The Earth's 'wrath', earthquakes and volcanic eruptions

Earthquakes as a natural function of the earth's crust

Most people consider the earth's crust to be very stable. In the previous chapter, its slow but extremely important mobility was emphasized. Our view of its stability, though deeply rooted within us, is seriously shaken when violent disturbances take place, for example, earthquakes, volcanic eruptions, landslides or seismic sea waves, now known as tsunamis. It is only when unusual, paroxysmal phenomena of this kind occur that public interest turns to the dynamic processes of the earth's crust. Earthquakes and the transmission of seismic waves are the earth's shiver when it is shaken all over: a shiver which is transferred to man with all its psychological consequences.

The smallest movements of the earth's crust pass unnoticed by the vast majority of people although they may be equally important. Faults creep slowly, aseismically, buildings and entire villages slide gradually, portions of ground sink imperceptibly. We only realize when they begin to have dangerous effects on our works. Imperceptible small earthquakes or other physico-chemical processes, as yet unknown to us, force portions of the crust gradually to slide. Excessive drawing of subterranean water supplies creates dangerous landslides. Underground cavities cause surface layers of rock to sink. Modern satellite measurements of small movements in large seismogenic zones at the boundaries of lithospheric plates indicate imperceptible small movements in the faults which are particularly slow but which have results similar to those of earthquakes. Time is needed in order for a movement of this kind, analogous to a seismic movement, to occur: a week for very large and particularly active faults and an entire year for large seismic zones and several years for smaller faults.

Microtremors or microearthquakes occur continuously, every minute, every second, beneath our feet inside the earth; we are simply not aware of them and for that reason have no interest in them. These tremors would be of no interest to the vast majority of people, with the exception of a few scientists, if they did not sometimes become larger and more powerful, that is, become strong earthquakes, and pose a threat to us. The trigger or cause of small and large earthquakes is exactly the same. Large earthquakes occur at large breaks in the crust while, correspondingly, small earthquakes arise as a result of small fissures. In addition to the small and large earthquakes familiar to us, extremely small low frequency or 'silent' earthquakes have recently been discovered which take place unceasingly inside the crust but never reach the surface and are only perceptible indirectly by hypersenstitive instruments. And yet they are extremely significant since they constitute the daily instantaneous movement of our planet, especially in zones of contact between tectonic plates.

An average of two perceptible earthquakes with a magnitude greater than two on the well-known Richter scale occur daily, while at least one which is moderate to strong occurs each week. However, powerful earthquakes, which are relatively less frequent, are among the most destructive and fearsome natural phenomena known to the human race. Historical records contain many descriptions of earthquakes which resulted in extended destruction, thousands of deaths and had significant economic and social repercussions on the whole world. Over 820,000 people were killed in the earthquake in Sian, China, in 1556, while 240,000 victims are reported in the same country during the Tangshan earthquake in 1976, which measured 7.8 on the eponymous Richter scale. In the Mediterranean region, many destructive earthquakes are known to us, including that in Crete in 365AD with approximately 50,000 victims, which was accompanied by a large seismic sea wave or tsunami, perhaps the most powerful in the Mediterranean in historic times, the earthquake in Messina in Southern Italy which occurred on 28 December 1908 and measured 7.5 on the Richter scale and resulted in 120,000 deaths, that of Lisbon, Portugal, on 1 November 1755 (estimated magnitude 8.7 on the Richter scale) which claimed 60,000 lives, that of Calabria in Italy, in February 1788 with 50,000 victims. The disappearance of an entire city, Helike, in Achaia (North Peloponnese-Corinth gulf) in 373 BC was the result of a strong earthquake and tsunami. The powerful tremor in northwest Asia Minor (Turkey) on 26 December 1939 (M 8.0) claimed 25,000 lives, the earthquake of 30 November 1980 in Empoli, Italy (M 6.8) resulted in over 10,000 deaths and recently the powerful earthquake of Izmit (Nicomedia -Kocaeli) in Turkey (17 August 1999) caused over 25,000 deaths. The earthquake in the Himalayas (Pakistan – Kashmir India) in 2005 brought the loss of 80,000 human lives in its wake. Also in China (March 2008), a long crust fault activated up to 160 km huge landslides, river's dam landslides, creating new lakes and artificial dams.[*1] In all cases, the deaths and casualties were due to the collapse of human constructions and not nature itself. Earthquakes threaten man and his works, they have an impact on the anthropogenic environment, yet they scarcely affect the other living creatures. We, however, have not come to terms with this on either the individual or the social level.

The first geological observations and opinions about earthquakes appear as early as the presocratic philosophers, Aristotle, Eratosthenes, Pliny and Strabo, although to a lesser extent than other scientific fields. Anaximenes, for example, gave a very good account of the causes of earthquakes in a description which relates with extreme precision the displacement of 'faults', though the reasoning underlying his description is flawed. He believed that earthquakes occur when the earth shatters and the collapse of the earth's broken walls makes her shake. He states, however, that the reason for the earth shattering is extended drought. Thus he links the phenomenon of the earthquake with one of our world's fundamental 'element': water. Conversely, in the classical, Hellenistic and Roman period the description of specific earthquakes and corresponding accompanying phenomena is systematic and in some cases particularly precise. The first *sea tidal wave* (nowadays known as tsunami), which is possibly linked to the subsea earthquake on the Thermaic Gulf (North Aegean) in 479BC, is described by Herodotus in the Persian siege of Potidaea: xxxx[*2] *'Artavazo de epeidi poliorkeonti egegonesan treis mines, ginetai ampotis tis thalassis megali kai xronon epi pollon…epilthe plimmuris tis thalassis megali, osi oudama ko, os oi epixorioi legousi pollakis ginomenis. Oi men di neein auton ouk epistaenoi diefhteironto, tous de epistamenous oi Poteidaiitai epiplosantes ploioisi apolesan"..*

Thucydides' precise description and concise explanation for the corresponding tsunami wave in the Malian – Euboean gulf (Central Greece) during the great earthquake of 426BC is also impressive. "I beleive that the cause of this phenomenon can be no other than the strong earthquake as the sea was suddenly pulled back in a violent manner causing thus the flood. I don't think that something like that could ever happen without the impact of the earthquake" *"…aition d'egoge nomizv tou toioutou, i isxurotatos o seismos egeneto, kata touto apostellein, te tin thalassan kai eksapinis palin epispomenin viaioteron tin epiklisin poiein; aneu de seismou ouk an moi dokei to toiouto ksumvinai genesthai…".* This excerpt from Thucydides could be considered the first definition of a seismic sea wave (tsunami).

The first memorial to the victims of earthquakes, under the name *Seismatias*, was erected in Sparta following the devastating earthquake of 464BC. Since then, memorials for this 'atrocious' and 'destructive' natural occurrence appear only in the second half of the twentieth century in Valparaiso, Chile, in 1960, in China in 1976 (Tang-Shang), in Japan in the 80s and 90s (Kobe) and Taiwan (1999-2003).

Aristotle refers to the earthquake of 373BC in Achaia (the magnitude of which is today estimated to be between 6.5 and 7.0) which, as mentioned above, gave rise to a powerful seismic sea wave or tsunami and which destroyed Helice, the capital of the twelve Ionian cities. References to this earthquake were also made by Strabo, who also discusses a surface fault, Pausanias, Diodorus Siculus and the Roman writer Aelian. However, it is Demetrius of Callatina (3rd century BC), a geographer and historian from the city of Callatina, Odessa, in the third century BC, who is considered to have to been the first to compile a complete and systematic catalogue of earthquakes in the wider Hellenic world. Unfortunately, this book has not survived, with the exception of a few references in Diogenes Laertius and especially Strabo: "Demetrius of Callatina was narrating about the earthquakes that had ever happened all around Greece" *("Dimitrios d'o Kallatianos tous kath'olin tin Ellada genomenous pote seismous diigoumenos…")*. In the Byzantine period, we also have excellent descriptions of earthquakes which provide much useful information despite the earthquakes being explained consistently as manifestations of divine wrath, with no attempt at interpretation. A large earthquake, for example, which shook Cyprus in 1221 is described in a Byzantine chronicle as 'The godsent wrath of the big earthquake…' *("Theoilatos orgi tou megalou seismou…")*.

Despite the destructive power of this phenomenon, despite the awe and general emotional charge it provokes, very little was known about its nature and causes before the twentieth century. Even the scientifically explosive nineteenth century passed with descriptions only of the manifestations of various earthquakes, with no deeper examination of its causes. It is only in the early twentieth century that the phenomenon began to be studied using scientific instruments and methodology, following the elaboration of the theory of waves in physics. Of course, in the final quarter of the century after the establishment of the theory of Lithospheric Plates, a rational assessment of this phenomenon began to be formulated. Earthquakes represent the sudden rupture (collision) of geological matter, that is rocks, as a reaction to the tectonic force (pressure or stress) applied to them. The stress accumulates for a period of time, for many years, usually decades, centuries or even millennia, especially along the length of the known active regions of the earth's crust which are sensitive and weaker, that is, more liable to break when the accumulated pressure surpasses the limit of the rocks' endurance. The energy in the rocks, which has accumulated over decades, centuries or millennia, is released in the few moments of the seismic rupture.

Over the course of its long history of some four and a half billion years, the earth's crust, continental or aquatic, has broken very many times in small and large breaks termed *faults* in geology. These have a length ranging from a few centimeters to tens of kilometres. It is generally accepted that large superficial earthquakes bring about breaks in the earth's crust, or are 'brought about' by pre-existing ruptures when they are reactivated. An earthquake is associated with a fault or usually a zone or groups of faults, while very deep tremors appear to be generally linked to lithospheric plates and are probably not related to superficial phenomena such as faults. Many of these faults were once active for long periods of time and now appear to be inactive or dead. It is only their imprints which have survived in the rocks and are now studied by geologists, as fossilized structures. Conversely, faults in the earth's crust which are geologically more recent – that is, by the standards of geologists: a few thousand or hundreds of thousands of years – begin to be active once again at certain times and the portions which were not broken in previous earthquakes break and bring about new earthquakes. Thus they do not break all at once, in one go, but gradually and in stages, at different points of time, and without regularity, as events have unfortunately proved. Daily minor earthquakes arising as a result of a very large number of small fissures also release large quantities of accumulated energy and generate or accelerate the rupture of larger faults.

From a geological point of view, the superficial impact of earthquakes on the geological environment, the relationship between faults and earthquakes and the recognition and characterisation of active faults within a geological environment are all important. The verification of an active fault is a key element in studies in order to ascertain the possibility of an earthquake occurring and its magnitude.

Many such faults cross Greece, particularly continental Greece, and it is to their activity over the course of the last 1 to 2 million years that the configuration and beauty of the Greek landscape, geothermal fields, hot springs and, of course, earthquakes are owed. The majority of the known active faults in Greece, upon which many villages and cities have been built and have survived for hundreds and thousands of years, have a length of 8 to 15 kilometres and extend to a corresponding depth of 5 to 20 kilometres. From a practical point of view, this means that when they are activated, they generally produce earthquakes with a magnitude of 6.0 to 7.0 on the well-known Richter scale.

Large superficial earthquakes leave intense 'marks' on the uppermost crust and surface of the earth, which are nowadays recognizable by geologists. The recognition, understanding and quantitative expression of the effects of earthquakes on the contours of the earth's surface afford a better understanding of this particularly complex phenomenon and contribute to an assessment of the seismicity and the seismic danger of an area. Geology examines earthquakes as a natural phenomenon, as an instantaneous tectonic event which, within the framework of geological actualism constitutes one of the principal causes of crust formation. Earthquakes are the architectural elements of the earth's crust.

Small and large earthquakes have exactly the same trigger. Small earthquakes are a daily occurrence and appear to be frequent and 'chance' happenings, while large earthquakes take place less frequently, at particular positions on the crust and tend to cumulate in time, that is, they occur successively in a relatively short space of time. Thus very many small earthquakes, several medium-sized earthquakes and few large earthquakes may occur in a short space of time from the same 'source', the fault, or from a wider area of the crust, while for a long time it is possible for the seismic 'source' to be calm and settled.

The earth's solid crust is in a state of apparent calm which nevertheless conceals a tension, like the string of a tightened bow: although seemingly motionless, it is actually in a dynamic state of charge. Likewise, the apparently calm and stable crust, or rather certain regions, resemble a tightened string which is in a critical state, continually on the brink of a small or large explosion and realignment. Sooner or later, earthquakes and a realignment of the rocks occur in these areas.

The rocks which are displaced are on a level of instability of great length, termed a geological fault. But earthquakes do not occur only on a single fault, even though until now our models point this way. Earthquakes arise from – or rather, on – a group of small or large faults the size of which starts out as crustal cracks, tiny fissures of a few centimeters in the rock masses, and starting from a few centimeters can reach a few metres or tens of metres and even many kilometres. As the contemporary American seismologist Christopher Scholz eloquently put it: '*An earthquake, when it begins,*' from a small rupture, '*does not know how big it is going to be'*. Imperceptible small ruptures occur continuously in the rocks beneath our feet and constitute part of the daily kinetic functioning of the crust. At some point they unite and grow rapidly, but fortunately only in areas which are tectonically active and ready to rupture, and in a few seconds they can spread kilometres, thus releasing large accumulated quantities of energy. Of course, like all things in nature, earthquakes, too, have their limits; that is to say, a rupture which started from a particular point cannot continue to all adjacent or even remote faults, because then the domino effect would activate all the planet's faults and we would consequently experience daily continuous large earthquakes, or rather, the earth would long since have shattered entirely.

A different definition of earthquakes, not described by books of geology and seismology, could be formulated as follows: seismic waves transmit and redistribute energy in the body of the earth, an energy which accumulates in certain nodal points of the earth's crust as a result of the pressure of the rocks and the physicochemical processes occurring in them. It is thus a question of 'thermodynamics' or 'statistical mechanics' and 'equal distribution of energy' in the crust. It is something which has been described in nature with reference to many variations, even those of living cells. As regards the excess of accumulated energy which is located or concentrated at a particular spot or rock mass in the crust, the system adopts a 'socialist line of thought' and at some point attempts to scatter it or distribute it equally. This is realized through a sudden action, the earthquake, or rather the transmission of energy from one point to all the others, until the level of energy is equal throughout and all activity is terminated so that the system reaches a state of equilibrium. How long, however, does this equilibrium and equal distribution of energy last? The answer is that everything starts afresh from the beginning. Thus we enter a 'seismic cycle', with a re-accumulation of energy, not only in another source, which might be "far-from-equilibrium", but also far from the source itself, the same fault that caused the earthquake and begins to recharge. Computing experiments for the equalization of energy (Fermi-Pasta-Ulam) in different points of a system showed different things. After certain time, the system acts nonlinear and repeatedly, that means it reverts again and again to its initial state i.e. the one it had when it received the first increased energy dose. In other words, it gains "memory" and "remembers" its initial state after it has followed a certain route. The same volume of rocks or the area around it is being recharged and after 100, 1.000 or 5.000 years it suddenly distributes again its re-accumulated energy in a few seconds, that means, it generates another earthquake. The source repeats this activity for thousands and millions of years, until it dies away and another source takes its place. "Where the earth once quaked will quake again" *("Opou eseistai tha seisei"),* according to the ancient Greek saying.

When does though the seismic fault repeat its reactivations? At regular intervals? The answer is no, because if this was the case, the problem of predicting earthquakes would not only be very easy but even empirically solved, at least for the regions where a good earthquakes' historic archive would be available. Nevertheless, nature's complexity does not allow problems to be solved that easy, however smart people who try to solve the problems might be, whatever terrific machine (computer) may be set at man's disposal. "Nature loves to hide" *("fysis kryptesthai filei"),* according to Heraclitus. Still, all these things related to understanding nature's endeavor to equalize its energy in its body, the far-from-equilibrium state, the faults' "memory" and the interconnection, would seem unreasonable and fictitious if it was not for the research conducted by smart, pioneers. The modern logic of the illogical in science, the creative fantasy and the mathematical tools open totally new and revolutionary ways in human thought as far as the understanding of nature's operation is concerned.

Volcanoes: pimples on the earth's body

We are familiar with volcanic eruptions as particularly violent and destructive natural phenomena. In contrast to all the other geological phenomena which develop at a very slow pace, earthquakes in particular and volcanic eruptions are extremely rapid events. In a few minutes, in a few hours and days, a volcano can scatter huge quantities of ash over many kilometres, spread a fine ash over the entire planet, spew huge quantities of pyroclastic matter which, traveling at 'aerodynamic speeds', comparable to those of modern aeroplanes, destroy everything around them, it can create sea tidal wives, cover forests, lakes, rivers, villages and cities with a stream of lava. The ash alone, scattered over an extremely large area, is estimated to range between 1 and 100 cubic kilometres in the case of large explosions, while fine ash spreads throughout the atmosphere and embraces the entire planet. Moreover, when the volcanic matter comes into contact with water, it is at once both destructive and creative. At the bottom of the ocean, in a few hours it obliterates entire ecosystems while also creating space for the development of new ecosystems. It has been estimated that the lava which reaches the sea creates large quantities of hydrochloride (HCI) in addition to the steam and other gases it produces, and in this way 'pollutes' the atmosphere. This pollution is, however, natural. For example, in the eruptions in Hawaii of 1840, 1919 and 1950, it has been calculated that as much as 2,200 tons of hydrochloride 200 was produced and escaped each day: an 'environmental disaster' greater than that which could be produced by many chemical industries together.

The planet's primordial matter is suddenly spewed from the bowels of the earth, man and his creations are shaken violently and then, after the birth of new land, just as after the pains of labour, calm is once again restored. Nature is not familiar with what we consider to be good and evil. Volcanic explosions are one of the planet's essential natural processes, a process whereby earth is born, land is created and the atmosphere is enriched with gases. The volcanic rocks created by the streams and jets of lava take on the most peculiar shapes and the landscape constructed by the earth's violent forces impresses us.

Volcanoes played an extremely significant role in the first stages of the formation of the earth's crust, hydrosphere and atmosphere. They created and continue to create new land, new ground suitable for the establishment of many life forms. When volcanoes destroy an area, almost immediately they give the opportunity for new ecosystems to develop rapidly, and essentially renew many ecosystems. They supplied and continue to supply the surface of earth, essentially the biosphere, with primordial matter. It is striking how quickly new volcanic land is flooded and enriched with life and how quickly it presents a great variety of biological forms. In the past and to the present day, volcanoes have given and continue to offer air and water to the atmosphere and play an important part in climate formation. For some years they are able to decelerate or accelerate the processes of temperature change on a worldwide level. We know that all large volcanic eruptions which occurred in historic times and have been studied closely brought about tremendous changes to the atmosphere, albeit temporary. For example, the eruption of the Laki volcano in Iceland in 1783 brought unusual changes of such magnitude to the atmosphere and its circulation that rainfall decreased for one year and many rivers in the northern hemisphere ran dry, including the Nile, the important supplier of freshwater. Moreover, the same eruption resulted in one of the coldest summers of the last centuries. The eruption of Tomboro volcano on the island of Sumbawa, Indonesia in 1815, caused a particularly cold winter in Europe, with extreme temperatures: the year without a summer. As is well known, the heavy winter of 1812-13 was the principal cause of the defeat of the French troops and their decimation in the freezing Russian steppes. Thus a natural, earthly change brought about a series of chain reactions in the military campaign and the politics of the time, and had a decisive role in the course of history.

Volcanoes provoke both our awe and wonder. They remind us of the creation of the world and of the infernal roots of life. Our foundations are in the mountains, as the poet Elytis says.

The tsunami, or seismic sea wave

The seismic wave tsunami bears no relation to the large tidal waves of the ocean which occur as a result of the effect of the atmosphere and disappear in depths of 10 to 20 metres. The tsunami is an instantaneous impulse wave created by the violent displacement of rocks at the sea bed, usually after a powerful earthquake. It is made up of a huge column of water, which often even exceeds 1000 metres. It is a series of partially concurrent waves, which 'unite' the particles of water. In this way, they acquire a 'connected memory' and, the series move like a wave train, transferring an enormous amount of energy, approximately one tenth of the earthquake which triggered it. It is many kilometres in length while the wave width is small when it crosses the ocean. The length, width and speed of this ferocious wave change continually during its course since they depend on the depth and the geomorphological anomalies of the sea bed. No mathematical relationship can describe this movement fully, although ingenious computer models offer an adequate approximation and interpret most empirical facts and measurements. At the same time, a complex internal swirling movement digs up the seabed, lifts sand and microorganisms and the wave, like a black wall, follows its lonely course. The tsunami is a 'solitary wave of high velocity and low energy losses' which could travel around the earth many times if the right conditions existed and there were no attrition and obstacles. However, when it reaches shallow seas, it is strained and rises, its width increases as was mentioned above, it grows more savage, refracts, retracts, swirls and breaks out on the coastline in the form of a 'cobra's head', to use the apt description of many eyewitnesses, releasing as much energy as it has remaining. Then nature directly and mercilessly 'kills' her children, living creatures at the seabed, communities of corals in shallow seas, seaweed and as many living organisms as were unable to escape its sphere of action over land, which can range from a few metres to a few kilometres. Thus the tsunami kills directly and not indirectly as in the case of earthquakes, which bring about deaths and injuries primarily in man's creations, that is, when buildings are hit, damaged or collapsed as a result. Animals and man in his primeval state are almost never at risk from earthquakes.

This was a brief and, as far as possible, easily comprehensible description of the tsunami phenomenon or seismic sea wave which contains all the scientific, empirical and mathematical

forms of expression. It has also been termed high energy ‘advancing solitary wave’ or ‘soliton wave’, which appears out of nowhere, travels fast alone and tries to spread everywhere. It usually appears in good weather, it hits the coast for only a few minutes and both beforehand and afterwards the sea resumes its usual activity, with small or large waves, as if nothing had happened.
*1 Η πρόταση αυτή είναι γραμμένη χειρόγραφα πάνω στο κείμενο-την έχω μεταφέρει αυτούσια και διατηρώ επιφυλάξεις για το αν έχω καταφέρει να τη διαβάσω σωστά.

*2 Quote in English missing, to be added – Θέλω να βρω την επίσημη μετάφραση γιατί δεν είμαι σίγουρη για τις μεταφράσεις που προέκυψαν από βοήθεια φιλολόγων σε κάποια σημεία, οπότε και θα την προσθέσω για να είμαστε 100% σίγουροι.