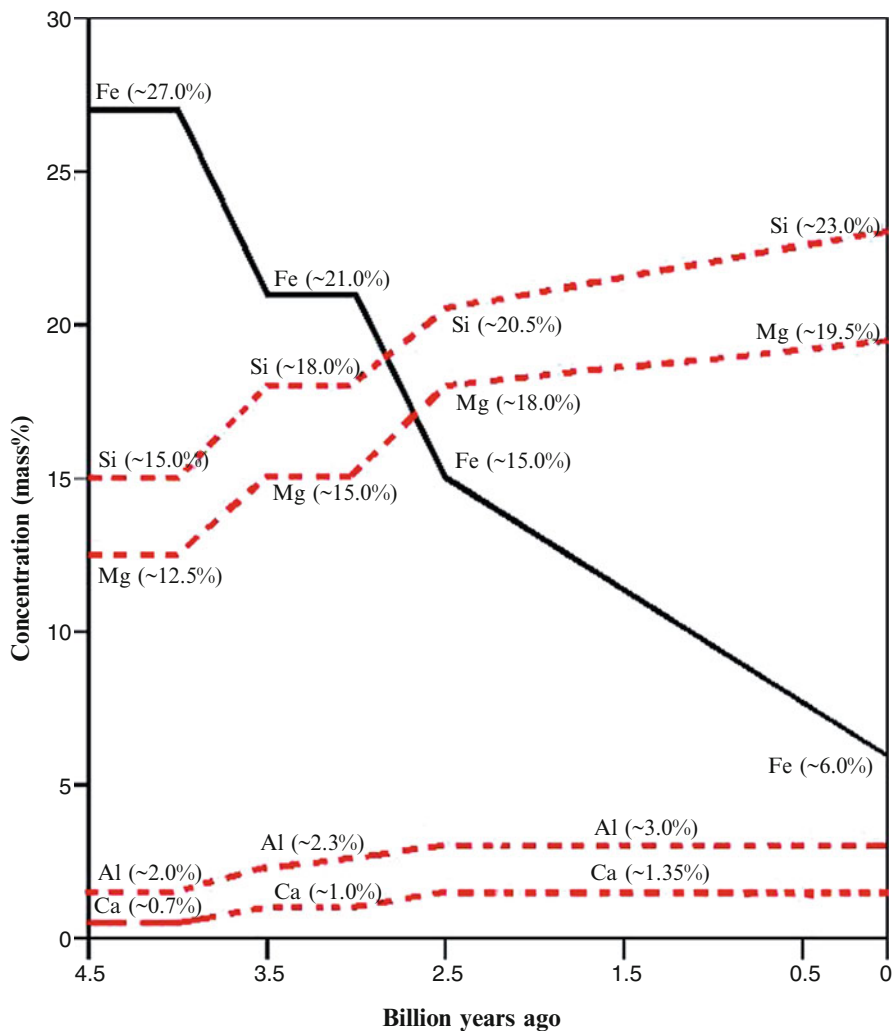
Fig. 13.3 Evolution of the concentrations of Fe, Al, Si, Mg and Ca in the terrestrial mantle over the Earth's lifetime [32]

in Ca appear to balance the reduction in Fe almost perfectly (see Fig. 13.3). The reaction involving Fe as the starting element and Ca together with C as resultants not only accounts for the increase in Ca in the mantle, but could also offer an alternative and compelling explanation for the formation of C and its anomalous concentration in the Mantle [32]. The current theories sustaining that Carbon was transported into the Mantle through the subduction of the Earth's Crust, in fact, do not seem to be entirely convincing [32].

The nearly perfectly matched balance taking place between iron and the elements increasing their concentration in both geological critical periods is surprising, and may be explained by means of the piezonuclear reactions described above.

However, it is necessary to assume that the Earth's Mantle, unlike its Crust, went through a further change in concentration, that involved the same elements analyzed earlier, from 2.5 billion years ago up to the present time (Fig. 13.3).

In this last change, we can see that the elements' concentrations have varied continuously and not step-wisely, and that these variations were thus not confined to a very narrow span of time as they were in the previous cases. From 2.5 billion years ago up to the present time, there has been a further decrease in the concentration of Fe amounting to approximately 11.5 %, and increases in other elements (in particular, Si and Mg) which have only partially balanced this reduction [32]. Indeed, significant increases can be observed in Si (+2.4 %) and Mg (+1.6 %), with an overall increase of only 4 %.

Whereas the remaining not balanced decrease in Fe is approximately equal to 7.5 % of the Mantle's mass. This decrease could be explained considering the formation of the Earth's Core. This percentage of iron may have gone to making up part of the Outer Core, where the concentration of iron is approximately of 80 % [8, 9, 28, 32].

13.4 Conclusions

The main results of the present paper are related to the evidence of compositional changes which affected the Earth's Crust, Atmosphere, and Mantle, from the early period of their evolution until today. It was observed how some anomalies in the concentrations of the most abundant elements in the Mantle can be interpreted by the piezonuclear fission reactions already introduced by Carpinteri and his team. In addition, it was observed that a further reaction involving Fe, Ca, and C may be assumed to comprehend the Earth's Mantle evolution. This reaction not only accounts for the increase in Ca at the Mantle, but could also offer an alternative and compelling explanation to the formation of Carbon and to its anomalous concentration in the Mantle [32]. The current theories sustaining that Carbon was transported into the Mantle through the Crust's subduction, in fact, do not seem to be entirely convincing [32]. From 2.5 billion years ago up to the present time, there has been a further decrement in the concentration of iron amounting approximately to 11.5 %, as well as related increments in other elements (in particular, Si and Mg) which have only partially balanced this reduction [32]. Indeed, significant increments can be observed in Si (+2.4 %) and Mg (+1.6 %), with an overall increase of only 4 %. The decrease in Fe which is not balanced by the increases in these two elements (Si and Mg) amounts to 7.5 % of the total Mantle's mass. This decrement could be related to the formation of the Earth's Core, as this percentage of iron may have gone to making up part of the Outer Core, where the concentration of iron is approximately of 80 % [8, 9, 28, 32].

In this context many hypotheses have been proposed to explain the time lag. Some of the most known are the Tectonic Trigger [50], the Nickel famine [5] and the Bistability model [51]. According to these hypothesis is very difficult to determine a quantitative evaluation about the causes producing the Oxygen concentration 2.5 billion years ago and today. Among these explanations the proposed conjecture based on tectonic activity and piazonuclear reaction seems to be useful under the light of a scientific debate devoted to clarify the causes producing the Earth oxygenation.

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