

New Concepts in Global Tectonics



NEWSLETTER

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CONTENTS

From the Editor Right earthquake model and a multidisciplinary approach: keys for earthquake prediction...	2
Letters to the Editor London Geological Society and <i>Geoscientist</i> , Stephen FOSTER.....	4
Articles	
Solar activity linked to high-magnitude earthquakes, <i>Stephen A. REYNOLDS</i>	6
Magnetometer data from GOES for 2001 to 2011 were assessed against 7.0-plus magnitude earthquakes worldwide. Results showed these earthquakes clustered towards strong solar activity. The statistical correlation was then validated against a hypothesis, that fault lines were fed increased electrical energy in a similar way to geomagnetic-induced current.	
9/56 year cycle: 18 th & 19 th century world earthquakes, <i>David McMINN</i>	15
The 9/56 cycle was assessed in the timing of major 18 th and 19 th century world earthquakes. Remarkably, most 1765-1885 seismic events ($M \Rightarrow 7.9$) took place in one half of the complete 9/56 year grid. Since 1900, world mega quakes ($M \Rightarrow 8.5$) also occurred preferentially in 54/56 year grids, something that was considered in relation to earlier centuries.	
Can IMF and the electromagnetic coupling between the Sun and the Earth cause potentially destructive earthquakes? <i>Valentino STRASER</i>	27
Trends in the Interplanetary Magnetic Field (IMF), detected by GOES satellites 13 and 15, show some recurrences in the graph, as a characteristic "σ" shaped hook that is detected before earthquakes of magnitude M6+. Due to the recurrence of the event, in the form of "σ", almost always present before strong earthquakes, the method aims to provide a contribution to the interdisciplinary study of seismic precursors of a global character.	
Intervals of pulsation of diminishing periods and radio anomalies found before the occurrence of M6+ earthquakes, <i>Valentino STRASER</i>	35
From spectral analysis of more than 350 earthquakes, it was noted that the micro pulsations and the radio interference detected, respectively, at a value of 665 mHz and in the range between 0.1 and 20Hz, precede by a few hours the occurrence of M6+ earthquakes.	
The Raffaele Bendandi earthquake warnings based on planetary positions, <i>Cristiano FIDANI</i>	47
Raffaele Bendandi was well known during the first half of the twentieth century for his warnings on the onset of earthquakes which were made in newspapers worldwide.	
Essays	
Earthquake and volcano "predictability vs crustal diagnosis", <i>Giovanni P. GREGORI</i>	55
The Tethys configuration and principal tectonic features of the Middle East: a wrench tectonic survey, <i>Karsten STORETVEDT and Soheila BOUZARI</i>	103
Geopolitical Corner	
Bad vibrations: Lessons from l'Aquila, <i>Michael KILE</i>	143
Publications	
The tsunami threat, <i>Nils-Axel MÖRNER</i>	149
News	
Earthquake sessions at the European Geosciences Union General Assembly, Vienna, 7-12 April, 2013.....	151
IEVPC press release, no. 3, 2012.....	151
Financial support and About the NCGT Newsletter	154

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FROM THE EDITOR

Right earthquake model and a multidisciplinary approach: keys for successfully forecasting major earthquakes

As is well known, earthquakes have been officially declared unpredictable. In a report on the recently-held special symposium of the Japanese Seismological Society in October 2012, “Blue print, 50th anniversary – history of earthquake study and its future”, seismologists were accused of lying to the public; despite knowing that earthquakes can never be predicted, their predictability (or possible predictability) has been exploited to secure public funding for their own researches, which have no relevance to actual earthquake prediction (*Shukan Post*, 9 November 2012). Earthquake “unpredictability” was invoked to defend seismologists in the recent court case arising from the April 2009 l’Aquila earthquake in Italy, in which six scientists and an administrator were sentenced to 6 years in prison. You can read more about the l’Aquila case in the Geopolitical Corner of this NCGT issue.

Ironically, the present pessimistic and chaotic state in earthquake prediction science is a self-generated quagmire, created by the reigning tectonic model – plate subduction as the cause of earthquakes. What has become increasingly clear from our studies, however, is that deep Earth-sourced energy causes the tectonic and magmatic activities at the Earth’s surface. The new model is based on a much-improved understanding of Earth structures and workings – particularly planetary fracture systems and the geology of the Earth’s surface including ocean floors, which control energy transmigration from the outer core to the surface, earthquake generation, and trap structures. Furthermore we have started to recognize the interaction between the Earth, the Sun and other planetary forces, and their relation to tectonic activities.

Guided by the new tectonic model and concepts, the recently formed International Earthquake and Volcano Prediction Center (IEVPC) (in which many NCGT members are involved) has demonstrated that strong earthquakes are predictable months to weeks prior to the events. Their latest press release, which is printed elsewhere in this issue, referred to their three successful test cases. Because we have reached a pivotal historic point which changes the longstanding view of earthquakes and their predictability, I will present further details here for our readers.

The first case is the Kamchatka quake. It was predicted based on Blot’s energy transmigration concept (ET concept, *Géophysique*, v. 13, Orstom, Paris, 206p.). Two deep quakes that occurred in the northern Okhotsk Sea in 2008 were used to project their shallow appearance. Based on geological structure and historical earthquakes, the epicenter was placed in the continental slope to the trench area off Kamchatka, with a possible time in the early half of 2012 and a magnitude 7.4+. Independently from us, Russian seismologists based in Petropavlovsk-Kamchatka, Kamchatka, warned local residents in February of a possible strong earthquake (M6 to 7) based on their own studies. This news prompted us to establish the IEVPC. As expected, the predicted epicentral area has started to show various kinds of precursory signals including earthquake clouds, gas eruption and thermal phenomena with moderate-size shocks in the continental slopes after March, particularly from May onwards in the wide area of Kuril-Kamchatka-Aleutians (Kamchatka triangle). The activity reached its climax in late October to early December when a powerful short-term signal, the VLF electromagnetic wave propagation anomaly, was detected by Dr. Hayakawa (IEVPC associate) between the transmission stations in Seattle, USA, and Japan. It appeared three times (1 to 3 Oct., 3 to 4 Nov. and 16 Nov.), each followed by a spate of intensive, strong shocks in the continental slopes of the Kamchatka triangle including an M6.8 (on 16 Nov., later downgraded to M6.5 by USGS) 12 to 14 days after the appearance of the VLF anomaly. It is noteworthy that the first cycle of the VLF anomaly included an intriguing fact; one of the stations in Japan recorded an extremely strong anomaly which exceeded the one that appeared just before the March 2011 Tohoku earthquake (M9.0). We believe this is the real magnitude of the energy of the predicted earthquake. Additional data on radon in the soil, provided by local Russian seismologists in late November, indicated very active radon gas discharge at that time.

We consider that the quakes that occurred in the Kamchatka triangle from October to December are primarily foreshocks, but they failed to trigger a mainshock, despite the spectacular display of many precursory phenomena in the wide area of the northwest Pacific and the epicentral area. As noted in the press release, a remarkable series of quakes spread along a line of almost 1,500 km, expended much of the mainshock's energy from 14 to 22 October in the form of ten quakes ranging from M4.6 to M5.8, some of which struck at the predicted epicenter. Thus instead of a single M7.4+ quake with possible loss of life and Pacific wide tsunami we fortunately saw many predicted quakes within the forecast time frame, including at the predicted location.

We noted in the sea surface temperature (SST) and outgoing longwave radiation (OLR) trends that the energy from the deep Okhotsk Sea peaked in early September and then started to recede in the epicentral block. But instead, powerful regional heat in the deep northwestern Pacific continued to feed the region; a distinctive thermal peak was established exactly in the predicted area from September to early December, which receded rapidly in the latter half of December. During the receding period, a cauldron volcanic structure appeared in the area. The thermal history of the region is comparable to that in terrestrial cauldron development as described in Kubota (*Boll. Soc. Geol. It.*, vol. spec. no. 5, p. 159-168.). This explains the missing mainshock – the energy from the deep Earth has been spent in feeding volcanoes with the peak of energy expenditure with the quake series in late October. The energy trap structure was incomplete and leaky – a result of the oceanization process in the area.

The second case is the Myanmar quake (M6.8) on 11 November 2012. Dr. Bapat of India (one of the IEVPC associates) noted an unusually high total electron content (TEC) anomaly for more than one month from 21 September to 5 November 2012 in the eastern India to Myanmar area. The sea surface temperature (SST) also indicated the strong heat emanating from north (or land) to south (Bengal Sea). He asked me for other data. On the satellite images, I noted that many earthquake clouds appeared on 14 September (58 days before the mainshock) in the wide area along a major NW-SE fault running from the foot of the Himalayas through East India to Myanmar where it meets the N-S Shan Boundary Fault. A quake later occurred at the junction of these two block-boundary fault systems. Also noted were radiating, concentric cloud (or cloudless) patterns which appeared on 15 September, 3 October and 20 October near the future epicenter, the last one being spot-on. Dr. Bapat submitted a note of his observations to the Indian magazine *Current Science* on 8 November (3 days prior to the quake), and also informed the Indian government, National Disaster Management Authority (NDMA), New Delhi, on 6 November (5 days in advance) providing the predicted parameters: 1) epicenter, where concentric clouds appeared (result, correct), 2) magnitude, 6.5 to 7.0 (it was 6.8 – correct), and 3) time frame, two to four weeks from 5 November (one week difference, almost correct).

Independently from Dr. Bapat, Dr. Hayakawa of Japan detected a VLF electromagnetic wave propagation anomaly on 31 October between stations in Australia and Japan, and issued a warning for a M6.0+ quake somewhere in the Philippines and Indonesia region to his clients. He wrote to me, "...although Myanmar is out of the Fresnel zone, if your magnitude is much greater than 6, our issued prediction might correspond to your Myanmar Eq as in the 2004 Sumatra Eq." (31 Oct. 2012 communication). His VLF wave anomaly usually appears one to two weeks prior to the seismic events. Thus it matches the Myanmar event, as there were no other major M6.0+ quakes in the region during the period.

The third case is the Molucca Sea, Indonesia. The IEVPC warned of the Molucca Sea threat in their early press release in a general form. It was based on a series of very strong deep shocks in the northern Celebes Sea in July, 2010 (Choi, NCGT no. 56, p. 75-85, 2010). A prediction test was made on the basis of a unique, regional concentric pattern (probably formed by ionized radon discharge) which usually appears on satellite images a few weeks prior to a mainshock, which we learnt while studying major historical earthquakes. As expected, an M6.0 quake occurred at the predicted site in the Celebes Sea. Regardless of this test, the Molucca Sea region has already entered an active stage with the 31 August M7.6 quake off Samar Island, Philippines, as a symbolic harbinger. The region is being shaken almost every day by moderate to strong shocks.

The IEVPC's comprehensive studies on Kamchatka, Myanmar and Indonesia as described above prove that there are unmistakable precursory signals that can be used for detecting impending strong earthquakes: 1) deep strong shocks (ET concept) for long-term prediction, 2) clouds and electromagnetic/thermal phenomena such as SST, OLR and TEC for intermediate-term prediction, and 3) VLF wave propagation and electromagnetic phenomena for short-term prediction. When these data are combined with geology, we can reasonably forecast strong (M6.5+) earthquakes well in advance.

In addition, though still not acknowledged by authoritative seismological organizations, the March 2011 Tohoku earthquake in Japan was correctly forecasted by the Global Network for the Forecasting of Earthquakes (GNFE). They detected a sudden, strong anomaly in super-long gravity four days prior to the quake and published the locality, time and magnitude on their website two days prior to the event with pinpoint accuracy (http://www.seismonet.org/page.html?id_node=130&id_file=129). Another well-known successful case is the Haicheng earthquake in China in 1975 (*EOS*, no. 58, p. 236-272, 1977).

In the light of all these successful cases, do you still consider earthquakes to be unpredictable? If we have the will and determination, we can learn to understand earthquake mechanisms and decipher precursory signals by adopting a multidisciplinary approach. In this way, many lives will be saved.

LETTERS TO THE EDITOR

The Editor,
New Concepts in Global Tectonics Newsletter.

Thank you for the e-mail re-correspondence with B. Erickson to be published in the next edition of *NCGT Newsletter*. I am sending you some more information concerning my correspondence with *Geoscientist* which you may wish to consider bringing to the attention of a wider audience.

After I had received a rejection letter for my brief essay pointing to evidence from rocks on the ocean floors which refutes plate tectonic theory and published in *NCGT Newsletter* no. 62, I submitted a revised version with more details and less controversial comment. In reply I received the following:

"Thank you for your re-write of your original piece addressing subsea anomalies that seem not to fit with the standard model of plate tectonics and specifically subduction.

After extensive discussion in the editorial board I am afraid that the overwhelming view was that, while you have identified a number of apparent anomalies, many may not be as anomalous as you present them; that of those remaining, many are dubious records whose location is only sketchily known; that while these may be worthy of investigation, they are likely each to have interesting but unique - and essentially trivial - explanations; and that even if they did not, they would not form a heavy enough counterweight to the overwhelming evidence that exists in favour of the existence of subduction.

In short, the Board did not feel that subduction falls into the category of 'oppressive theoretical models refusing to collapse under the weight of contrary evidence by virtue of power exerted through the corruption of peer review', a charge levelled previously with some justice at such questions as the existence of mantle plumes and the connection between the Chicxulub crater and the end Cretaceous impactor. Therefore we have decided not to publish. J. McCall (a senior editor) will write to you."

I would point out that my essay mentioned only in passing that I had previously pointed to a significant and substantial body of evidence that disproves subduction; the main purpose of the essay was to bring reader's attention to the evidence from rocks from the ocean floors that falsifies the sea-floor spreading hypothesis. This point was never addressed in any of the correspondence that I received from *Geoscientist*. Readers can

draw their own conclusions from the remainder of the comments quoted above, in particular the implication that those who have carried out extensive deep sea drilling and dredging are only vaguely aware of the location of their vessels and are clearly unable to identify and accurately date rock samples so obtained. The third paragraph requires no comment from me. In April 2012 I wrote a 14 page personal letter to J. McCall giving many more details and references concerning the overwhelming evidence that disproves sea-floor spreading: I have received no reply, nor do I expect one. I have never been given any of the "overwhelming evidence in favour of the existence of subduction" or any references to it which seems rather strange when dealing with a supposed scientific magazine, or am I missing something?

In the October issue of *Geoscientist* a short article by W. Jacoby was published about A. Wegener and his ideas. His concluding sentence read "...we must take Wegener as the true 'Newton of continental drift' - the man who made mobilists of us all." I wrote a short letter to the editor challenging this assertion:

"Prof. W. Jakoby's interesting and informative article on Wegener (*Geoscientist* October 2012) had a serious flaw. Not all of us are mobilists: to my certain knowledge there is a significant minority of our society membership who are not. Added to that most Russian and Japanese geologists are not, and a significant number of practising and non-practising geologists in Australia, New Zealand and the rest of the world do not support the idea either. The reasons are simple: there is a substantial (some would say overwhelming) body of geological and geophysical evidence which has been published over the past 60 years that disproves both sea floor spreading and subduction, although little of this has ever appeared in the pages of *Geoscientist* or the *Journal of the Society*. Consequently there is and has been a lively, highly informed and successful debate concerning the history of this planet, and creating models for the accurate long term prediction of earthquakes and volcanic eruptions, location of metaliferous ore bodies, oil and gas reserves and much else of geological importance in which mobilism has taken no part because there is no need for that hypothesis. Wegener was a truly remarkable scientist who made important contributions to knowledge and some less important ones to geology - please can we remember him for that."

After 4 days my e-mail was returned because the queue time had expired, i.e. *Geoscientist* has now blocked my electronic correspondence with them. Am I being paranoid if I suspect that the corruption of peer review is being used to block contrary opinions and evidence which refute the current dogma, in spite of the website claiming that "strong opinions are welcome"? Can anyone tell me why I should no longer regard the Geological Society of London as being any different from its origin: a very expensive London dining club with a rather good library attached?

Yours very sincerely

Stephen Foster

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ANNOUNCEMENT

The NCGT editorial board has decided that the current *NCGT Newsletter* will become *NCGT Journal* from the next issue, March 2013. This is a more appropriate name considering the present status of the *Newsletter* in the world geoscience communities and the future activities of the NCGT group.

ARTICLES

SOLAR ACTIVITY LINKED TO HIGH-MAGNITUDE EARTHQUAKES

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Abstract: This report investigates whether strong solar activity has the potential to trigger high-magnitude earthquakes, following recent observations. Magnetometer data from GOES (Geostationary Operational Environmental Satellite/s) - for 2001 to 2011 were assessed against 7.0-plus magnitude earthquakes worldwide. Results showed these earthquakes clustered towards strong solar activity. The statistical correlation was then validated against a hypothesis, that fault lines were fed increased electrical energy in a similar way to geomagnetic-induced current. Ground-based data from HAARP the High frequency Active Auroral Research Program based in Gokona, Alaska, backed up this hypothesis along with present understanding of ground telluric currents. Similar studies investigated also showed a possible similar process by which large increases in ground current and magnetic fields preceded earthquakes, suggesting a positive statistical correlation between strong solar activity and the triggering of high-magnitude earthquakes.

Keywords: *Solar, earthquakes, geomagnetic-induced current, GOES, magnetometer*

Introduction

During regular solar activity observations, it was noted that prior to many high-magnitude earthquakes there is strong solar activity. Just prior to the Japan mega earthquake of 9.0 magnitude in March 2011 there were several strong solar flares for example. Strong solar activity versus earthquake activity was initially considered a coincidence but warranted further investigation to confirm or rule this out.

A hypothesis was put forward that fault lines were fed increased electrical energy in a similar way to geomagnetic-induced current. The hypothesis is tested using a ground based magnetometer and present understanding of ground currents and magnetic field changes prior to high-magnitude earthquakes. Given the observed possible link between strong solar activity and earthquakes and the widespread alternative belief to the standard paradigm that solar activity has an influence on earthquakes the aim of this research was to investigate whether high solar activity has the potential to trigger high-magnitude earthquakes. If a link does exist this may add to the ability for earthquakes to be predicted with accuracy in the future by increasing our understanding of trigger mechanisms.

Measuring solar activity

Geomagnetic activity is often observed on Earth after strong solar events such as coronal holes, flares and magnetic filament eruptions occur. Strong solar events often send charged particles towards Earth via the Sun's wind stream. Solar activity is measured and observed by several satellites and observatories to assess risk to satellites and global communications as strong solar activity can damage instruments. On rare occasions power outages can occur at ground level from geomagnetic-induced currents which damage transformers and other equipment (Marusek, 2007).

One parameter for measuring incoming solar activity is the magnetometer data from GOES. Magnetometer data is produced by two satellites. There have been several GOES over the years but at present these are GOES 13 and 15. These satellites maintain geosynchronous orbits. The word "geosynchronous" comes from the Greek *geo*, meaning "Earth" and *syn chromos*, meaning "at the same time", so geosynchronous orbits more or less keep the satellites parked at the same distance from Earth and rotating around set longitudes.

The satellites measure Earth's magnetic field at their respective orbits. Earth's magnetic field is contained within a "bubble" known as the *magnetosphere*. In basic terms, changes in solar activity caused by solar wind streams containing charged particles from strong solar events, push or extend the magnetosphere below or outward from a GOES orbit. The solar wind pushes and compresses the magnetosphere bubble, lowering the magnetic field with respect to the satellite's orbit. Charged particles eventually break through and fill the magnetosphere bubble which then extends away from the satellite's orbit. The level of compression or extension is an indicator of solar activity strength. Changes in magnetic field levels are measured in one-minute averaged intervals throughout the day, producing a time (Universal Time, UTC) versus magnetic field change with respect to the satellite's orbit (Russell and McPherron, 1973; Lakhina et al., 2006).

Method of correlation analysis

Magnetometer data from GOES provides a tidy way to assess whether there is a correlation between strong solar activity and high-magnitude earthquakes due to the time line of the magnetic field strength data produced.

Magnetic field strength is measured in nanoteslas (nT). A baseline was set at 50 nT or very close to 50 nT and greater for the change in magnetic field strength: both downwards (below satellite's orbit), a dip on the graph; and upwards (extending outwards from satellite orbit), a spike on the graph. The 50 nT up and down variation indicates reasonably strong solar activity and sets a baseline for easier assessment.

The quiet-day curve has a sine wave curve appearance with the middle of the graph around 100 nT (**Fig. 1**). An upward spike or expansion of the magnetosphere bubble of 50 nT or greater will push the graph reading to 150 nT or greater. A downward spike or compression of 50 nT or greater will push the graph down to 50 nT or less (**Fig. 2**).

The solar cycle is around 11 years in duration and includes a maximum of high solar activity and minimum of low solar activity. Solar maximum will therefore produce more variations away from the sine curve appearance on GOES magnetometer graph plots over time compared to solar minimum. To get a true indication of whether strong solar activity triggers high-magnitude earthquakes an 11-year period covering both solar minimum and maximum is therefore included in the analysis for GOES magnetosphere data from 2001 to 2011.

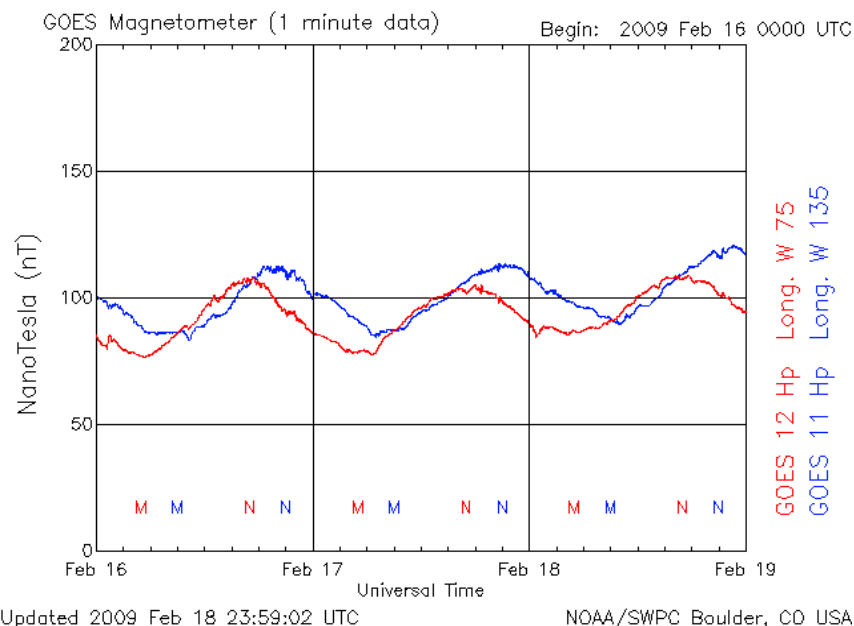
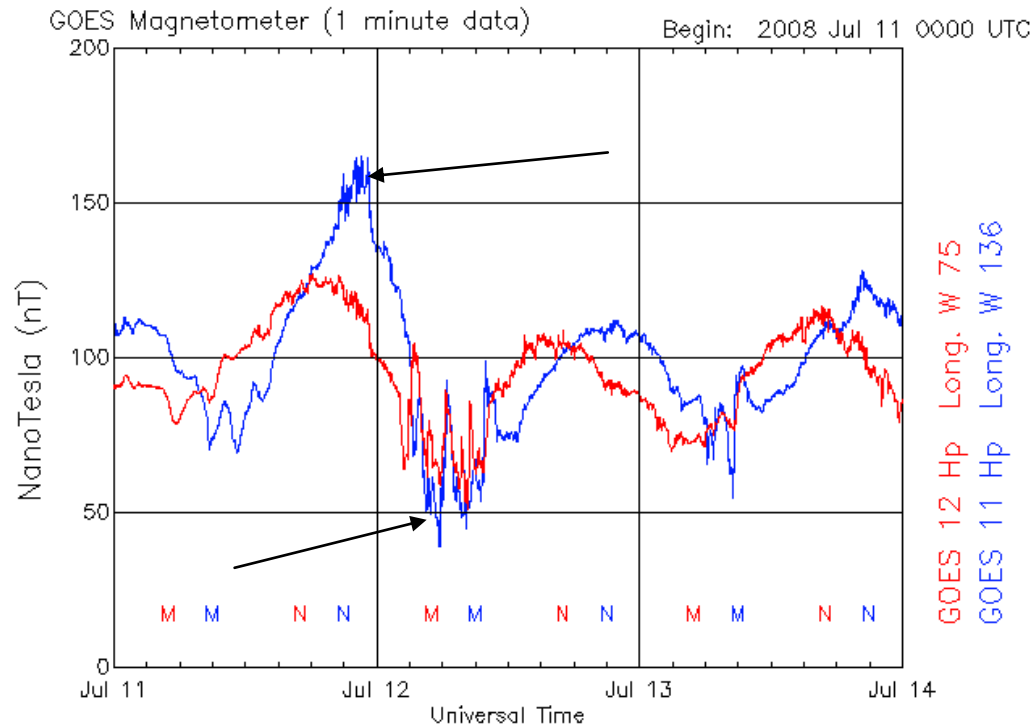


Fig. 1. GOES magnetometer graph showing quiet day curve. M- Midnight on Earth under satellite, N- Noon on Earth under satellite. (National Oceanic and Atmosphere Administration Space Weather Prediction Centre, 2009).



Updated 2008 Jul 13 23:59:04 UTC

NOAA/SWPC Boulder, CO USA

Fig. 2. GOES magnetometer graph showing magnetic variations during strong solar activity. (National Oceanic and Atmosphere Administration Space Weather Prediction Centre, 2008).

The United States Geological Survey (USGS) database was used where required or its more recent data files for worldwide earthquakes of 7.0-plus magnitude from 2001 to 2011. The database can be set up to list the required year and magnitude with earthquakes in Universal time (UTC).

Earthquakes of 7.0-plus magnitude (173 in total) were assessed initially to reduce the quantity of data required and were plotted against the magnetic variations from GOES, followed by 6.0-plus magnitude earthquakes as an extended investigation for 2009 and 2011.

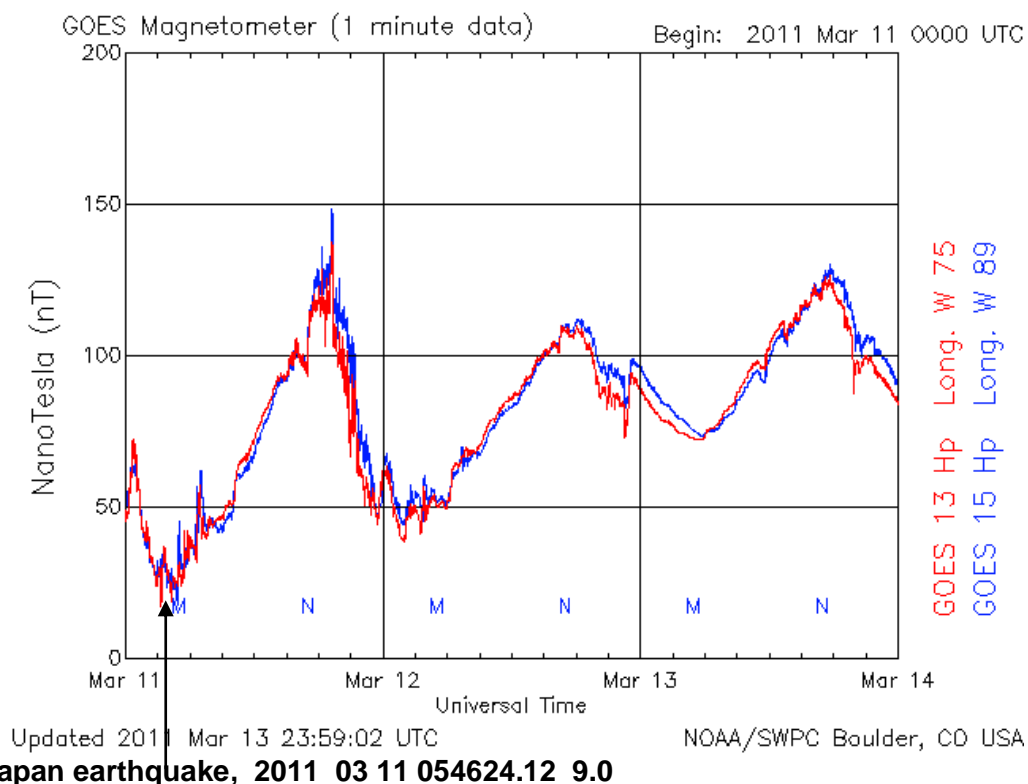
Results of Analysis

It was found that earthquakes occurred on the same day of the magnetic variation, either during the variation on that day (**Fig. 3**) or after the variation on that day (**Fig. 4**) and up to 9 days after the magnetic variation.

The majority of 7.0-plus magnitude earthquakes (41.6%) occurred on the same day as the magnetic variation followed by the day after (24.8%). On day two onwards, percentages tailed off (**Fig. 5**).

Similar results were obtained with 6.0-plus magnitude earthquakes for 2009 and 2011: 31.4% occurred on the same day of the magnetic variation and 15.8% the day after. On day two the percentage was 14.3%; day three, 13.8%; day four, 7.6%; and reducing here after.

During the complete solar cycle assessment of 7.0- plus magnitude earthquakes the percentages of earthquakes occurring on the same day and the day after increased as each year was added. This would most likely be the trend for the 6.0-plus magnitude earthquakes if assessment continued, as after adding 2011 percentages to 2009 the total percentages of earthquakes occurring on day of magnetic variation and the day after increased.



Japan earthquake, 2011 03 11 054624.12 9.0

Fig. 3. GOES magnetometer graph with earthquake of 9.0 magnitude during magnetic variation. Earthquake occurred on March 11th 2011 at 05:46 UTC. (National Earthquake Information Centre United States Geological Survey, 2011). (National Oceanic and Atmosphere Administration Space Weather Prediction Centre, 2011).

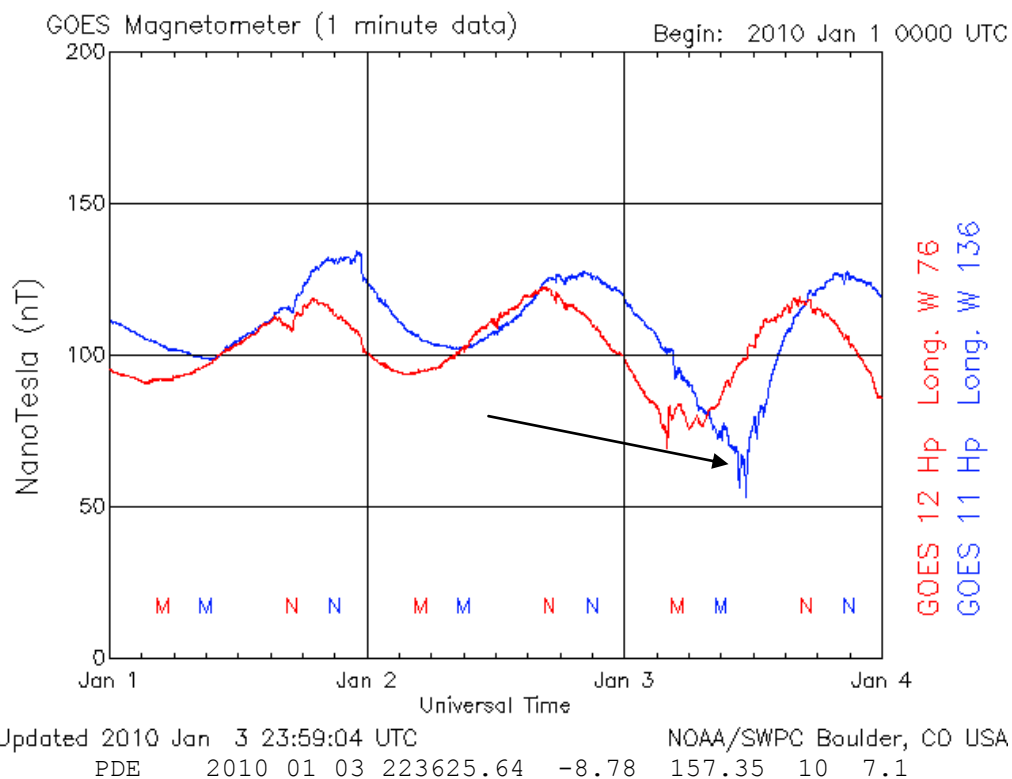


Fig. 4. GOES magnetometer graph with earthquake of 7.1 magnitude occurring after magnetic variation and on same day. Earthquake occurred on January 3rd 2010 at 22:36 UTC. (National Earthquake Information Centre United States Geological Survey, 2010). (National Oceanic and Atmosphere Administration Space Weather Prediction Centre, 2010).

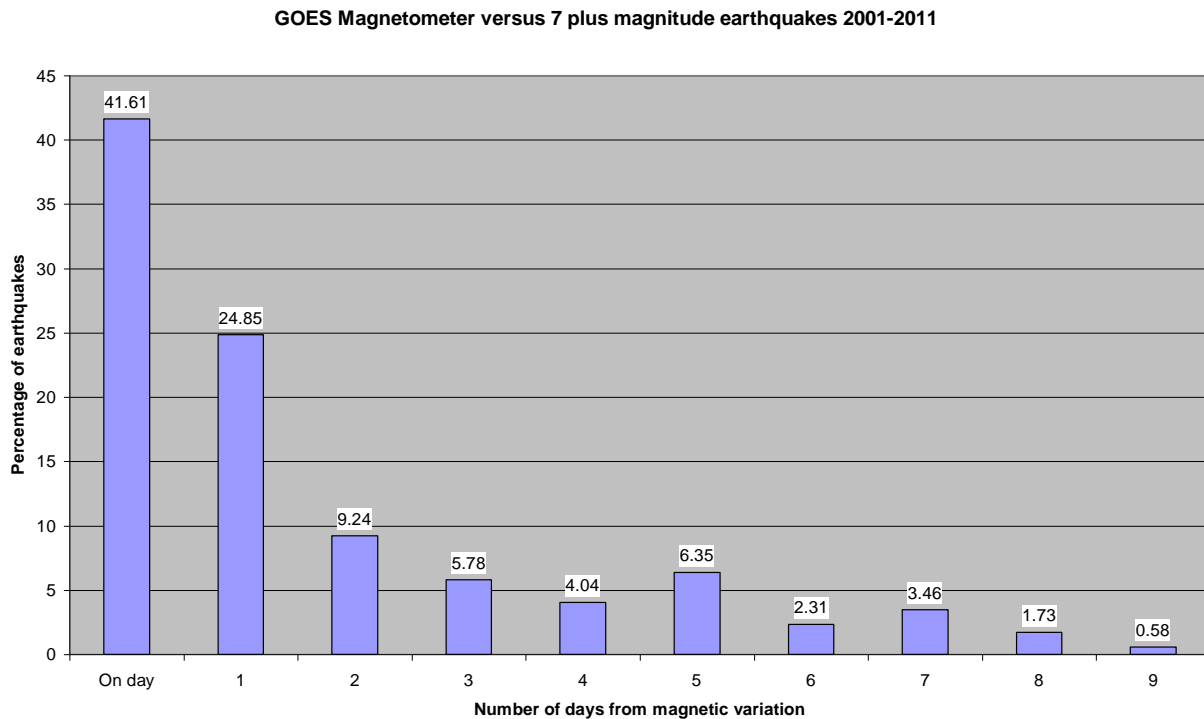


Fig. 5. Percentages of 7.0-plus magnitude earthquakes during and following GOES magnetic variations for 2001-2011.

Discussion on induced current

To validate these results and rule out a statistical coincidence there needs to be a mechanism to create this pattern and evidence that this process works. Validation may include any other studies carried out that possibly indicate solar activity or magnetic variations playing a part in earthquake triggering.

An hypothesis on the cause of the clustering of earthquakes following the magnetic variations of 50 nT or greater is similar to the process of geomagnetic-induced current produced from very strong solar activity that cause power outages.

During very strong solar activity a ring current is produced around the Earth, caused by the charged particles trapped in the magnetic field. Ring current is known to interfere with the Earth's ground-level magnetic field, reducing it; this can be detected with ground based-magnetometers. If the ring current is strong enough, it will cause swift and large variations / movements in the Earth's magnetic field. The Earth's magnetic field will then bounce back. Any conducting material within this movement will therefore have the potential to gain an increase in voltage, called *geomagnetic-induced current*. Power outages can then occur from damage to transformers and other equipment. Geomagnetic-induced current has also been known to occur within pipelines underground (Marusek, 2007).

On a large scale, a fault line is potentially a large conductor, containing water and conducting compounds such as metals and quartz within the rocks. Any fluctuation of reasonable size (less than the fluctuations required to cause power outages) in theory could be enough to increase ground currents and therefore energy into a fault line. A smaller variation than what occurs during power outages may be required due to increased size of the conductor in this case the fault line. Any pending earthquakes may then be brought forward a few days or so, resulting in a cluster of earthquakes following GOES magnetic variations.

Validation assessment with HAARP data.

A further assessment was then carried out to determine if GOES magnetometer variations of 50 nT or greater were enough to cause a dip in the Earth's magnetic field at ground level. A dip at ground level would occur beneath the forming or developed ring current as it rotates around the globe, potentially adding energy to fault lines.

Magnetic variation at ground level should occur either immediately after GOES magnetic variations or a few hours later depending on the rotation of the ring current and prior to the earthquake (**Figs. 6 and 7**).

The High frequency Active Auroral Research Program (HAARP) was selected due to ease of access to data which includes an archive with graphs from the ground-based fluxgate magnetometer also in UTC. Earthquakes close to HAARP in Alaska were examined. Earthquakes examined were therefore from the northern hemisphere with longitudes between 100 degrees west, across the Pacific Ocean to 130 degrees east which included Japan. Within this category, earthquakes that occurred up to three days after a GOES magnetic variation were chosen, as these earthquakes are the ones most likely induced by extra electrical current. Readings were taken from the Z component (the blue trace on the graph) as this shows a vertical change in the magnetic field (**Fig. 7**).

Ground-based magnetic variations compared well with GOES magnetic variations with respect to size of variation and duration indicating that both sets of variations were related and therefore most likely influenced by solar activity and not any other factor. Previous days of GOES magnetic variations were also often seen on ground-based HAARP magnetic variations.

Of the 35 earthquakes examined within the latitude-longitude and time frame after GOES magnetic variations, all earthquakes had a ground-based dip after the GOES magnetic variations and prior to the earthquakes.

One set of GOES magnetometer graph data needed to be reassessed because ground-based magnetic variation occurred at HARRP two days prior to an earthquake in Japan instead of on the same day, as with the initial GOES magnetic variation assessed. It was found that solar activity had been strong for two days earlier as well with the first day of strong solar activity producing a ground-based dip at HARRP only, prior to the earthquake. This indicated that the initial GOES magnetic variation (before validation) had not created a ring current above the earthquake epicentre prior to the earthquake, but only the first day of solar activity. The size and duration of the reassessed GOES verse HARRP for this earthquake compared well with size and duration and therefore this was a possible triggered earthquake. The change in statistics was insignificant with the earthquakes occurring "on day two" after the magnetic variation rising slightly and "on the day" reducing slightly. Therefore the majority of earthquakes were still clustered towards strong solar activity. Due to the large percentage of earthquakes occurring during or shortly after high solar activity there is significant room in the statistical results for this occurrence.

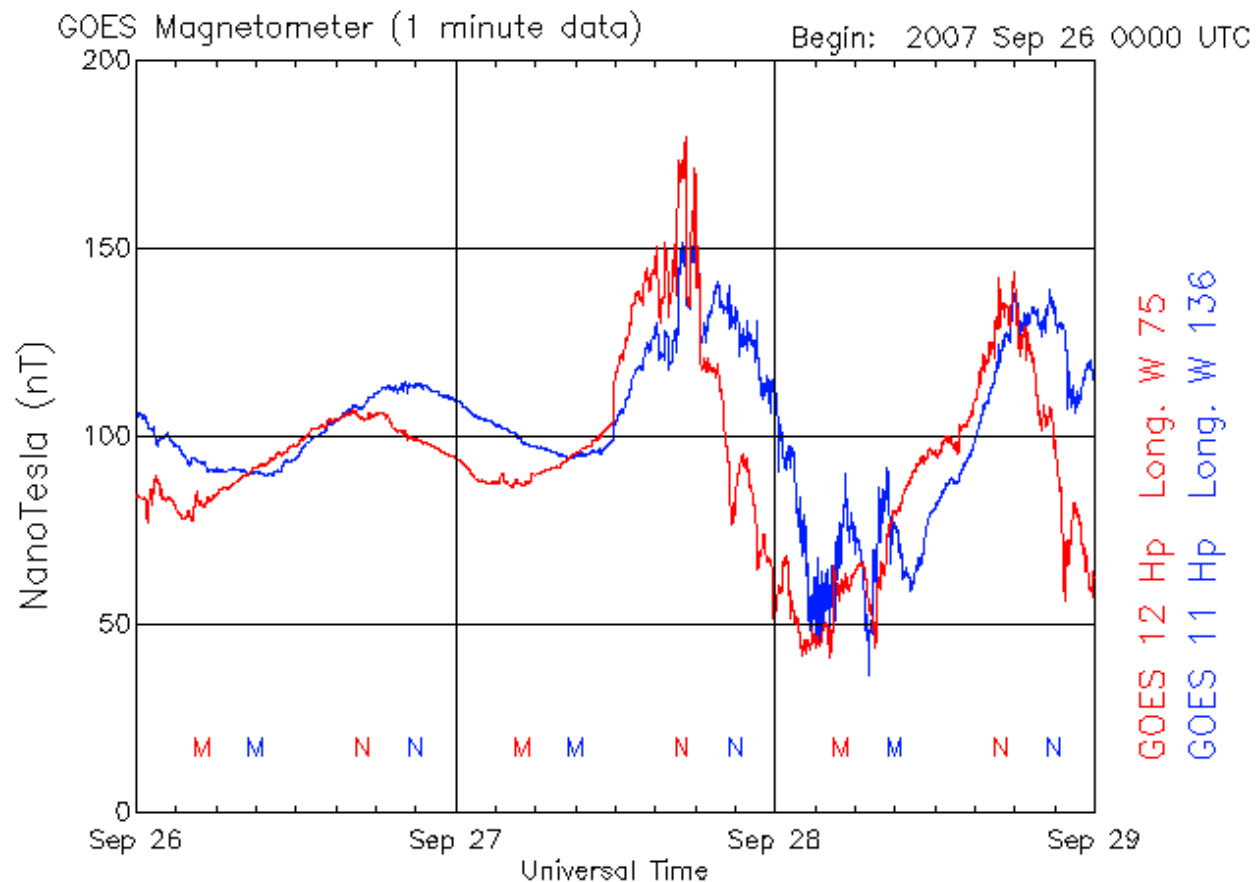


Fig. 6. GOES magnetometer graph with magnetic variation prior to HAARP magnetic variation. (National Oceanic and Atmosphere Administration Space Weather Prediction Centre, 2007).

Present Understanding of Ground Currents

There are known telluric currents that are generated constantly in the Earth's outer layers (lithosphere and mantle) from the Earth's internal magnetic field (magnetic dynamo) and ionosphere via electromagnetic induction. Regular solar activity ionises particles in the ionosphere, creating electric currents within the ionosphere. Electromagnetic induction from the ionosphere currents produces a diurnal fluctuation in the Earth's internal magnetic field (a GOES graph sine wave curve appearance) (Yazdi and Elam, n.d.).

Telluric currents are stronger the deeper into the Earth they go, as temperature increases conductivity, but this is not uniform due to other factors. The potential depth and strength of the telluric currents will therefore cover all fault lines capable of a significant earthquake. Many minerals in the Earth's crust are abundant in a fault lines and have piezoelectric properties (e.g., quartz). When stress is applied- for example by means of a charge (current), physical stress or heat- an electrical current is generated (Chavalier, 2007; Wood, 1986).

Telluric currents are large-scale and strong currents which are easily measured. Magnetotellurics, for example, uses telluric currents to image the Earth's subsurface for mining, because minerals have different electrical conductivities with depths ranging from 300 metres to more than 10,000 metres. Rapid changes in the ionosphere currents (often caused by strong solar activity) can disturb these geophysical surveys due to increased voltage into the Earth's crust (Chavalier, 2007; Duma, n.d.; Wikipedia, n.d.). Changes in the internal magnetic field are the main inducing mechanism and the sun is therefore the main driver for this process and thus telluric current in the Earth's crust (Yazdi and Elam, n.d.).

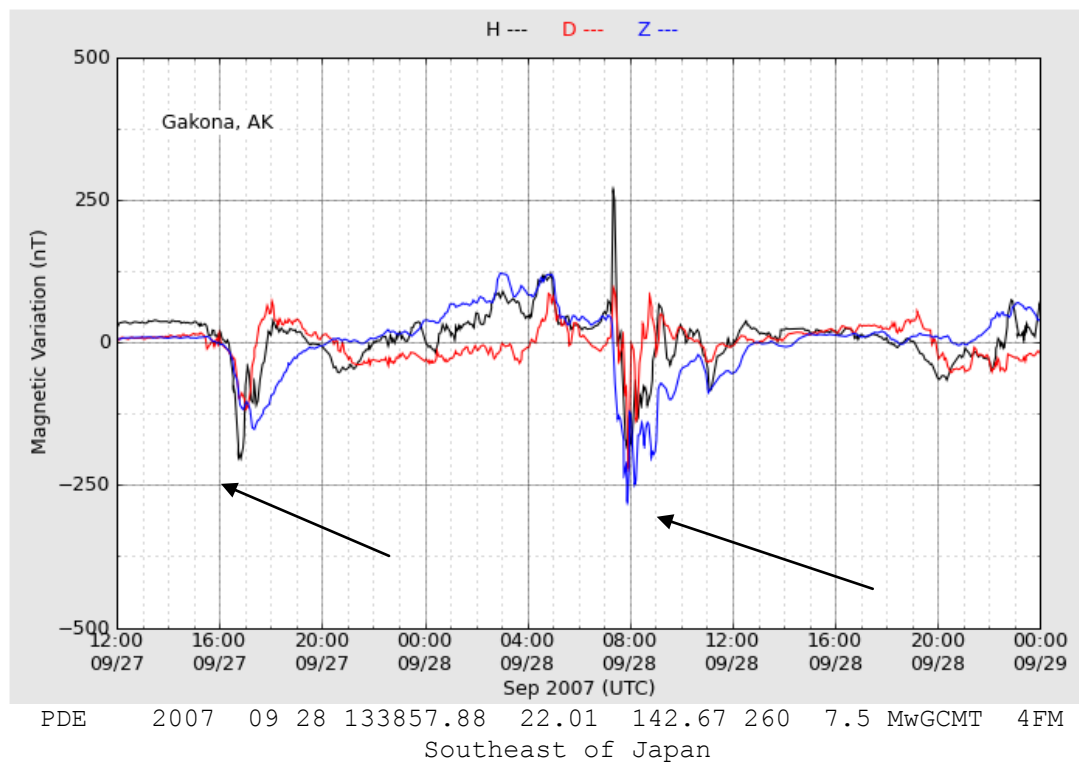


Fig. 7. HAARP magnetic variations preceding earthquake of 7.5 magnitude South East of Japan. (National Earthquake Information Centre United States Geological Survey, 2007). (The High Frequency Active Auroral Research Program, 2007).

Earthquakes vs magnetic field and current changes.

Many researches have monitored large changes in magnetic field and electrical current several hours prior to high-magnitude earthquakes, even some distance away and as a result they have monitoring systems, such as the Parkfield-Hollister Electromagnetic Monitoring Array in California, to measure any patterns in changes. The mechanism for these changes is not understood, but it could well be initiated by strong solar activity (Boyd and Morrison, n.d; Wood, 1986).

A study done by the Central Institute for Meteorology and Geodynamics in Vienna, Austria, has shown that regular daily solar (via diurnal effect from ionosphere), seasonal and long-term variations of increased magnetic field intensity correspond to an increase in earthquake numbers. Referred to as the *magneto-seismic effect* (Duma, n.d). Results of this study indicate a similar process of induced current, whereby the increase in magnetic field could be increasing telluric current into fault lines. Generation of electricity is the same: one way to increase the current strength is to increase the magnetic field strength by adding a stronger magnet to a generator (Duma, n.d).

A study in California examined Pc1 pulsations (“Pc” meaning “pulsation continuous” as opposed to “irregular”) which are a continuous magnetic pulsations ranging from 0.2 to 0.5 Hertz, usually lasting minutes to hours within the ionosphere and increasing two to seven days after geomagnetic storms at low latitudes. The research showed there was a three to five times higher likelihood that an earthquake would occur in the first week following Pc1 pulsations with increases in numbers of Pc1 occurrence increasing the odds, not just an observation of one Pc1 (Bortnik et al., 2008).

There are a couple of hypotheses on the cause of Pc1 changes in the ionosphere with one suggesting that if the positive statistical correlation with earthquakes is correct then they could be generated within the Earth due to electric currents (Bortnik et al., 2008). If Pc1 pulsations are generated by electric currents then an

earthquake would only occur if electric current was within a fault line and pulsation was over an epicentre, hence that earthquakes do not always occur.

Conclusions

The research carried out suggests a positive statistical correlation exists between strong solar activity and high-magnitude earthquakes, using GOES magnetometer magnetic field variation data. Variations in the HAARP ground-based magnetometer data confirmed the given hypothesis of possible ground current being induced into fault lines.

The present understanding of ground currents and other research on magnetic field variations and ground current increases prior to high-magnitude earthquakes, adds weight to the hypothesis of current induced into fault lines and therefore to the possible link between strong solar activity and triggering of high-magnitude earthquakes.

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9/56 YEAR CYCLE: 18th & 19th CENTURY WORLD EARTHQUAKES

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Abstract: A 9/56 year cycle had been established in the timing of earthquakes in various countries and regions. In this paper, the cycle was assessed in the timing of major 18th and 19th century world earthquakes. Remarkably, most 1765–1885 seismic events ($M \Rightarrow 7.9$) took place in one half of the complete 9/56 year grid, a finding that was repeatable for two listings of major earthquakes. Since 1900, world mega quakes ($M \Rightarrow 8.5$) also occurred preferentially in 54/56 year grids, something that was considered in relation to earlier centuries. Such studies were important in appraising long term trends in seismic cycles. Earthquake fatalities, both worldwide and in the USA, were also reviewed in relation to the 9/56 year cycle.

Keywords: 9/56 year cycle, 18th century, 19th century, world earthquakes, fatalities.

Introduction

The timing of 18th and 19th century world earthquakes was assessed in relation to the 9/56 year seismic cycle. Three reference sources were used in the assessment – Wikipedia, Fujita and the US Geological Survey (USGS). Any catalog over very long time frames was biased towards the more recent years. The further one goes back in time the more questionable the various listings become in terms of both accuracy and comprehensiveness. In particular, estimated magnitudes varied considerably according to reference source. Information on historical Alaskan mega quakes was also virtually nonexistent before 1890 and thus there was a critical gap in the available raw data. Despite such obvious limitations, the three sources were still selected because they were the best available. Additionally, the database of the National Geophysical Data Center (NGDC) provided another important reference on pre 1900 earthquakes.

Most major earthquakes ($M \Rightarrow 7.9$) occurring in the 1765–1885 period fell in 50% of the complete 9/56 year cycle (see **Table 1**), something that applied very well for listings from Wikipedia – Fujita – USGS, as well as the NGDC. The very high significance and the repeatability of the finding should counter the unreliability of the early data. Furthermore, 54/56 year grids were established for post 1900 mega quakes (McMinn, 2011b, 2012b), which may, in part, be extrapolated back into earlier centuries.

The 9/56 year cycle was fundamental in the timing of earthquakes (McMinn, 2011a, 2011b, 2011c) and consisted of a grid with intervals of 9 years on the horizontal (called sub-cycles) and intervals of 56 years on the vertical (called sequences). The 56 year sequences have been numbered in accordance with [McMinn \(Appendix 2, 2002\)](#), with Sequence 01 being designated as 1817, 1873, 1929, 1985, Sequence 02 as 1818, 1874, 1930, 1986 and so forth. The year of best fit was applied in the various tables presented in the paper. Earthquakes that occurred within a few days of each other and in the same country/region were treated as one event (eg: the December 1811 New Madrid quakes, the April 1819 Chilean quakes and the December 1854 Japanese quakes).

18th & 19th Century Earthquakes

Wikipedia listed some 31 major quakes ($M \Rightarrow 7.9$) for the 1700 to 1899 epoch (see **Appendix 1**). This listing was expanded to include other early earthquakes presented in catalogs by Fujita and the [USGS](#) (see **Appendix 2**). The three sources gave a total of 42 major events between 1700 and 1900, of which 33 showed up in 50% of the complete 9/56 year cycle (see **Table 1**) (significant $p < .01$). Significance could be boosted hugely by considering the 1765-1885 era, when 24 earthquakes appeared in **Table 1** WITH NO EXCEPTIONS (significant $p < 10^{-6}$). Relatively few pre 1900 major quakes happened in the other half of the complete 9/56 year grid (see **Appendix 3**).

There was a propensity for major 1765-1885 earthquakes to take place within 50% of the complete 9/56 year cycle. This strong patterning did not continue into the 20th century for whatever reason.

Table 1 9/56 YEAR CYCLE: MAJOR WORLD EARTHQUAKES ($M \Rightarrow 7.9$) 1700–1899 Wikipedia, Fujita and USGS Year ending September 30													
Sq 18	Sq 27	Sq 36	Sq 45	Sq 54	Sq 07	Sq 16	Sq 25	Sq 34	Sq 43	Sq 52	Sq 05	Sq 14	Sq 23
										1700 0126	1709	1718	1727
				1702	1711	1720	1729	1738 1737 1017	1747 1746 1023	1756 1755 1101	1765	1774	1783
1722	1731	1740	1749	1758	1767 1766 1021	1776	1785	1794	1803 1802 1026	1812 0207 1811 1216	1821 0710	1830	1839
1778	1787	1796	1805	1814	1823 1822 1119	1832	1841	1850	1859	1868 0403 1868 0813	1877	1886	1895
1834 1833 1125	1843	1852	1861 0216	1870	1879	1888	1897 0612 1897 0921						
1890	1899 0904 1899 0910												
Continued.....													
Sq 32	Sq 41	Sq 50	Sq 03	Sq 12	Sq 21	Sq 30	Sq 39	Sq 48	Sq 01	Sq 10	Sq 19	Sq 28	Sq 37
									1705	1714	1723	1732	1741
			1707	1716	1725 0203	1734	1743	1752	1761	1770	1779	1788	1797 0204 1797 0210
1736	1745	1754	1763	1772	1781	1790	1799	1808	1817	1826	1835 0202	1844	1853
1792 0822	1801	1810	1819 0616	1828	1837	1846	1855 0125 1854 1223 1854 1224	1864	1873	1882 1881 1231	1891	1900	
1848	1857	1866	1875	1884	1893								

	0109											
Events in red appeared in the Wikipedia listing. Events in blue did not appear in the Wikipedia listing, but were listed by the USGS and/or Fujita. Sources of Raw Data: Wikipedia, Fujita and USGS .												

54/56 year and 9-45/56 year grids correlated with the timing of post 1900 world mega quakes based on the listing by Fujita (McMinn, 2011b, 2012b). These 54/56 year grids were hypothesized to endure through the 18th and 19th centuries. In **Table 2**, Grid A contained 14 major pre 1900 events as listed in **Appendix 2**, compared with an expected 5.3 (significant $p < .001$). In contrast, only three early events showed up in Grid B something that could have happened by chance. Strangely, pre 1900 events appeared preferentially in Grid A, but not in Grid B.

Table 2 54/56 YEAR CYCLE: WORLD EARTHQUAKES 1700 TO 2012 1900-2012 Quakes M => 8.5 - Year ending October 30 1700-1899 Quakes M => 6.9 - Year ending November 25						
Grid A						
Sq 29	Sq 27	Sq 25	Sq 23	Sq 21	Sq 19	Sq 17
						1721
					1723	1777
				1725 0201	1779	1833 1125
			1727 1118	1781	1835 0220	1889 0711
		1729	1783	1837	1891 0227	1945
	1731	1785	1839	1893	1947	2001
1733	1787 0502	1841 0517	1895	1949	2003	
1789	1843 0208 1843 0425	1897 0612 1897 0921	1951	2005 0328 2004 1226		
1845	1899 0904 1899 0910	1953 1952 1103	2007 0921			
1901	1955	2009				
1957 0309	2011 0311					
2013						
Grid B						
Sq 36	Sq 34	Sq 32	Sq 30	Sq 28	Sq 26	Sq 24
						1728
					1730 0708	1784
				1732	1786	1840
			1734	1788 (a)	1842	1896 0615

		1736	1790	1844	1898	1952
	1738	1792 0822	1846	1900	1954	2008
1740	1794	1848	1902	1956	2010 0227	
1796	1850	1904	1958	2012 0411		
1852	1906 0131 1906 0820	1960 0522	2014			
1908	1962	2016				
1964 0328	2018					

Pre 1900 events in **red** appeared in the Wikipedia Fujita USGS listing in **Appendix 2**.
Post 1900 events in **blue** appeared in Fujita's catalog (M => 8.5).
In Grid A, Sqs 21, 23, 25, 27, 29 showed up in the 54/56 year grids for world mega quakes in Appendix 4, McMinn (2012b).
In Grid B, Sqs 28, 30, 32, 34, 36 fell in the 54/56 year grids for world mega quakes in Appendix 4, McMinn (2012b).
(a) Major Alaskan earthquakes (M 8.0) occurred on July 21 and August 6.
Sources of Raw Data: Wikipedia, Fujita and [USGS](#).

An 18/56 year cycle appeared in the timing of early earthquakes. Of the 42 earthquakes listed for 1700-1899 in **Appendix 2**, 19 showed up in the 18/56 year layout presented in **Appendix 4** (significant $p < .01$).

The extreme significance was achieved for the 1765–1885 era, based on catalogs by Wikipedia, Fujita and the USGS. The NGDC was sourced to produce another listing of 50 earthquakes between 1765 and 1885 (see **Appendix 5**). Very high significance could again be realized. Some 39 earthquakes appeared in the same one half of the complete 9/56 year cycle as shown in **Table 1** (significant $p < 10^{-6}$) (see **Appendix 6**).

Earthquake Fatalities

The [USGS](#) listed 11 US earthquakes (ex Alaska) causing 30 or more deaths (see **Appendix 7**), of which 9 fell between Sequences 34 to 32 (see **Table 3**). This represented about 13% of the complete 9/56 year grid, yet it accounted for 81% of the events causing 30 or more deaths. The anomalies were the 1946 Alaskan tsunami that killed 165 people in Hawaii and the 1994 Northridge event. The link was notable despite the small sample. This pattern of US fatalities arises in part from the propensity for large Californian earthquakes (M => 6.9) to take place in Sequences 34, 43, 52 and 05 (eg: 1812, 1868 (Oct 21), 1906, 1989) (McMinn, 2011a).

Table 3 EARTHQUAKES CAUSING OVER 30 FATALITIES IN THE USA (a) Calendar Years						
Sq 34	Sq 43	Sq 52	Sq 05	Sq 14	Sq 23	Sq 32
	1803	1812 1208	1821	1830	1839	1848
1850	1859	1868 0403 1868 1021	1877	1886 0901	1895	1904
1906 0418	1915	1924	1933 0311	1942	1951	1960 0527

Discussion & Conclusions

Scientific findings can only ever be as good as the raw data upon which they were based. Unfortunately, listings of 18th and 19th century world earthquakes were incomplete and prone to inaccuracies. To help overcome such limitations, three reference sources were considered – Wikipedia, Fujita and [USGS](#). Only 9 earthquakes showed up in each of the three listings, which raised suspicions that none of the compilations were very comprehensive. Between 1765 and 1885, all 24 events ($M \geq 7.9$) listed by Wikipedia, Fujita and the [USGS](#) occurred in one half of the complete 9/56 year cycle (significant $p < 10^{-6}$). For the same era, the NGDC database yielded some 50 major earthquakes ($M \geq 7.9$), of which 39 appeared in the identical pattern (significant $p < 10^{-6}$). The correlates were extremely significant, which countered the poor quality of the early seismic data. The strong emphasis on one half of the complete 9/56 year cycle was applicable for the 1765 to 1885 era only, as it did not persist into the 20th century.

54/56 year grids could be firmly established in the timing of 20th century world mega quakes ($M \geq 8.7$) (McMinn, 2011b, 2012b). Grid A in **Table 2** could be extrapolated back into the 18th and 19th centuries with significance, but Grid B contained few early earthquakes. Such 54/56 year grids were important in patterns of major world quakes over the past three centuries.

McMinn (2011b) commented on Sequence 52, which experienced three early great quakes affecting Cascadia (M 9.0 Jan 26, 1700), Lisbon (M 8.7 Nov 1, 1755) and Arica (M 9.0 Aug 26, 1868). Other pre 1900 mega events ($M \geq 8.7$) took place in 1727, 1730, 1762, and 1833 (see **Appendix 2**).

Sq 52	Event	Record
1700	Great Cascadia quake M 9.0. Jan 26, 1700	Record for western USA (ex Alaska).
1756	Great Lisbon quake M 8.7. Nov 01, 1755 Katla volcano VEI 5 Oct 17, 1755	Record for Western Europe. Equal 1 st rank eruption for Iceland
1812	New Madrid quakes	Records for eastern USA.
1868	Great Arica quake M 9.0 Aug 13, 1868	19 th century record for South America.
1924	Tokyo quake M 8.7. Sep 01, 1923	3 rd rank Japanese quake for the 20 th century.
1980	Mt St Helens volcano VEI 5. May 22, 1980.	Record US eruption (ex Alaska).

Major earthquakes tended to fall in 9/56 year patterns and thus episodes with high death rates should also show up in these layouts. It is a topic that needs further investigation before any conclusions can be drawn. Two examples based on USGS data have been presented in this paper, but more research was necessary.

The 9/56 year seismic cycle was believed to arise from Moon Sun tidal harmonics, which triggered seismic activity. This topic has already been covered by McMinn (see Appendix 5, 2011a) and thus will not be discussed here. Assessing earthquake activity over the centuries was important, as it helped to understand how seismic cycles changed over very long time frames. Secular trends in Moon Sun cycles are hypothesized to activate long term trends in earthquake timing. Alas, nothing can be offered to support this speculation and it remained another great unknown.

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Appendix 1 PRE 1900 MAJOR WORLD EARTHQUAKES (M => 7.9) Wikipedia		
Date	Location	M
Jan 26, 1700	Cascadia	9.0
Dec 31, 1703	Kanto, Japan	8.2
Oct 28, 1707	Japan	8.6
Jul 08, 1730	Valparaiso, Chile	8.7
Oct 16, 1737	Kamchatka, Russia	8.3
Oct 28, 1746	Lima & Callao, Peru	8.6–8.8
May 25, 1751	Concepción, Chile	8.5
Nov 01, 1755	Lisbon, Portugal	8.7
Apr 02, 1762	Northeastern Bay of Bengal	up to 8.8
Oct 21, 1766	Saint Joseph, Trinidad and Tobago	7.9
Feb 10, 1797	Sumatra, Indonesia	8.4
Oct 26, 1802	Romania	7.9
Dec 16, 1811	New Madrid, USA	8.1
Feb 07, 1812	New Madrid, USA	8.0
Jun 16, 1819	Gujurat, India	7.7–8.2
Nov 19, 1822	Valparaiso, Chile	8.5
Nov 25, 1833	Sumatra, Indonesia	8.8–9.2
Feb 20, 1835	Concepcion, Chile	8.5
Dec 23 1854	Honshu, Japan	8.4
Dec 24 1854	Honshu, Japan	8.4
Jan 23, 1855	Wairarapa, New Zealand	8.0
Jan 09, 1857	Fort Tejon, California	7.9
Feb 16, 1861	Sumatra, Indonesia	8.5
Apr 03, 1868	Hawaii, USA	7.9
Aug 13, 1868	Arica, Chile	9.0
May 10, 1877	Iquique, Chile	8.8
Dec 31, 1881	Andaman & Nicobar Is, India	7.9
Oct 27, 1891	Mino-Owari, Japan	8.0
Jun 15, 1896	Offshore Sanriku, Japan	8.0–8.1
Jun 12, 1897	Assam, India	8.3
Sep 04, 1899	Alaska, USA	7.9
Sep 10, 1899	Alaska, USA	8.0
Events in red appeared in 9/56 year grid in Table 1 .		
Sources: Wikipedia. Historical Earthquakes. Wikipedia. Largest Earthquakes by Magnitude.		

Appendix 2 PRE 1900 WORLD EARTHQUAKES (M => 7.9) Wikipedia, Fujita & USGS					
Date UT	M	Location	Wiki	Fujita	USGS
18990910	8.0	Alaska, USA	Y		Y
18990904	7.9	Alaska, USA	Y		Y
18970921	8.0	Philippines		Y	
18970612	8.3	Assam, India	Y	Y	Y
18960615	8.5	Sanriku, Japan	Y	Y	Y
18911027	8.0	Mino-Owari, Japan	Y	Y	Y
18890711	8.3	Chilik, Kazakhstan		Y	
18811231	7.9	Andaman & Nicobar Is, India	Y		
18770510	8.3	Iquique, Chile	Y	Y	Y
18680813	9.0	Arica, Chile	Y	Y	Y
18680403	7.9	Hawaii, USA	Y		Y
18610216	8.5	Sumatra, Indonesia	Y		
18570109	7.9	Fort Tejon, California	Y		Y
18550123	8.0	Wellington, New Zealand	Y		Y
18541223	8.4	Honshu, Japan	Y	Y	
18541224	8.4	Honshu, Japan	Y	Y	
18430425	8.3	Kuriles		Y	
18430208	8.3	Leeward Is		Y	Y
18410517	8.4	Kamchatka		Y	
18350220	8.2	Concepcion, Chile	Y		Y
18331125	9.0	Sumatra, Indonesia	Y		
18221119	8.5	Valparaiso, Chile	Y		
18210710	8.2	Camana, Peru			Y
18190616	8.3	Gujarat India	Y	Y	Y
18120207	8.0	New Madrid, USA	Y		(a)
18111216	8.1	New Madrid, USA	Y		(a)
18021026	7.9	Romania	Y		Y
17970204	8.3	Ecuador	Y	Y	
17970210	8.4	Sumatra, Indonesia	Y		
17920822	8.4	Kamchatka		Y	
17870502	8.0	Puerto Rico			Y
17661021	7.9	Trinidad & Tobago	Y		
17620402	8.8	Bay of Bengal	Y		
17551101	8.7	Lisbon, Portugal	Y	Y	Y
17510525	8.5	Concepcion, Chile	Y	Y	
17461028	8.7	Lima, Peru	Y		Y
17371017	8.3	Kamchatka	Y	Y	
17300708	8.7	Valparaiso, Chile	Y	Y	Y
17271118	8.7	Lima, Peru	Y		Y
17250201	8.2	Eastern Siberia, Russia		Y	
17071028	8.4	Tosa, Japan	Y	Y	
17031231	8.2	Kanto, Japan	Y	Y	
17000126	9.0	Cascadia	Y	Y	Y
(a) The USGS gave lower magnitudes (M =< 7.8) for these events and were not included in the appendix. Events in red appeared in the 9/56 year grid in Table 1 . Wikipedia earthquakes were compiled from two listings – Historical Earthquakes and Largest Earthquakes by Magnitude, Sources: Wikipedia, Fujita and USGS.					

Appendix 3
9/56 YEAR GRID WITH FEW PRE 1900 QUAKES (M => 7.9)
Wikipedia, Fujita and USGS
Year ending September 30

Year ending September 30													
Sq 46	Sq 55	Sq 08	Sq 17	Sq 26	Sq 35	Sq 44	Sq 53	Sq 06	Sq 15	Sq 24	Sq 33	Sq 42	Sq 51
							1701	1710	1719	1728 1727 1118	1737	1746	1755
	1703	1712	1721	1730 0708	1739	1748	1757	1766	1775	1784	1793	1802	1811
1750	1759	1768	1777	1786	1795	1804	1813	1822	1831	1840	1849	1858	1867
1806	1815	1824	1833	1842	1851	1860	1869	1878	1887	1896 0615	1905	1914	1923
1862	1871	1880	1889	1898									
Continued.....													
Sq 04	Sq 13	Sq 22	Sq 31	Sq 40	Sq 49	Sq 02	Sq 11	Sq 20	Sq 29	Sq 38	Sq 47	Sq 56	Sq 09
												1704 1703 1231	1713
						1706	1715	1724	1733	1742	1751 0525	1760	1769
1708 1707 1028	1717	1726	1735	1744	1753	1762 0402	1771	1780	1789	1798	1807	1816	1825
1764	1773	1782	1791	1800	1809	1818	1827	1836	1845	1854	1863	1872	1881
1820	1829	1838	1847	1856	1865	1874	1883	1892 1891 1027					
1876	1885	1894											

Events in **red** appeared in the Wikipedia listing.

Events in **blue** did not appear in the Wikipedia listing, but were listed by the USGS and/or Fujita.

Sources of Raw Data: Wikipedia, Fujita and USGS.

Appendix 4
18/56 YEAR CYCLE: MAJOR WORLD EARTHQUAKES (M => 7.9) 1700–1899
Wikipedia, Fujita and USGS
Year ending September 30

[illegible]

1899													
0904													
1899													
0910													

Events in **red** appeared in the Wikipedia listing in **Appendix 1**.
Events in **blue** did not appear in the Wikipedia listing, but were listed by the USGS and/or Fujita in **Appendix 2**.
Sources of Raw Data: Wikipedia, Fujita and USGS.

Appendix 5 MAJOR WORLD EARTHQUAKES (M => 7.9) 1765 – 1885 National Geophysical Data Center				
YYYY	MM	DD	Location	M
1784	5	13	PERU: AREQUIPA, CAMANA	8.0
1787	3	28	MEXICO: SAN MARCOS, OAXACA	8.3
1788	7	21	ALASKA PENINSULA: UNGA ISLAND	8.0
1788	8	6	ALASKA PENINSULA	8.0
1792	8	22	RUSSIA: NEAR KAMCHATKA	8.4
1793	2	17	JAPAN: SANRIKU, RIKUZEN, RIKUCHU	8.3
1797	2	4	ECUADOR: RIOBAMBA	8.3
1797	2	10	SW. SUMATRA	8.0
1811	12	16	ARKANSAS: NORTHEAST	8.5
1811	12	16	ARKANSAS: NORTHEAST	8.0
1812	1	23	MISSOURI: NEW MADRID	8.4
1812	2	7	MISSOURI: NEW MADRID	8.8
1812	3	8	CHINA: XINJIANG	8.0
1817	3	11	FRANCE: CHAMONIX VALLEY	8.0
1818	11	8	INDONESIA: SUMBAWA ISLAND: BIMA	8.5
1819	4	3	CHILE: COPIAPO	8.0
1819	4	4	CHILE: COPIAPO	8.0
1819	4	12	CHILE: COPIAPO	8.5
1822	11	20	CHILE: VALPARAISO	8.5
1826	6	18	COLOMBIA: ENGATIVA, BOGOTA	8.2
1826	(a)		NEW ZEALAND: FJORDLAND	8.0
1828	3	30	PERU: LIMA, CALLAO	8.3
1833	8	26	NEPAL: KATHMANDU; INDIA: BIHAR	8.0
1833	9	6	CHINA: YUNNAN PROVINCE	8.0
1833	11	24	INDONESIA: SUMATRA: BENGKULU	8.3
1835	2	20	CHILE: CONCEPCION	8.2
1837	11	7	CHILE: VALDIVIA	8.5
1841	5	17	RUSSIA: OFF KAMCHATKA	8.4
1842	5	7	HAITI: CAP-HAITIEN	8.1
1843	2	8	GUADELOUPE: POINTE-A-PITRE	8.3
1843	4	25	JAPAN: HOKKAIDO: YEZO, KUSHIRO	8.4
1845	4	7	MEXICO: MEXICO CITY	8.0
1852	11	25	INDONESIA: MALUKU: BANDANAIRA	8.3
1854	12	23	JAPAN: ENSHUNADA SEA	8.3
1854	12	24	JAPAN: NANKAIDO	8.4
1855	1	23	NEW ZEALAND: WELLINGTON	8.0
1855	7	25	SWITZERLAND: HAUT-VALAIS	8.5
1856	8	23	JAPAN: OSHIMA	8.0
1857	1	9	CALIFORNIA: FORT TEJON	8.3
1857	4	17	BISMARCK SEA	8.0
1861	2	16	INDONESIA: LAGUNDI, SIMUK, TELLO	8.5
1865	11	18	TONGA ISLANDS	8.0
1867	2	4	GREECE: CEPHALONIA	7.9
1868	4	3	HAWAII: SE OF	7.9
1868	8	13	CHILE: ARICA	8.5
1868	8	15	ECUADOR: EL ANGEL, CONCEPCION	8.0
1870	5	11	MEXICO: OAXACA	7.9
1873	(a)		MACLAY COAST	8.0
1875	3	28	NEW CALEDONIA: LOYALTY ISLANDS	8.0

1877	5	10	CHILE: OFF NORTH COAST	8.3
1878	1	23	CHILE: TARAPACA	7.9
1878	2	11	VANUATU ISLANDS	8.0
1879	7	1	CHINA: GANSU PROVINCE	8.0
1881	12	31	INDIA: ANDAMAN & NICOBAR ISLANDS	7.9
1882	9	7	PANAMA: SAN BLAS ARCHIPELAGO	8.3

(a) The 1826 New Zealand and 1873 Maclay Coast quakes were not included in the assessment as no date was given for these events. If they occurred in the 9 months to September 30, then they would have appeared in **Appendix 6**.

Events highlighted in **red** fall in the 9/56 year grid as presented in **Table 1 & Appendix 6**.

Source: National Geophysical Data Center. Database parameters: 1700 –1899. $M \geq 7.9$

[illegible]

Appendix 7		
EARTHQUAKES CAUSING 30 OR MORE DEATHS IN THE USA		
Date	Location	Fatalities
1812 12 08	San Juan Capistrano, CA	40
1868 04 03	Hawaiian Island, HI	77
1868 10 21	Hayward Fault, CA	30
1886 09 01	Charleston, SC	60
1906 04 18	San Francisco, CA	3000
1933 03 11	Long Beach, CA	110
1946 04 01	Hawaii, HI (a)	165
1960 05 22	Hawaii, HI (a)	61
1971 02 09	San Fernando, CA	65
1989 10 18	Santa Cruz County, CA	63
1994 01 17	Northridge, CA	60
(a) Deaths caused by tsunamis originating from Alaska in 1946 and Chile in 1960. The table does not include Alaskan earthquakes. Earthquakes in red appeared in the 9/56 year grid in Table 3 . Source: USGS .		

Appendix 8			
POST 1900 WORLD EARTHQUAKES CAUSING DEATHS OF 6000 OR MORE			
Year ending August 30			
Date UTC	Location	Deaths	Magnitude
2010/01/12	Haiti	316000	7.0
1976/07/27	Tangshan, China	242769	7.5
2004/12/26	Sumatra	227898	9.1
1920/12/16	Ningxia, China	200000	7.8
1923/09/01	Kanto, Japan	142800	7.9
1948/10/05	Turkmenistan	110000	7.3
2008/05/12	Eastern Sichuan, China	87587	7.9
2005/10/08	Pakistan	86000	7.6
1908/12/28	Messina, Italy	72000	7.2
1970/05/31	Chimbote, Peru	70000	7.9
1990/06/20	Western Iran	50000	7.4
1927/05/22	Gulang & Gansu, China	40900	7.6
1939/12/26	Erzincan, Turkey	32700	7.8
1915/01/13	Avezzano, Italy	32610	7.0
2003/12/26	Southeastern Iran	31000	6.6
1935/05/30	Quetta, Pakistan (Baluchistan, India)	30000	7.6
1939/01/25	Chillan, Chile	28000	7.8
1988/12/07	Spitak, Armenia	25000	6.8
1976/02/04	Guatemala	23000	7.5
2011/03/11	Japan	20896	9.0
2001/01/26	Gujarat, India	20085	7.6
1974/05/10	China	20000	6.8
1905/04/04	Kangra, India	19000	7.5
1999/08/17	Turkey	17118	7.6
1960/02/29	Agadir, Morocco	15000	5.7
1978/09/16	Iran	15000	7.8
1962/09/01	Qazvin, Iran	12225	7.1
1907/10/21	Tajikistan, Turkestan	12000	8.0
1949/07/10	Khait, Tajikistan	12000	7.5
1968/08/31	Dasht-e Bayaz, Iran	12000	7.3
1934/01/15	India-Nepal border	10700	8.1
1931/08/10	Fuyun & Koktokay, China	10000	8.0
1970/01/04	Yunnan Province, China	10000	7.5
1993/09/29	Latur-Killari, India	9748	6.2
1985/09/19	Mexico, Michoacan	9500	8.0
1933/08/25	Sichuan, China	9300	7.5
1944/01/15	San Juan, Argentina	8000	7.4
1976/08/16	Mindanao, Philippines	8000	7.9
1909/01/23	Silakhor, Iran	6000	7.3
Events in red appeared in the 9-27/56 year grid presented in Table 4 . Source: USGS .			

CAN IMF AND THE ELECTROMAGNETIC COUPLING BETWEEN THE SUN AND THE EARTH CAUSE POTENTIALLY DESTRUCTIVE EARTHQUAKES?

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ABSTRACT: Trends in the Interplanetary Magnetic Field (IMF), detected by GOES satellites 13 and 15, show some recurrences in the graph, as a characteristic " σ " shaped hook that is detected before earthquakes of magnitude M6+. The study, initiated in 2009 by LTPA Project, which took into account more than 1,500 pieces of data, identified characteristic configurations in the form of graphs of the IMF, referring to potentially destructive earthquakes that occurred on a global scale. The recurrent anomalies in the GOES graphs precede an earthquake of magnitude M6+, 5 hours before its occurrence. The time-lag of 8 minutes or multiples thereof, calculated from the "ridge" of the " σ " and the earthquake, has allowed us to hypothesize an "electromagnetic coupling" between the Sun and the Earth, in the light of the theory of the "Flux Transfer Event", proposed by David Sibeck. According to this hypothesis, this electromagnetic coupling might be able to alter the delicate balance present in rocks under tectonic stress and cause earthquakes. Due to the recurrence of the event, in the form of " σ ", almost always present before strong earthquakes, the method aims to provide a contribution to the interdisciplinary study of seismic precursors of a global character, since a potentially destructive earthquake affects the entire Earth System.

Keywords: *Interplanetary Magnetic Field, electromagnetic coupling between the Sun and the Earth, global seismic precursors, potentially destructive earthquakes, flux transfer event.*

INTRODUCTION

The research into seismic precursors has oriented studies in recent years in various fields of investigation to counter in advance the tragic effects caused by strong earthquakes. Earthquakes, in fact, are the only natural disasters that do not directly cause the death of people, which are caused by the collapse of buildings or infrastructure. Among the possible elements of analysis cosmic events have been investigated and, in particular, the interaction of the Interplanetary Magnetic Field and the flow of charged particles from the Sun (Kalinin, 2009; Khazaradze et al., 2007; Zátópek et al. 1976, and others).

The analysis of the Interplanetary Magnetic Field, seen in relation to potentially destructive earthquakes of magnitude M5.5+ and more usually M6+, was recently verified by the disastrous Japanese earthquake of 11 March 2011 (Straser, 2011a) and the outcome of this study was presented at Kanyakumari in 2011, at the EDPD Conference (Straser, 2011b). The research is based on two assumptions: first that there exists a gravitational and electromagnetic coupling of the Sun with the Earth and the other, on the concept of "circular time", that is, of natural phenomena that occur periodically on a planetary scale, with a temporal recurrence that is calculable and instrumentally detectable. The investigation was divided into two phases. Firstly, observation of data from satellites (GOES 13 and 15) to investigate possible recurrences in the pattern of IMF graphs before earthquakes of magnitude M6+, from several hours to a few minutes before the triggering of earthquakes. **Fig. 1** shows, by way of example, the trend of the IMF and the moment when there were two earthquakes of M7.8 and M7.6 that occurred in the Kermadec Island Region on July 6, 2011. In analyzing 24/7 data sent from the GOES satellites 13 and 15 by the LTPA Project team, from 2009 until the summer of 2012, it was noted that the IMF graph undergoes a slight deformation before strong earthquakes on a global scale, drawing in the trace the characteristic letter "S" (**Fig. 2**), named in this work with the Greek letter " σ " (Straser, 2011b). More frequently, as the trace shows, with reference to Honsu on March 31, 2011, there was a variation from 2 nT to 5 nT as a lag between the initial and final values of the curve; the latter values being present in most of the cases studied.

The IMF graph also shows other similarities in the run-up to earthquakes of magnitude M5+, and more commonly M6+, as you can see, for example, in the seismic sequence from 22 to 24 August 2011. In all three cases analyzed, we can identify some recurrences, in addition to the aforementioned hook in the form

of an " σ " in the curve before an earthquake. **Fig. 3** shows a repetition of the cusps when the IMF values are minimal. The cusps, in the figure, are indicated by the letter "A" and the repetitions by the letters *A1*, *A2*, and *A3* ... *An*. A second characteristic that follows the cusps of type "A" is hook in the graph, which can be noted in correspondence with the letter "B". Normally, the appearance of this hook of type "B" precedes by about 5 hours the appearance of the " σ " and then the earthquake associated with it. The characteristics of the three recurrences were noted for earthquakes occurring in different seismic zones: Sumatra (M6), Papua New Guinea (M5.2), and Peru (M7.0).

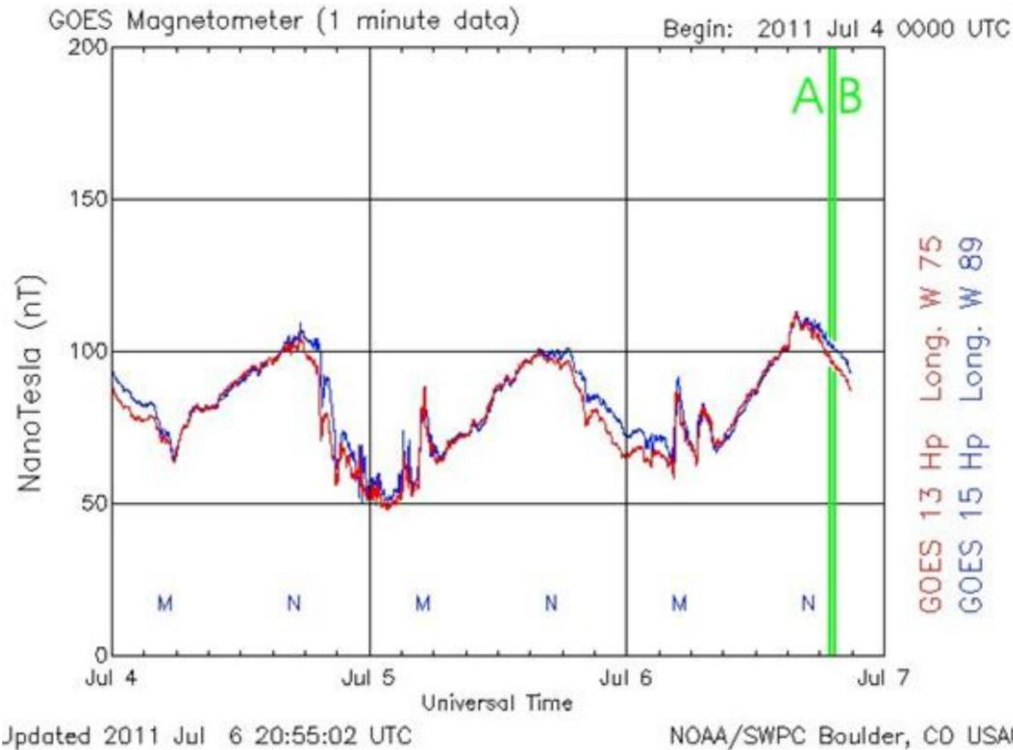


Fig. 1. The trend of the IMF, detected by GOES satellites 13 and 15, is consultable online 24/7, as is the list of earthquakes on a global scale (USGS). In this case, the green line indicates the occurrence of earthquakes of magnitude M7.8 (letter A) and M7.6 (B) that occurred in the Kermadec Island Region on 6 July 2011. The letters "M" and "N" are the initials of, respectively, "Midnight" and "Noon".

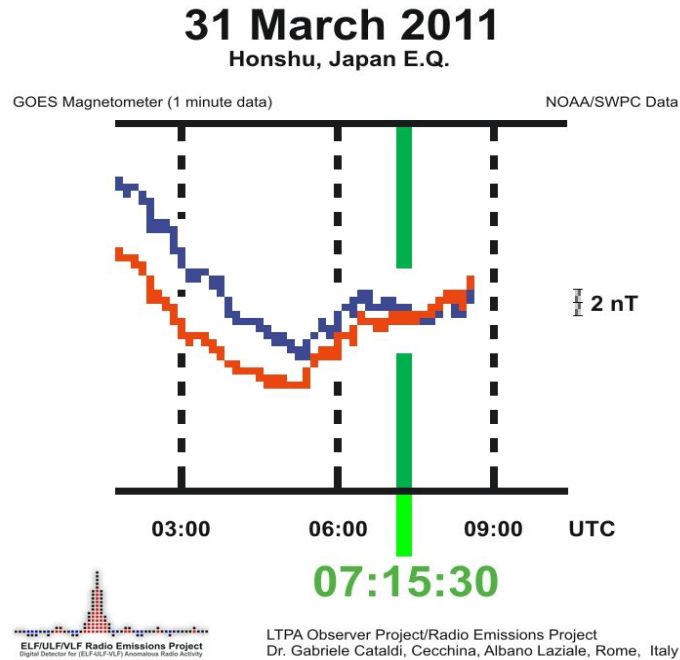


Fig. 2. The figure summarizes the appearance of the " σ " in the graph of the Interplanetary Magnetic Field, and the traces from the GOES 13 and 15 satellites, distinguished by their respective colours. The example refers to the earthquake in Honshu on March 31, 2011, which highlights a "typical" variation in 2 nT.

The sequence just indicated, however, does not always manifest itself in a distinct manner for all potentially destructive earthquakes, while the recurring presence of the " σ " before a strong earthquake, in this case in the Fiji Islands on July 29, 2011, with a magnitude of M6.7 (**Fig. 4**).

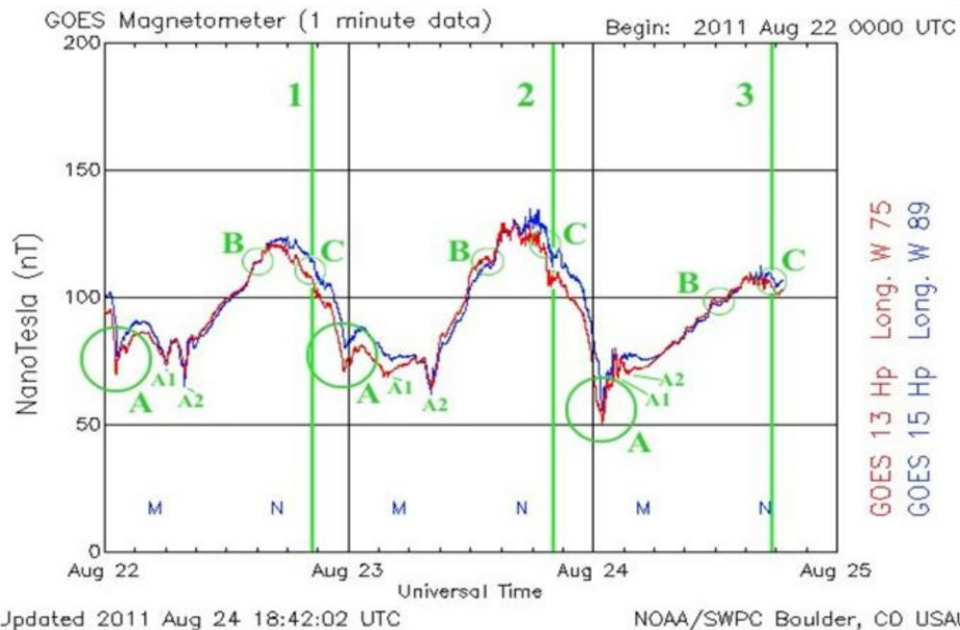


Fig. 3. In all three cases, you can notice the recurrence of the cusps of the Interplanetary Magnetic Field during the run-up to earthquakes of magnitude M5+. The seismic sequence refers to the period between 22 and 24 August 2011. The letter "A" indicates the values of the IMF when they are minimal, an hook of the ascending phase of the design with the letter "B" that normally precedes by about 5 hours the appearance of " σ " and then the earthquake. The number 1 on the graph indicates the earthquake of 22 August in Sumatra with a magnitude of M6, the number 2 the earthquake of magnitude M5.2 in Papua New Guinea on 23 August and the number 3 the earthquake of August 24, 2011 in Peru of magnitude M7.0.

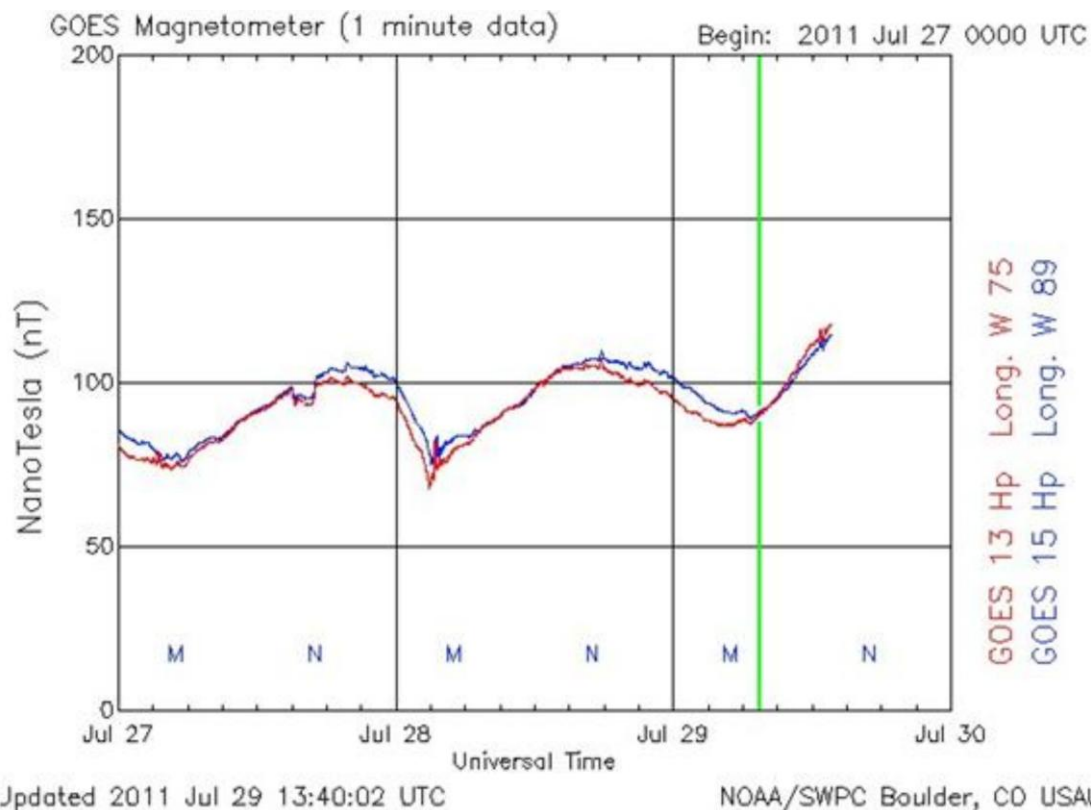


Fig. 4. Recurrence of the "σ" before a strong earthquake in the GOES 13 and 15 satellite trace. In this case, the graph refers to the earthquake that occurred in the Fiji Islands on July 29, 2011, with a magnitude of M6.7, indicated by the green line on the graph.

Methods and data

The method used in this study consists in comparing data, recorded 24/7, on variations in the IMF and, in particular, in Identifying "σ" shapes in the trace close to the 2-5 nT value.

Satellites

Data from satellite tracking system (Orbitron) are as follows:

(<http://www.swpc.noaa.gov/Data/GOES.html>)

GOES 13 (Primary): orbiting at 35,809 km; Long 74.5403° W; Lat 0.3317° S; Azim 272.3°; Elev -10.7°; RA 12 h 26 m 24 s; Decl. -7° 07' 04".

GOES 15 (Secondary): orbiting at 35,782 km; Long 88.9147° W; Lat 0.0344° N, Azim 284.2°; Elev -18.6°; RA 11 h 29 m 43 s; Decl. -6° 37' 18".

DISCUSSION

The investigation focused, in particular, the appearance of the "σ", because this is always present in the Interplanetary Magnetic Field graph before potentially destructive earthquakes. In the graph of **Fig. 5**, the "σ" can be represented, schematically, in five distinct stages.

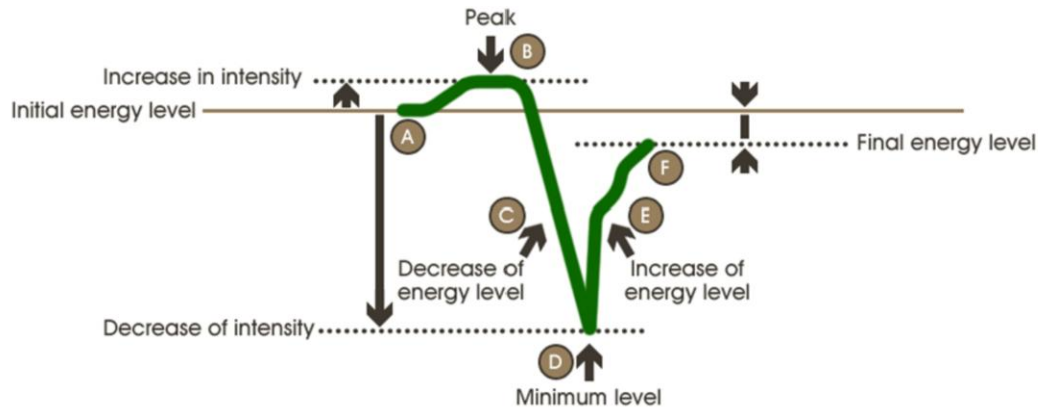


Fig. 5. Schematic diagram of the shape of a "σ" in the GOES 13 and 15 satellite trace that precedes an earthquake. The "σ" is presented in a schematic way with an initial energy level, followed by a reduction in intensity, a minimum level, and a slope, until reaching a final energy level.

It starts with an initial energy level, which is followed by a reduction in intensity until it reaches a minimum level, at which point the chart returns to climbing until reaching a final energy level. The difference between the initial and the final value is normally between 2 nT and 5 nT. A second parameter considered in this study is the time lag between the crest of the "σ" and the earthquake associated with it. To proceed with the study earthquakes on a global scale were taken into account, of magnitude M6+ from 14 September 2011 to 9 January 2012 (**Fig. 6**), with the support of Gabriel and Daniel Cataldi. **Fig. 6** shows the recurrent interval of 8 minutes or multiples thereof, between the crest of the IMF (the curve at the earthquake) and the earthquake itself. This mechanism can be interpreted as a magnetic connection between the Sun and the Earth, in the light of the study by Sibeck (Phillips, 2008).

The magnetic connection, according to Dr. David Sibeck of the Goddard Space Flight Center, author of a study published in 2008, is not continuous, is often brief, sudden and very dynamic. Every eight minutes, approximately, the two fields merge or "reconnect" briefly, forming a portal through which the particles flow. The portal takes the form of a magnetic cylinder almost as wide as the Earth. The mechanism is known as "flux transfer event" or FTE. Every 8 minutes, therefore, on any magnetic connection, stress is created until reaching the "effective" one associated with earthquakes.

How can FTEs trigger earthquakes?

If we imagine the lines of the Earth's magnetic field as a sum of local magnetic fields (**Fig. 7**), generated, for example, by ferromagnetic materials transported by the flows in ascending slope, arranged randomly, by effect of terrestrial degassing, then the direction the IMF can be added to or subtracted from the lines of force of the magnetic field and its resulting value, i.e. the one that emerges from underground. This mechanism is assumed to induce variations of stress in a rock close to its breaking load.

Location	Date	UTC Time	Magnitude (Mw)	Interval (minute) from Italic-S peak to earthquake	Magnetic variation (nT) from Italic-S peak to earthquake	Magnetic variation (nT/min) from Italic-S peak to earthquake	Depth (Km)	Magnetic variation (nT/min) of IMF between Italic-S peak and Earthquake	Depth (Km/10)
Aleutian Islands	14/09/2011	18:10:07	6,1	16	2,6	0,1625	1	162,5	0,1
Jujuy, Argentina	06/10/2011	11:12:29	6,2	32	2,08	0,065	9,5	65	0,95
Banda Sea	30/09/2011	06:57:41	6,8	16	0,52	0,65	465	650	46,5
Canada	09/09/2011	19:41:35	6,7	16	10,4	0,65	25,9	650	2,59
Honshu, Japan	16/09/2011	19:26:42	6,6	32	1,04	0,0325	36,3	32,5	3,63
Bali, Indonesia	13/10/2011	03:16:30	6,1	8	0,52	0,065	35,1	65	3,51
Fiji Region	15/09/2011	19:31:03	7,3	32	4,68	0,14625	626,1	146,25	62,61
Kermadec Islands	06/07/2011	19:03:16	7,8	16	3,12	0,195	125	195	12,5
Kermadec Islands	06/07/2011	19:22:10	7,6	32	1,56	0,04875	20	48,75	2
Kermadec Islands	07/10/2011	08:58:30	6,5	16	9,36	0,585	34,6	585	3,46
Hokkaido, Japan	21/10/2011	08:02:38	6,1	8	0,52	0,065	185	65	18,5
Kermadec Islands	21/10/2011	17:57:18	7,4	56	1,04	0,018571429	32,9	18,57142857	3,29
Papua N.G.	14/10/2011	03:35:15	6,7	8	0,52	0,065	45,4	65	4,54
Papua N.G.	18/10/2011	05:05:06	6	56	8,32	0,148571429	21	148,5714286	2,1
Perù	24/08/2011	17:46:12	7	8	0,52	0,065	145,1	65	14,51
Perù	28/10/2011	18:54:34	6,9	24	2,08	0,086666667	23,9	86,66666667	2,39
Russia	14/10/2011	06:10:15	6,1	8	0,52	0,065	15,3	65	1,53
Sandwich Islands	03/09/2011	04:49:01	6,2	16	22,88	1,43	106	1430	10,6
Est Turkey	23/10/2011	10:41:21	7,2	8	0,52	0,065	20	65	2
Est Turkey	23/10/2011	20:45:37	6	32	2,6	0,08125	9,8	81,25	0,98
Vanuatu	03/09/2011	22:55:36	7	8	0,52	0,065	132,4	65	13,24
Vanuatu	04/09/2011	21:44:21	6,1	32	4,68	0,14625	59,4	146,25	5,94
Vanuatu	20/08/2011	16:55:03	7,1	48	2,6	0,054166667	40,6	54,16666667	4,06
Vanuatu	20/08/2011	18:19:25	7	56	2,6	0,046428571	28,5	46,42857143	2,85
Honshu, Japan	11/03/2011	05:46:24	8,9	24	2,6	0,108333333	29	108,3333333	2,9
Pacific	02/11/2011	14:59:26	6,2	48	2,6	0,054166667	1,1	54,16666667	0,11
Revilla Gigedo Islands	01/11/2011	12:32:00	6,3	24	1,04	0,043333333	5	43,33333333	0,5
Taiwan	08/11/2011	02:59:07	6,9	16	5,72	0,3575	209,5	357,5	20,95
Bolivia	22/11/2011	18:48:15	6,2	8	1,56	0,195	533,3	195	53,33
New Zeland	18/11/2011	07:51:27	6	8	1,04	0,13	26,8	130	2,68
Honshu, Japan	23/11/2011	19:24:32	6,1	8	2,08	0,26	33,3	260	3,33
Hokkaido, Japan	24/11/2011	10:25:35	6,2	16	3,12	0,195	42,3	195	4,23
Atacama, Chile	07/12/2011	22:23:09	6,1	32	1,56	0,04875	15,6	48,75	1,56
Mexico	11/12/2011	01:47:26	6,5	48	8,84	0,184166667	64,9	184,1666667	6,49
Sandwich Islands	11/12/2011	09:54:55	6,2	88	1,04	0,011818182	115,5	11,81818182	11,55
Sulawesi	13/12/2011	7:52:12	6,1	16	0,52	0,0325	160,9	32,5	16,09
Papua N.G.	14/12/2011	05:04:57	7,1	16	1,04	0,065	121,2	65	12,12
Kermadec Islands	15/12/2011	10:10:08	6,3	32	3,12	0,0975	34,1	97,5	3,41
Russia	27/12/2011	15:21:56	6,6				6,9		0,69
Izu, Japan	01/01/2012	05:27:55	6,8	112	4,16	0,037142857	348,5	37,14285714	34,85
Santa Cruz Islands	09/01/2012	04:07:17	6,6	80	16,64	0,208	38,9	208	3,89

Fig. 6. The time interval between the crest of the "σ" and the earthquake varies from 8 to 112 minutes. And, more generally, with multiple intervals of eight minutes, as can be seen, for example, in the earthquakes of magnitude $M > 6$ occurred on a global scale, between 14 September 2011 and 9 January 2012.



Fig. 7. Lines of the Earth's magnetic field, hypothesized in this study as a sum of local magnetic fields, generated by ferromagnetic materials transported by the flows in ascending slope, arranged randomly, and due to terrestrial degassing.

A key element in this hypothesis is the polarity of the IMF. The analysis is based on the earthquakes recorded by USGS, of M5+, in the months of March and April 2012. It can be noted that most of the earthquakes occurred with the negative polarity of the IMF, i.e. the Southward Interplanetary Field. The peak (IMF with positive polarity) refers to the earthquake that occurred on April 11, 2012 in Sumatra with a magnitude of M8.9 (**Fig. 8**).

However, in addition to a hypothesized interaction of an electromagnetic character between the Sun and Earth, a gravitational relationship between the Earth and the Sun cannot be excluded, since their distance of about 8 light minutes, a time that corresponds precisely to the range that elapses between the crest of the IMF and the earthquake.

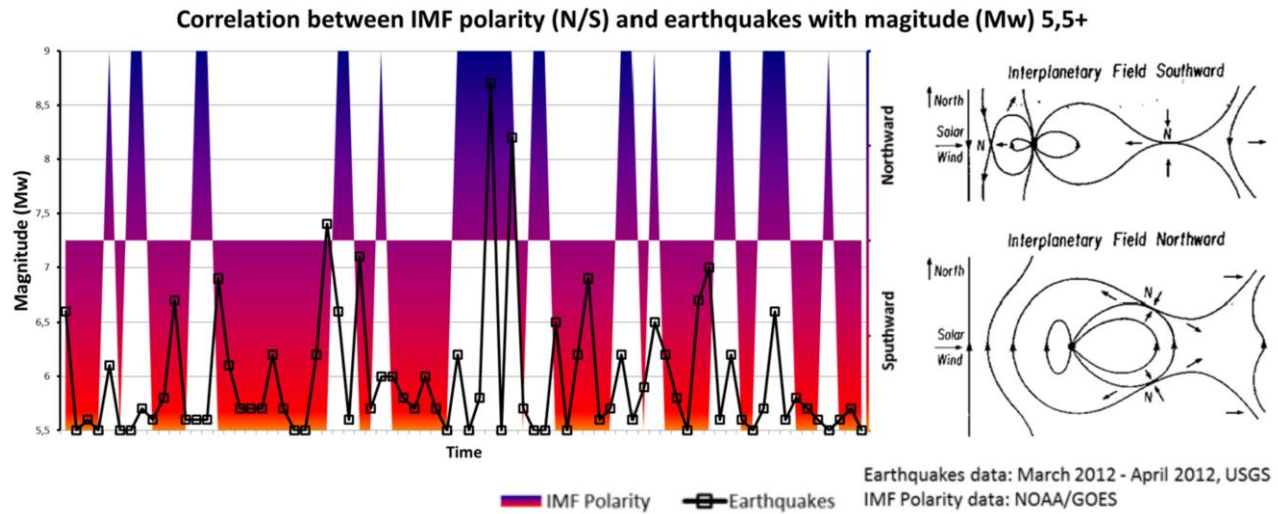


Fig. 8. Polarity of the IMF. The analysis is based on the earthquakes recorded by USGS, of M5+, in the months of March and April 2012. It can be noted that most of the earthquakes occurred with negative polarity of the IMF, i.e. the Southward Interplanetary Field. The peak (IMF with positive polarity) refers to the earthquake that occurred on April 11, 2012 in Sumatra with a magnitude of M8.9.

CONCLUSIONS

The method of investigation imposes as a limit that of not specifying the future epicentral area of the earthquake, with a good approximation, the time lag between the earthquake, the appearance of the "σ", and the earthquake, generally with a magnitude of M6+. It has been concluded that the appearance of the "σ" in the IMF graph represents the beginning of the disruption, gravitational or electromagnetic in nature, which precedes an earthquake, at time intervals of 8 minutes or its multiples. This method of investigation is part of the global seismic precursors (Straser, 2011b), since a potentially destructive earthquake is an event of global significance for our planet. The method cannot provide, by itself, a 100% reliable forecast and, for this reason, lends itself as an element of investigation for an interdisciplinary study aimed at analyzing seismic precursors. Given the pioneering phase of the method, application of the study requires some caution in the analytical phase for the investigation of precursory signals of an earthquake.

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INTERVALS OF PULSATION OF DIMINISHING PERIODS AND RADIO ANOMALIES FOUND BEFORE THE OCCURRENCE OF M6+ EARTHQUAKES

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ABSTRACT: From spectral analysis of more than 350 earthquakes, it was noted that the micro pulsations and the radio interference detected, respectively, at a value of 665 mHz and in the range between 0.1 and 20Hz, precede by a few hours the occurrence of M6+ earthquakes. This analysis was performed instrumentally 24/7, starting from 2009, at the LTPA Project station in Rome (Italy). The amount of data collected, with more than 1,900 earthquakes studied, especially those relating to potentially destructive earthquakes such as the violent earthquake in Japan of 2011 or that of Sumatra in 2012, confirmed that the geomagnetic micro pulsations are associated, especially for earthquakes of magnitude M6+, with the run-up to an earthquake. The Intervals of Pulsations of Diminishing Periods and radio anomalies are simultaneous with an increase in the geomagnetic background which, based on experience, come in four different types, ranging from 15 to 2 hours before the main shock. The point of convergence of these four variables, IPDP, PC1, Radio Interference and earthquakes consists in the dynamics of the fault, a progressive decrease in grain size of the lithons (fracture-bounded particles) and fluid circulation in the period preceding the earthquake.

Keywords: *radio anomalies, PC1, IPDP, earthquakes, global seismic precursors.*

(Note: This paper was presented at the 34 IGC, Brisbane, 2012)

Introduction

In nature no earthquake is ever the same as another one. There are, however, recurrent signals and anomalies that precede earthquakes which can be defined as "Global Seismic Precursors", instrumentally detectable and comparable via monitoring stations located in different parts of the Earth. The possibility that rocks placed under tectonic stress indicate their condition by emitting electromagnetic signals before a strong earthquake is a concept by now well established in the scientific community (Hattori, 2004; Fraser-Smith et al., 1990; Hayakawa et al., 2007).

Global Seismic Precursors (Straser, 2011a and 2011b) differ from traditional ones because they do not manifest in the site where the earthquake will actually occur, but indicate the imminence of an earthquake on a global scale, generally measuring M6+, without specifying the epicentre area and the exact magnitude. Candidate precursors presented in this study are based on two assumptions:

- a) rocks placed under stress emit electromagnetic signals;
- b) there is an electromagnetic coupling between the Sun and the Earth.

The first type of "Global Seismic Precursors" comes from analysis of radio-anomalies, whereas, the second comes from analysis of Intervals of Pulsations of Diminishing Periods (IPDP). Both the radio interference and the IPDP are detectable by monitoring stations, 24/7, in this case in Rome (Italy), by the LTPA Project and analyzable on special spectrograms (**Fig. 1**).

Intervals of Pulsations of Diminishing Periods (IPDP) are micro pulsations observed at high latitudes in the frequency below 1Hz, generally between 0.1 and 0.6Hz (**Fig. 2**). At lower latitudes, however, they are observed with values of just a few Hz. In Italy, the location for their detection is optimal since it is halfway between the equator and the pole; normally at values of 665 mHz (0.65 Hz).

Radio-anomalies

The radio anomaly is an unknown radio emission that has no characteristics (duration, extension, intensity, etc.) compatible with:

- the classification by IAGA (International Association of Geomagnetism and Aeronomy) of geomagnetic pulsations;
- emissions of an anthropic type
- known natural emissions (Whistler, Chorus, lightning, electrophonic meteoric sounds, plasma, etc..).

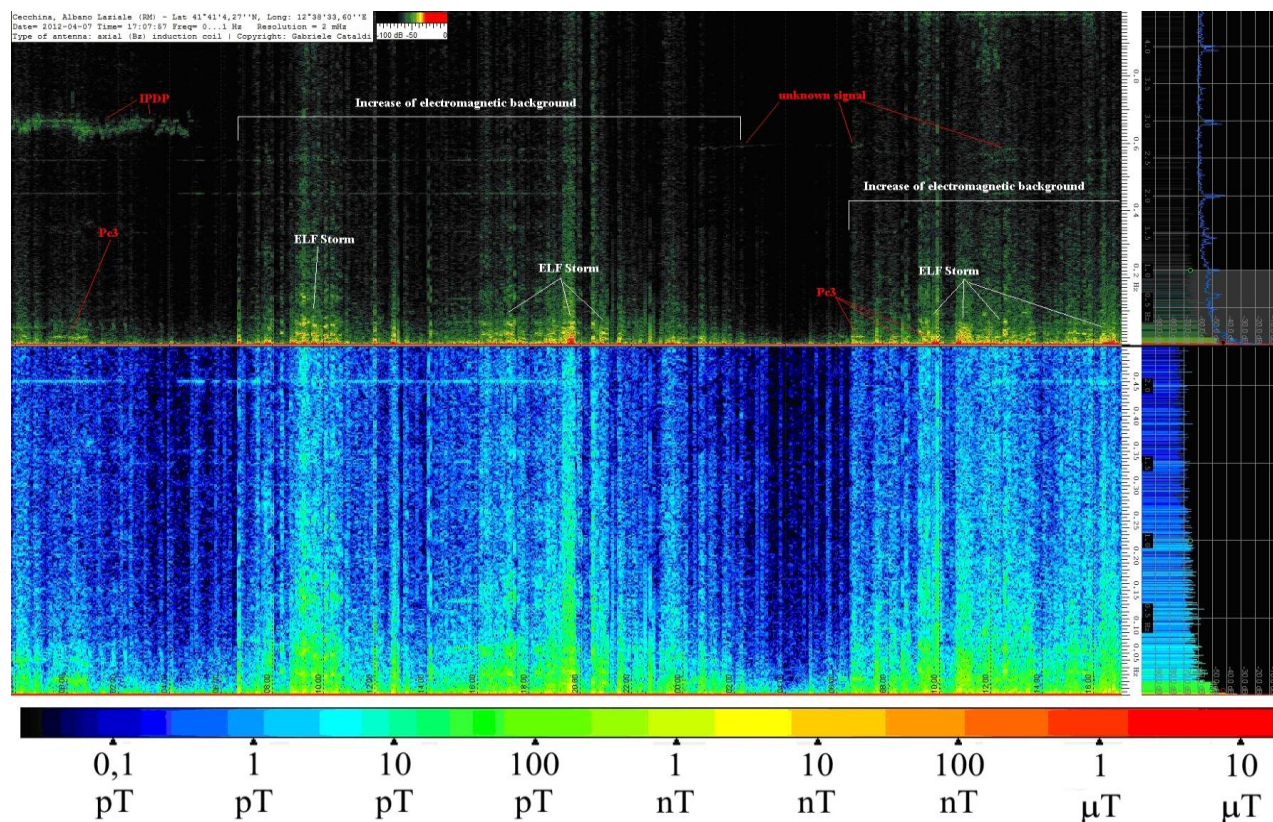


Fig.1. Signals detectable with the Spectrum Lab at the LTPA station in Rome, in the various frequency bands: Pc1, Pc3, elf storm, radio-anomalies, IDPD and increases in the geomagnetic background (Courtesy of Gabriele Cataldi).

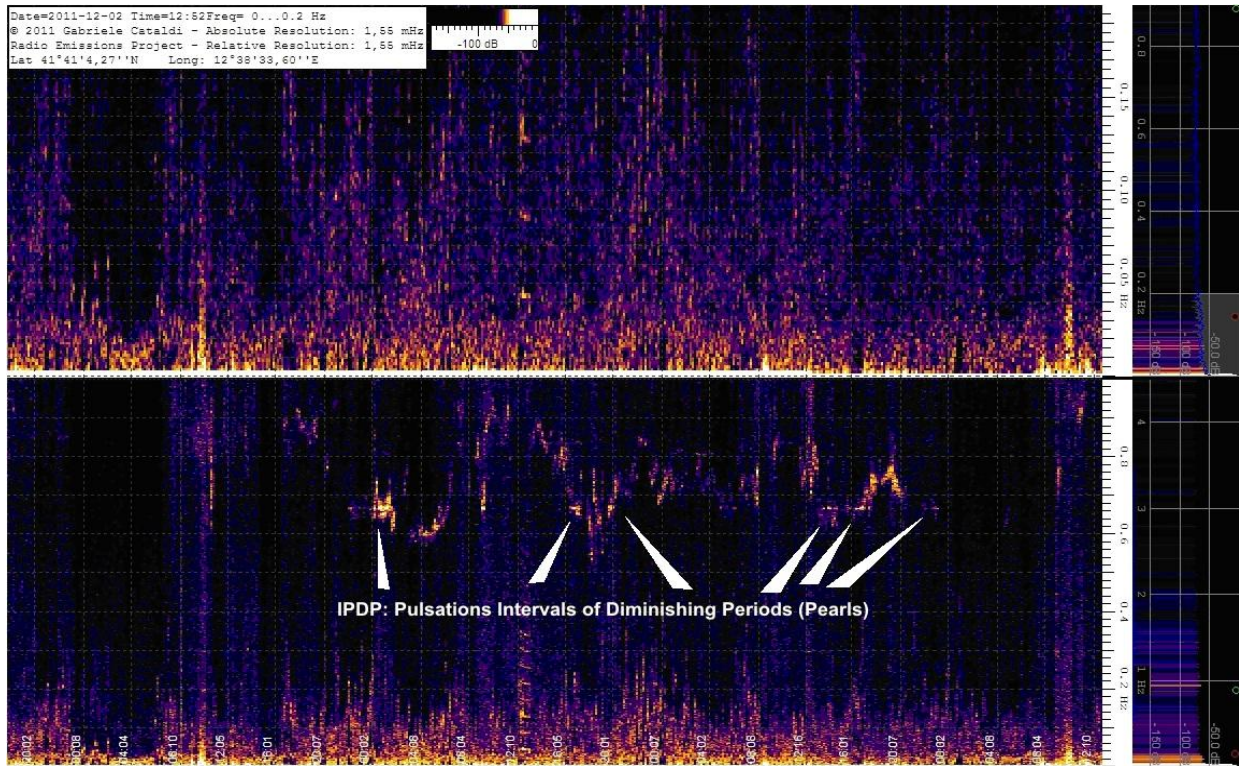


Fig. 2. Example of Intervals of Pulsation of Diminishing Periods on the LTPA screen in Rome, at a frequency of 0.65Hz, which overlap the increase in geomagnetic background.

For this reason, since Radio anomalies are not related to known phenomena they were considered in this study as candidate seismic precursors. After experience gained in the field, the concept of "radio anomaly" is now identified with an increase in the geomagnetic background that is not listed in the IAGA classification of geomagnetic pulsations. In the early stages of the experiments, however, the radio-anomalies were considered simply as non-classifiable IAGA emissions.

Most of the radio anomalies are observed below 32 Hz and, generally, between 0.1 and 20 Hz and occur in association with an intense increase in the geomagnetic background that precedes the occurrence of a seismic event. From an instrumental point of view, the increase in electromagnetic background is easily identifiable in the frequency band from 0 to 150 Hz (**Fig. 3**).

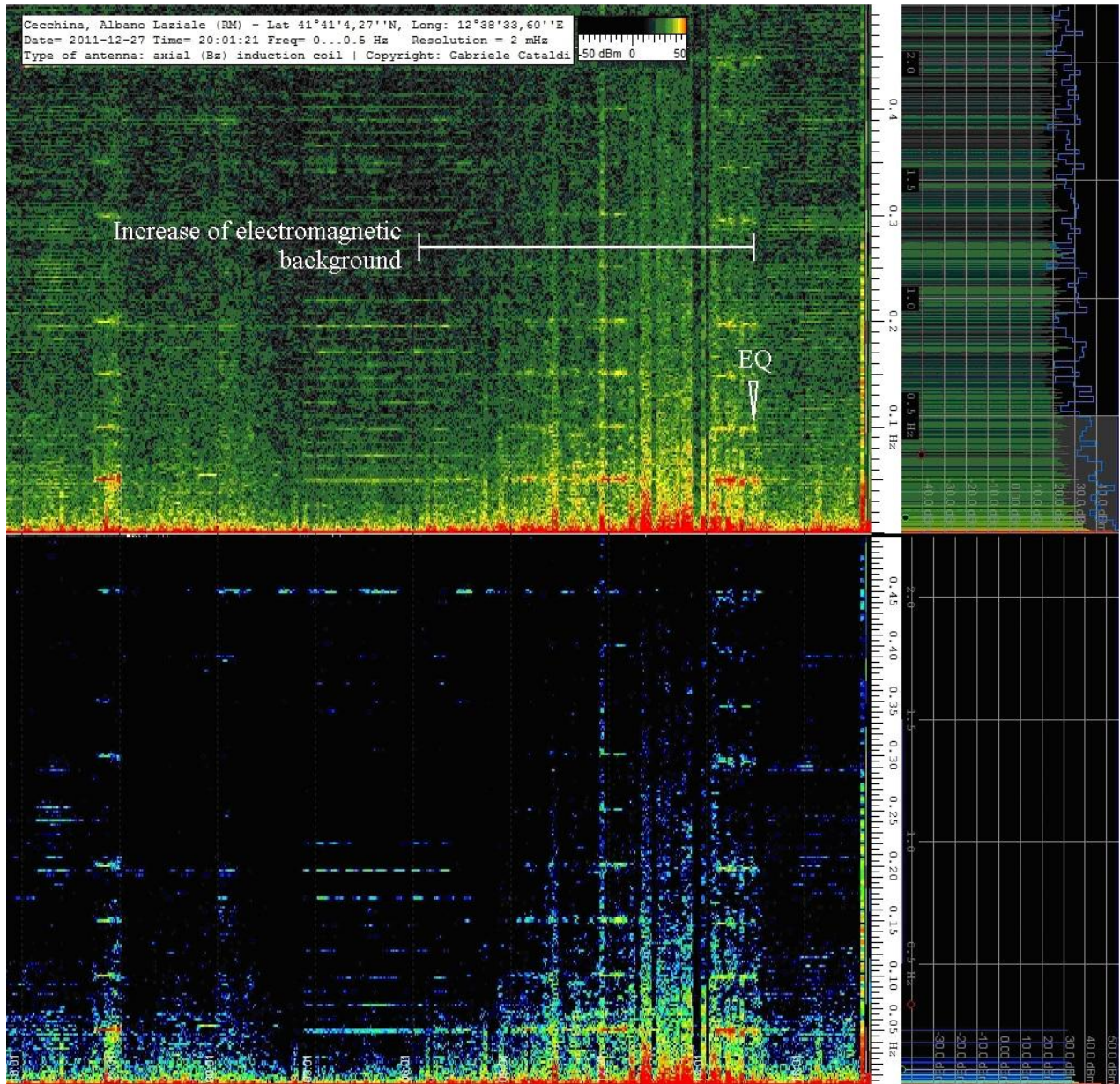


Fig. 3. Increased geomagnetic background that is highlighted by the vertical yellow lines and radio-interference (red) prior to the occurrence of earthquakes.

Radio anomalies, IDPD and Pc1 were detected instrumentally before earthquakes with a magnitude greater than M6+ (**Fig. 4**) and, for this reason, it has been assumed that they may have a relationship with the run-up to earthquakes.

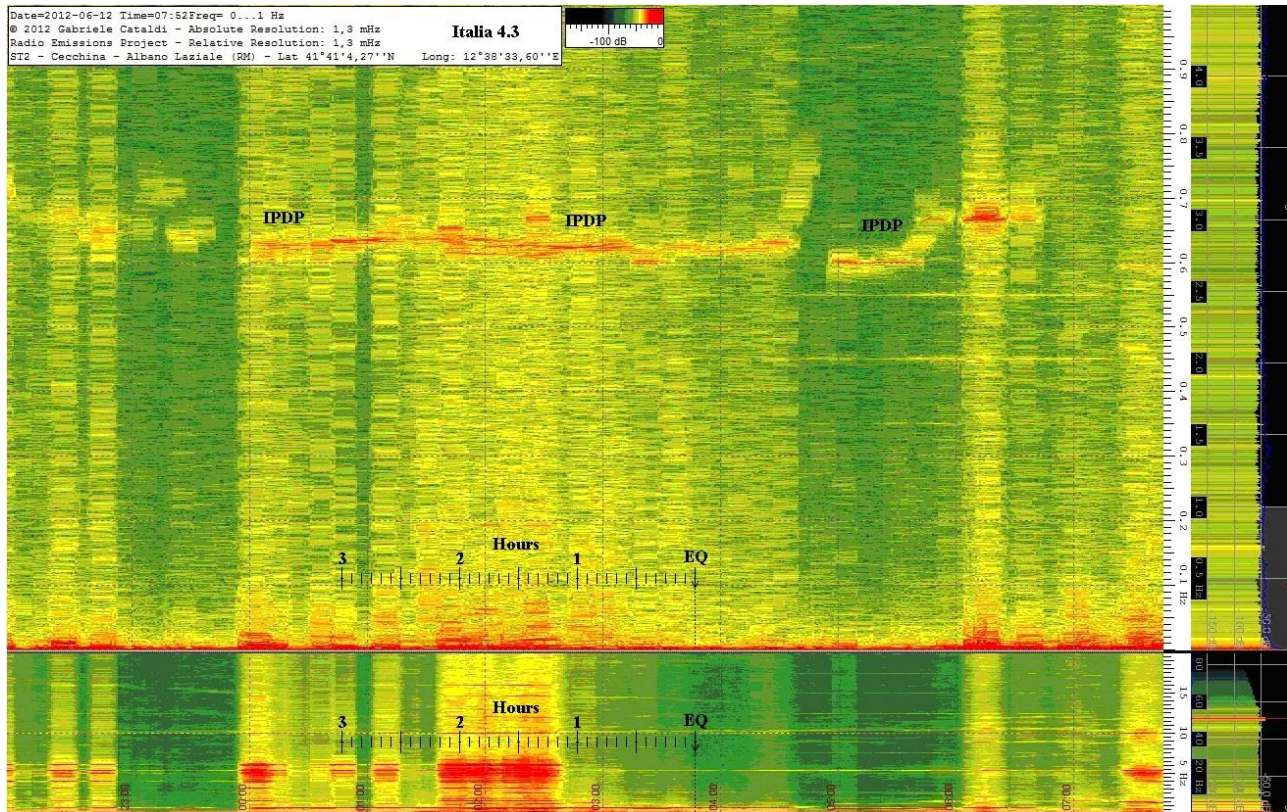


Fig. 4. The figure shows the appearance of IPDP four hours before the earthquake in the Emilian Po Valley (Italy June 6, 2012, indicated by the abbreviation EQ). In the same spectrum of notes the increase in geomagnetic background (yellow vertical lines) and the radio-anomalies in the low frequency band in red (Courtesy Gabriele Cataldi).

Some considerations on radio anomalies and Pc1

1 - **The intensity of the signal detected by the instrument** is equal to or greater than 100 nT. In fact, the 100 nT value is equivalent to the intensity of electromagnetic pollution in homes in the countryside generated by the 50 Hz (220 V) power of domestic dwellings. According to some studies, radio signals in the ELF band with an intensity of about 60nT have been observed to appear before earthquakes. Signals of at least 100nT, therefore, reduce even more drastically the number of signals "related" to a probable pre-seismic nature.

Most radio anomalies are observed below 32 Hz (generally between 0.1 and 20 Hz) and, given their intensity, are not absolutely compatible with emitters of a magnetospheric type since, between 0.1 and 20 Hz, emitters would require a maximum intensity of 3 nT.

According to the IAGA classification of geomagnetic pulsations, the 1nT value corresponds to a frequency between 0.2 and 5 Hz; 3nT to a frequency between 0.1 and 0.2Hz and 10nT to between 22 mHz and 0.1 Hz. Higher magnetic intensity can be observed only at frequencies less than 22 mHz. The decision not to monitor such low frequencies was dictated by the outcome of experiments carried out in recent years, which have always confirmed the validity of the signals above 0.1Hz up to a maximum of about 45 Hz.

Instead, "irregular geomagnetic pulsations" may appear between 25 mHz and 1 Hz to a maximum intensity of 10nT, which is, also in this case, a datum incompatible with the radio interference values.

As for Schumann's resonance, which has been observed at: 8, 14.1, 20.3, 26.4, 32.5 Hz, and so on ... the radio signal of these resonance harmonics has an extremely low intensity: 1.8 picoTesla which, also in this case, is incompatible with the detection of radio interference.

2 - **frequency:** The only emissions known in the ELF and SLF bands are of the magnetospheric and Alfvén type. To be precise, between 0.1 and 10 Hz, it is possible to observe emissions related to the Alfvén cavity, and this type of emission falls within the range of frequencies where radio interference appears. In addition, the background emission that is usually detected during the surveys originates from 0.1 Hz

3 - **bandwidth:** this is extremely wide compared to the bandwidth of the geomagnetic pulsations, except for Pc1, which have an extension of about 5 Hz. But in this latter case the intensity of the geomagnetic pulsation assumes a value of 1 nT, which represents a much lower value of the signals detected between 5 and 0.2 Hz

4 - **harmonic resonance:** unlike anthropic-type emissions, radio anomalies do not have resonance harmonics.

5 - **trend:** anomalies appear to be affected in a manner directly proportional to solar activity and in many cases appear before major earthquakes, usually with a magnitude of M6+.

A clarification: EPS and geomagnetic pulsations are not the same thing

Both are found in the same frequency band, since geomagnetic pulsations are the result of solar activity on the magnetosphere and these interactions generate emissions that have a very low frequency. Instead, EPS are emissions that may have a very broad spectrum, but only the emissions that fall below 5 Hz have such a high intensity and a frequency as to be able to permeate the planetary body and be observed everywhere. Furthermore, some of these emissions can create disturbances in the Alfvén cavity and generate alterations in geomagnetic pulsations, which can also be observed using coil antennae.

Methods and data

The method used in this study consists in comparing data, recorded 24/7, on variations in IMF and, in particular, in identifying “ σ ” shapes in the trace close to the 2-5 nT value, with the appearance of radio interference as recorded by LPTA instruments at a monitoring station near Rome.

The LPTA station is equipped with a NASA INSPIRE VLF3 frequency data collector and a tri-axial magnetometer which are interfaced with a computer that records data 24/7

Instruments used

a) Spectrograms

The spectrograms obtained by the station were recorded every 10 minutes; i.e. 1 horizontal line every 1,600 milliseconds. The data of the Spectrum Lab setting are as follows:

Effect of FFT settings with $f_s = 44.1000$ kHz:

Width of one FFT-bin: 21.0285 mHz

Equiv. noise bandwidth: 28.5988 mHz

Max freq range: 0.00000 Hz to 1.37813 kHz

FFT window time: 47.554 s

Overlap from scroll interval: 96.6 %

Discussion and conclusions

IPDP and Pc1 were considered in this study after finding an inverse relationship with the ten-year pattern of sunspots. And, for the largest earthquakes, it was noted that the IPDP, several hours earlier, precede, accompany and follow an increase in the geomagnetic background and the earthquake itself (**Fig. 4**). Data on the inverse relationship between solar activity patterns, the PC1 and the IPDP come from the Sodankylä observatory recorded between 1974-95 by Kangas and colleagues (**Figs. 5 and 6**).

Both the PC1 and the IPDP pulsations are waves that are amplified in the plasmasphere and plasmopause, and indicate signs of changes in the Earth's plasma. Normally, the PC1 appear after a magnetic storm, while IPDP are intimately associated with sub-storm activity in the magnetosphere, although there is no lack of interpretations that associate Pc1 to potentially destructive earthquakes (Bortnik et al., 2008; Guglielmi et al., 2010). Also the frequency of earthquakes over the last 11 years follows the IDPD pattern in relation to the number of sunspots (**Fig. 7**) as described by Choi and Maslov (2010).

Given the parallelism between IDPD and Pc1, sunspot patterns and the number of earthquakes on a global scale, they were considered in this study as candidate seismic precursors.

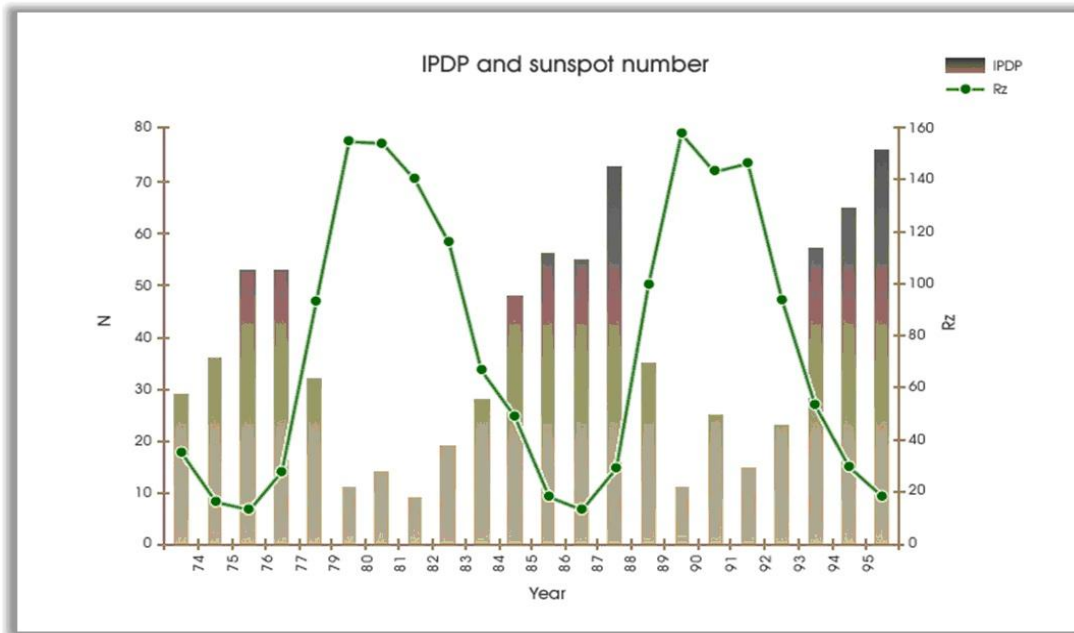


Fig. 5. Comparison of IDPD (shaded brown columns) and the solar cycle pattern (green line), measured from 1973 to 1995 at the observatory of Sodankylä by Kangas et al. (1999).

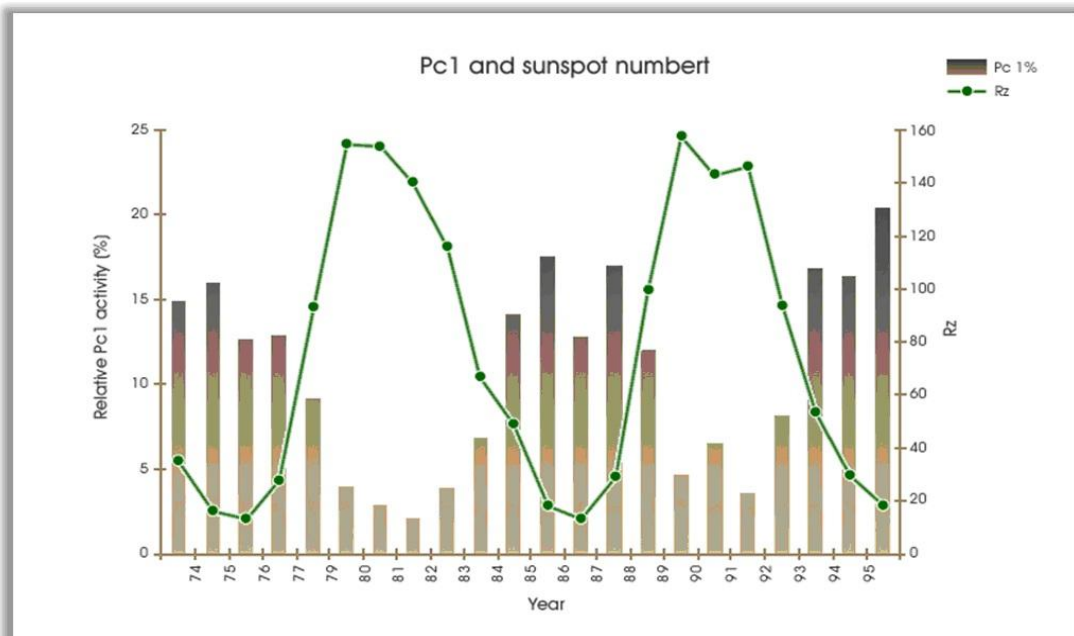


Fig. 6. Comparison of Pc1 (shaded brown columns) and the solar cycle pattern (green line), measured from 1973 to 1995 at the observatory in Sodankylä by Kangas et al. (1999).

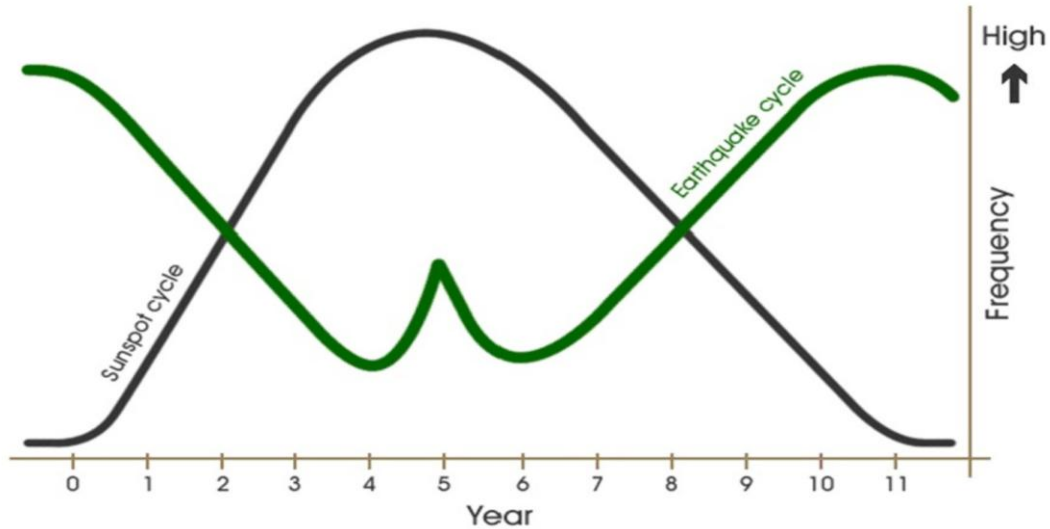


Fig. 7. Diagram of solar activity patterns (black line) with respect to the number of earthquakes on a global scale (green line), in the hypothesis of Choi and Maslov (2010).

From experience gained since 2009 the radio anomalies associated with increases in the geomagnetic background prior to earthquakes of high energy, can occur in four different ways, with different duration and type: Type A from 12 to 15 hours, Type B from 6 to 8 hours, Type C and Type D of four hours, a duration of 2 hours before normalization, i.e. an abrupt decrease that lasts until the earthquake occurs (**Fig. 8**). From an operational point of view, it has been noted that the increase in geomagnetic background and the appearance of radio anomalies are always followed by a normalization which precedes, in the overwhelming majority of the cases studied, the seismic event (**Fig. 9**).

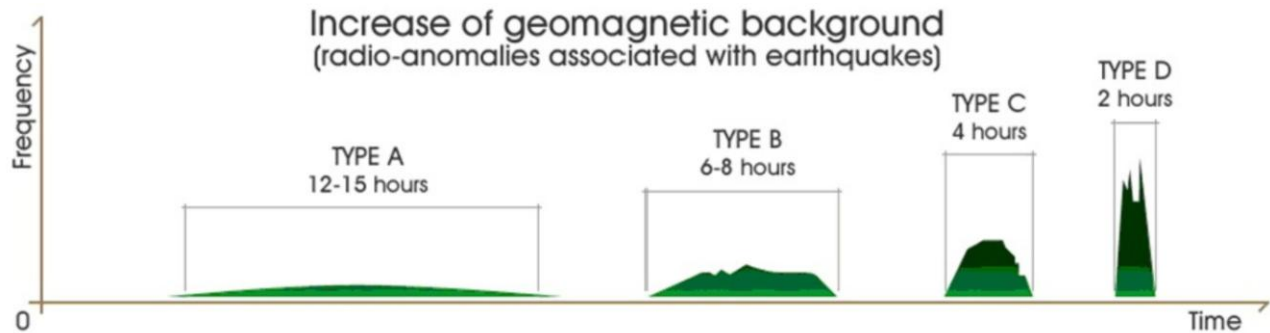


Fig. 8. The figure shows the four modes of appearance of the geomagnetic background before a potentially destructive earthquake of magnitude M6+. Type "A" from 12 to 15 hours before, "B" from 6 to 8 hours, "C" four hours, and "D" 2 hours prior to the main shock. You can note the increase in frequency depending on type as the unleashing of the earthquakes becomes more imminent.

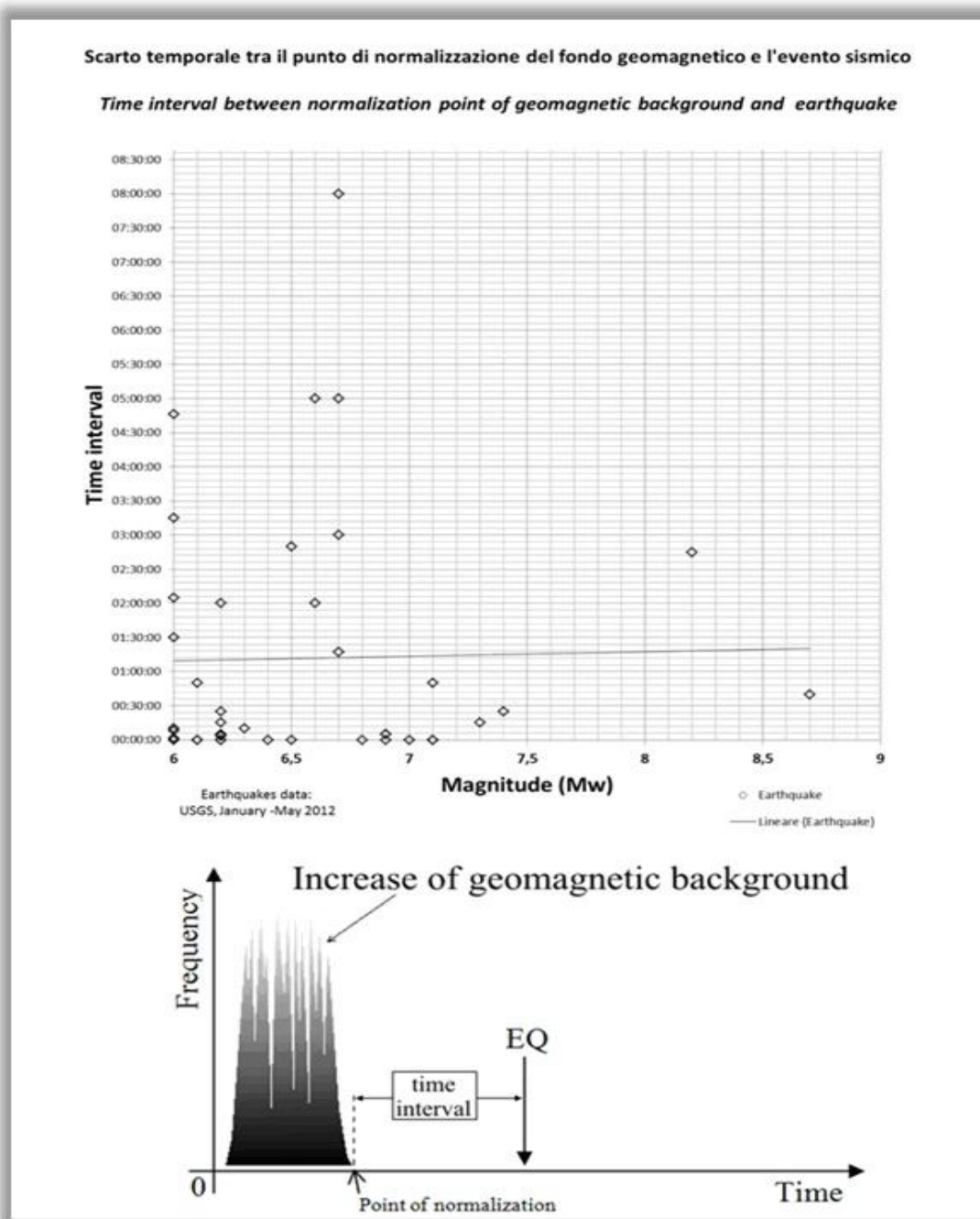


Fig. 9. Time lag between the point of "normalization" of the geomagnetic background and an earthquake with a magnitude of M6+. By point of "normalization" is meant the period of time following the sharp decrease in the geomagnetic field in Types "A", "B", "C" and "D".

After conducting an investigation into the repeatability of the relationship between the increase in the geomagnetic background and seismic occurrences, as an experiment the contrary operation was carried out: i.e. increases in the electromagnetic background were awaited to see whether the times of occurrence of global earthquakes with a magnitude of M6+ were respected, within an interval of 15 hours from the time the geomagnetic background stabilized. The result was encouraging, and the time intervals between the normalization of the geomagnetic background and earthquakes with a magnitude of M6+ were duly complied with (Fig. 10).

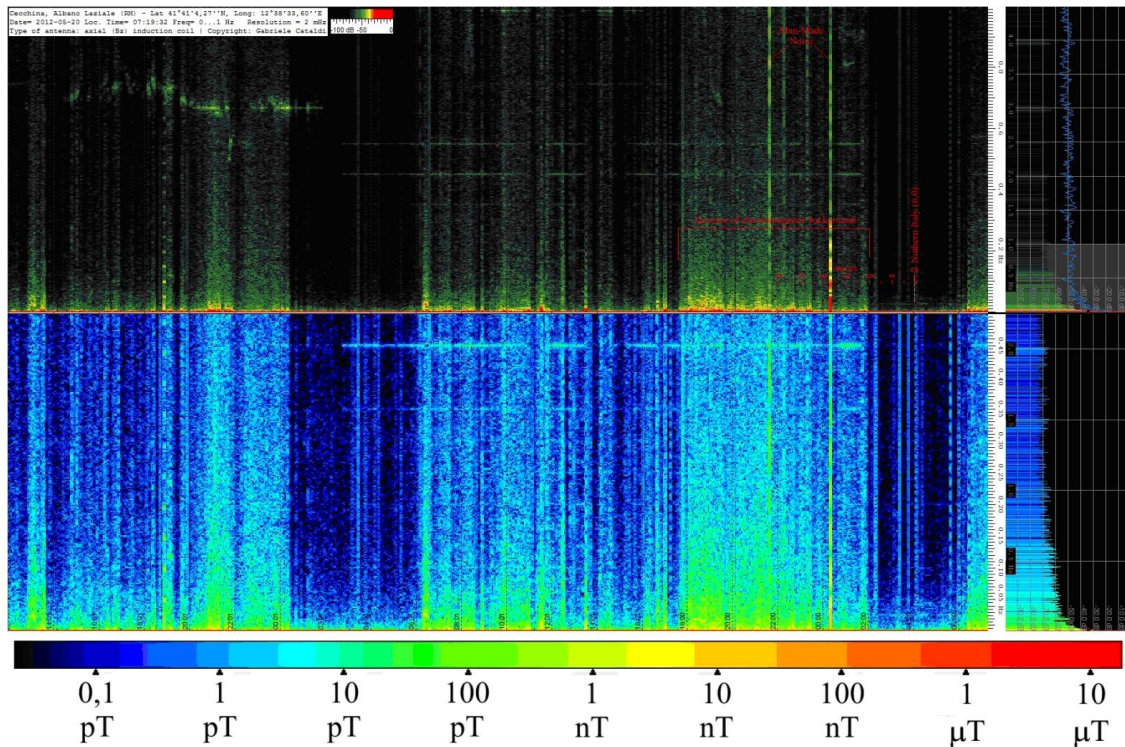


Fig. 10. The appearance of IDPD and radio anomalies before the earthquake of 6 June 2012 in Northern Italy. In the spectrum can be noticed also the increase in the geomagnetic background and the point of normalization before the seismic event (Courtesy of Gabriele Cataldi).

The experience was further extended to verification of earthquakes of magnitude less than M5, from the seismic sequence of the Emilian Po Valley, with a surface hypocentre approximately 500km away from the monitoring station. The superficiality of the foci, within 10 km of the surface, and the relative proximity of the monitoring station probably amplified the signals (and also in the Pollino sequence). Similarly, the same considerations were made for the seismic sequence of Pollino (Italy) in October 2012, which provided the same information as the Emilian sequence (also in Italy).

Despite the overlapping of the signals, the relationship was respected, and the difficulty that presented itself was that of discriminating the geomagnetic background values from the major earthquakes of the Emilian Po Valley and Pollino sequences and those on a global scale. A feature, the latter, which represents one of the limits of application of the Method of Investigation proposed in this study.

If, on the one hand, the two-way relationship between the increase in geomagnetic background, the radio anomalies, IDPD and Pc1 is respected in major earthquakes, on the other, the question remains open regarding the mechanism that actually generates the geomagnetic anomalies.

A first consideration on the interpretation mechanism concerns the relationship between the radio anomalies, the fracturing mechanisms of the rocks and the consequent movement of the fault blocks. In this regard, the following mechanism can be surmised.

In the initial phase the fracturing of the rock proceeds through orthogonal breaks (**Fig. 11**) and, as the stress gradually increases, the fractured parts of the rock (lithons) are rounded off and cause a decrease in particle size (**Fig. 12**) in the heart of the fault (Storti et al., 2003). Then, when the friction decreases, it generates the dislocation of two blocks which may give rise to an earthquake. It is assumed that at this stage, the process of fragmentation of the rock, in the presence of piezoelectric minerals, generates electromagnetic fields and radio interference. Upon the stress ceasing, and prior to the dislocation, the electric field drops abruptly and

becomes stable, since the friction movement is now exhausted. The first phase is associated with the fracturing of the rock in the heart of the fault and is represented by variations in the electromagnetic background, while the second coincides with the abrupt decrease in the geomagnetic field and the instrumental stasis preceding the earthquake.

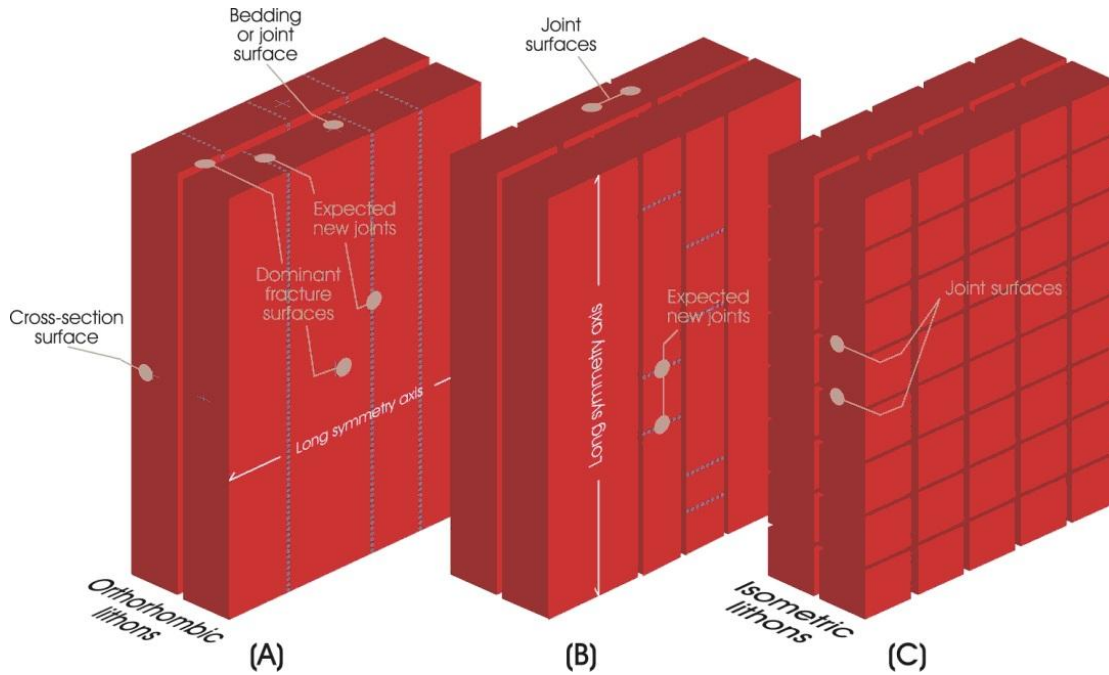


Fig. 11. Progressive fragmentation of the "lithons" under tectonic stress. The fracturing of the rock proceeds with orthogonal breaks that disrupt, over time, the rocky complex until dislocation occurs. Courtesy of Prof. Fabrizio Storti (drawing modified).

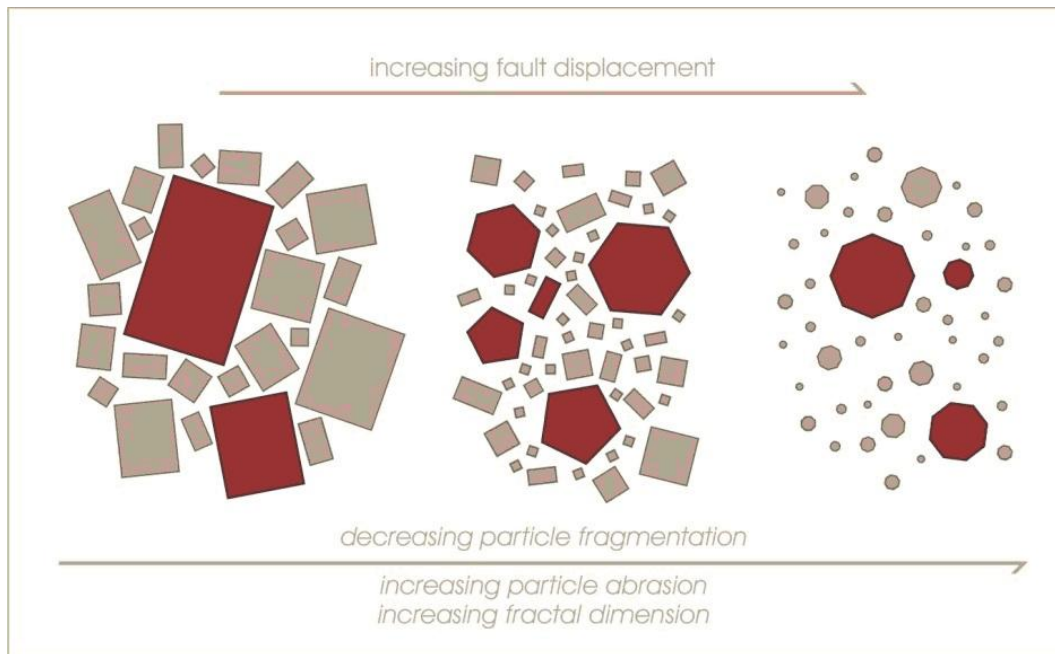


Fig. 12. Decrease in the size of the particles of rock placed under tectonic stress in the heart of the fault. The progressive decrease in the rock fragments promotes the circulation of fluids and dislocation of the fault blocks.

Since IPDP indicate a change in terrestrial plasma, it is believed that there may be a lapse in interaction between the increase in electromagnetic background during the run-up to an earthquake of high energy and the IPDP in the plasmopause and plasmasphere.

Another hypothesis on the interaction between radio-anomalies and satellite measurements:

The mechanism hypothesized is that stress produced underground can emit electromagnetic waves. And, to the possibility of finding electromagnetic emissions not linked solely to the variation in the magnetospheric background we must also add the phenomena of propagation of Electromagnetic Waves inside the Earth, exactly as happens for seismic waves (Palangio, 1993). In practice, it is possible that the electromagnetic fields produced by an earthquake manage to propagate inside the terrestrial crust to bounce off the innermost layers of the Earth exactly as happens to a ray of light when it passes through transparent materials with a different refraction factor due to different density. This phenomenon is known and, therefore, the probability of observing a radio emission deriving from a transmission of this type is not to be discarded. All electromagnetic emissions with a frequency between 0 and 1,000Hz can pass right through the planet without undergoing a reduction in intensity (Palangio, 1993). Within this "range" are also emissions of low pressure plasma, of a type that we can observe in our atmosphere.

Further explanations on the physical nature of anomalies in the ELF band have been provided by Draganov (1991) and Fenoglio (1995). However, it is now certain that this type of emission can be recorded at any point on the Earth's surface since they undergo virtually no significant attenuation if they are generated at a depth of around 10 km.

Acknowledgements: I am particularly indebted to Gabriel and Daniel Cataldi and LTPA Project Rome for providing the useful and indispensable data for this study.

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THE RAFFAELE BENDANDI EARTHQUAKE WARNINGS BASED ON PLANETARY POSITIONS

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Abstract. Raffaele Bendandi was well known during the first half of the twentieth century for his warnings on the onset of earthquakes which were made in newspapers worldwide. Today however, his name is less known and his forecasting method remains mysterious. Recently, a false claim that Bendandi had predicted a strong earthquake for Rome, Italy, on May 10, 2011, renewed interest in his warnings. Here, the warning characters are summarised, and it was seen that they had confirmation by newspapers and catalogues. Being so, through a comparison with past seismic events, using historical data, we would be able to express an opinion on these warnings.

Keywords: *planetary configurations, moon tides, earthquake predictions, historical catalogues, Raffaele Bendandi*

Introduction

Raffaele Bendandi, see **Figure 1**, was born in Faenza, Italy on October 17, 1893. His family was one of modest wealth, which is why he attended elementary school only up until the fifth year. Following this, he attended in a technical drawing specialization course, given his attraction to the mysteries of both astronomy and earthquakes. The total eclipse of the Sun on August 30, 1905 spurred him to pursue independent study on celestial phenomena and later influenced his decision to become an ornament woodcarver, which permitted him more time to devote to his astronomical studies (Fidani, 2009).



Fig. 1. Raffaele Bendandi circa 1960.

Upon hearing about the Messina earthquake of December 28, 1908, and reading on the Perret prevision of this earthquake based on the Moon-Sun positions (The New York Time, 1909), his studies of earthquakes truly initiated. Guided by a basic knowledge of astronomy, he used the principle of tide phenomenon that considered planetary positions and those of the Moon and Sun. The expert skills obtained in building precision mechanisms during a period as a watchmaker, enabled him to build a seismograph that was eventually sold worldwide (Lagorio, 2009). He became a member of the Italian Seismological Society in

1920 (Lagorio et. al, 1992). On October 27, 1914 he made his first attempt in predicting an earthquake, for January 13, 1915. This prediction was made by Bendandi and recorded in one of his notebooks. A seismic event on January 13, 1915, in Avezzano, Italy, gave him further impetus to continue his studies. Bendandi went on to analyse more than 20,000 past earthquakes. On December 20, 1923 he made his first officially registered earthquake warning by way of a notary act (Bendandi, 1924).

Here, the warnings collected by Bendandi are summarised. Many of these warnings had confirmation in newspapers. Moreover, the first and last warnings made by Bendandi over his lifetime were investigated.

Nature of warnings

In order to understand the character of Bendandi's warnings of impending earthquakes, the Raffaele Bendandi Observatory Archives, Via Manara n.17 in Faenza, Italy, were analysed and a catalogue was composed. The catalogue of earthquake warnings covers a period from October 1914 to April 1977 (Fidani, 2009) and includes, 143 seismic events located in the Mediterranean region and 167 in the rest of the world. The listed seismic events are not distributed evenly over the 63 years. Between 1924 and 1927 Bendandi's warnings appeared in newspapers weekly, monthly and fortnightly. During some weeks more than one warning appeared in newspapers. The number of newspaper articles gradually declined until the end of 1927 and in early 1928 they completely disappeared when the Italian government "*prohibited Bendandi from making further predictions*". The motivation for this decision was "*that these predictions were damaging Italian tourism*", and also encouraging emigration (Castelli, 1927). Few publications appear in years 1939/40. From 1950 up until 1964 a continuous Bendandi resumed his warnings activity. Furthermore, some seismic warnings were published in the years 1971 to 1977. There are also a series of papers in the Bendandi observatory containing dates without any reference to them, including May 10, 2011. It was from this that the unfounded claim that Bendandi had predicted a strong earthquake for Rome, Italy, on May 10, 2011, began circulating (Cartlidge, 2011); when in fact the location of Rome is not indicated in the archives. These dates without references could refer to solar activity, but it cannot be said that these dates are associated to seismic activity. Being so, one cannot reliably deduce future seismic events from these dates, given that Bendandi's method is not clearly understood.

Most newspaper warnings included multiple seismic events. The number of events for each warning ranged from one to thirteen. Each expected event included a date and location, and the spatial and temporal intervals covered were highly variable. Generally speaking, the descriptions of expected events up to the 1940's were more detailed and richer in earthquake number than those coming later. Up to 1940, Bendandi's articles described very precisely the warning by indicating the times, locations and intensities of events. The timings of events were very specific with: within a day in most cases and within a few hours in other cases. To define the intensity of a shock, words such as "mild", "moderate", "minor", "strong", "violent", "violent" and "parossisma" were used and in some cases the grades of the Mercalli scale were referred to. Bendandi explicitly stated that he was not able to determine with precision the location. When speaking about locations, he estimated a range of up to several hundred kilometres. Up to 1940, his articles were generally divided into two parts: the confirmation of previous warnings, with extensive discussions on the history of epicentres affected by strong earthquakes, and expected seismic events. The shocks that Bendandi considered were those of high intensity, capable of swinging the nibs of the most sensitive seismographs for several hours. He argued several of his warnings using graphs that indicated the height of the curve as a crust stress index, and warned that events would occur near these peaks. Finally, Bendandi stated that in order to consider warnings of impending earthquakes as a scientific achievement, they should be of the same type as meteorological forecasts (Bendandi, 1924).

Bendandi research

Bendandi's research on earthquakes was documented from research carried out by scientists who had published simultaneously with Bendandi or earlier. Confirmation of this can be found in Bendandi's home library in Via Manara 17, Faenza, Italy. Moreover, a vast quantity of newspaper articles regarding earthquake warnings and phenomena can be found in the same library attesting to Bendandi's profound knowledge of astrophysics and geophysics. To sustain these affirmations, in Faenza it was recovered the text

by Father Alessandro Serpieri, in *Sismological writings* (1888), which dealt with the possible influences of the Moon and the Sun on both the Earth and earthquakes. But, prior to this, Bendandi must have previously read the 1908 prediction, which revealed to be true in Messina on December 28, 1908, for a major earthquake or eruption in Sicily for the end of the same year by Perret (1908); which was based on the Moon tide and the Sun tide composition. However, subsequent predictions by Perret for 1909 failed and scientific interest in Perret's method waned. This was not the case for Bendandi, whose scientific research was rooted in astronomy. Bendandi's original approach to the study of earthquakes was based upon tidal forces, including the contributions of planets, which has been recently acknowledged (Fidani, 2006; Straser, 2008; Straser 2010). Additionally, this approach allowed Bendandi to confirm his pioneering theses (Bendandi, 1924), by analysing past planetary configurations and corresponding earthquakes. After the 1930's, these studies were the basis for other important research. Specifically, Bendandi's thesis on Sun activity leads to his hypothesis on the genesis of the eleven-year solar cycle, and the enigma of variable stars. The variabilities of these celestial bodies were associated by Bendandi with the positions of their planets. In these two fields of astronomy Raffaele Bendandi wrote two books: "A fundamental principle of the Universe: Genesis eleven-year solar cycle" (1931), and "A fundamental principle of the universe: the Stars Variables", 1932, the latter of which has only been recently published (Bendandi, 2006). This principle elucidated in these two publications was the same principle behind Bendandi's earthquake warnings. However, Bendandi never revealed the association between his principle and earthquakes, as he was not able to precisely predict earthquake position. He feared that revealing this association would have given academic scientists an advantage in resolving this problem (Bendandi, 1924). Bendandi's principle states that: "the link between the disturbances", be it an earthquake or solar and star emissions, "was the imbalance created by the phenomenon of gravitational tide produced by other larger and closer celestial bodies" to those considered (Bendandi, 1924; 1931; 2006). The major results obtained from this principle were three: an earthquake warning method, a Sun spot warning method and a method for interpreting light variation of other stars. Here, a single law is applied to solid crust and gaseous bodies, to explain three apparently distinct phenomena. Furthermore, tidal phenomena occur including the entire earth crust or gaseous bodies simultaneously. This is a type of global crust perturbation (Bendandi, 2006) that permitted Bendandi to formulate multiple earthquake warnings.

The method as described by Bendandi

Even if Bendandi did not reveal the exact method to build his warnings, he described the first steps of it in various newspapers in Italy. First of all, from the warning catalogue, it was observed that the warnings evolved in typology. In fact, prior to World War II, in connection with gravitational influence, the warnings were accurate and detailed in place, time and intensity. Bendandi repeatedly stressed that earthquakes were events that interested the entire globe (Bendandi, 2006). He elaborated on this point, saying that this lack of a global vision prevented others from successfully predicting earthquakes. From the 1950's onward, Bendandi's warnings became limited in number, imprecise and part of a more general forecast. This change in thinking reflected his inclusion of the Sun and possible Earth-Sun relations in his warning method. In the broad context of solar influence, many terrestrial phenomena were included in Bendandi's study: meteorological excesses, auroral and geomagnetic emissions, aeroplane accidents and increasing criminality. All of these, together with earthquakes, formed the so called "cosmic crisis", while the shared cause seemed to transform from a tidal effect to an electromagnetic effect of the solar wind. In fact, on several occasions Bendandi wrote that "*they are the power electromagnetic currents originating from the Sun which are responsible for the entire terrestrial activity*" (Bendandi, 1962).

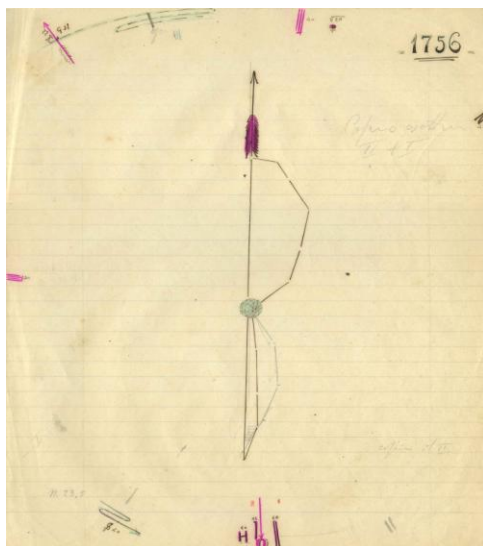


Figure 2. The parallelogram rule designed by Bendandi for two dates in 1756.

Following his indications (Bendandi, 1924), the initial method started by calculating the planetary positions in a given epoch. Then, an intensity of the perturbation was assigned to all celestial bodies and were composed in a design according to the parallelogram rule, see **Figure 2**. The intensities of each planet were empirically obtained by Bendandi by studying past earthquakes. From this, it was possible to calculate geometrically the resultant vector. The next step was to determine the period it reached the maximum value. In this same period, the gravitational contribution attributed to the Moon must be considered. Specifically, when the Moon goes through the resultant planetary, along its motion, the vector sums the gravitational contribution. Following this, the Earth suffers a maximum perturbation. For Bendandi, earthquake intensity was linked to the resultant intensity, time was linked to maximum resultant time while the position was indicated taking into account the maximum crust stress due to the tidal field.

The first earthquake warnings

Here we began with verifying the first warnings. The first official forecast by Bendandi was issued by deed on December 20, 1923 (LA NAZIONE, 1924; **Figure 3**).

NOTARY ACT

«Vittorio Emanuele III, by the grace of God, and the will of the Nation, King of Italy.

«The year 1923, this day of Thursday, December Twentieth in Faenza, Italy, in my notary office in Corso Garibaldi, n.o 8. In my presence Dr. Domenico Savini, Royal Notary resident in Faenza, inscribed at the Notary board of Ravenna, in the presence of the gentle person Olimpia Careli employed and Querzola Edward a.k.a Angelo employed; both born and domiciled in Faenza, called upon as witnesses, known and suitable under the law, you are here Mr: Raffaele Bendandi, son of Angelo, woodcarver, born and domiciled in Faenza, adult under law and of age, of his own will, which this notary has verified, has asked me to declare the following:

«The telluric events ahead between now and January 10, 1924 are two:

«The first, on December 21, that is tomorrow, from America (Central America).

«The second, however, will be greater in intensity on January 2, with a probable epicentre on the Balkan Peninsula, or at least in the Aegean Sea.

«Having prepared the patent to consign to the two parties, drafted by a colleague under my supervision, herein will be signed by Mr. Bendandi, witnesses and myself the Notary, after having read the Act to Mr. Bendandi, who attested to be fully satisfied with the document, in that it fully reflected his will. This document is made up of a single sheet of legal paper, that occupies two full pages and two lines of a third page.

«F.ti: Raffaele Bendandi; Olympia Caroli, witness Edward Querzola, witness Dr. Domenico Savini, Notary in Faenza;
«Registered in Faenza, December 20, 1923 Vol 84, No 485, reg mod 1. Exact fee: seven lire and ten cents. The
receiver: Suglia.



Figure 3. One of the titles that appeared in a newspaper in January 1924.

The confirmations to the first warnings

Confirmation of these warnings were reported by Italian newspapers in the early days of January 1924, see **Figure 4**, according to the reports, an earthquake struck the region of Sonora on 21 December 1923, an earthquake struck the coast of Senigallia, Marche Region, January 2, 1924 (Cavara, 1924). Currently, the verification of earthquake warnings time is very difficult due to the lack of tools that were available in the last century. In this case, there was not indication that the first shock was recorded by the Mexican seismic network. Furthermore, the first report of an earthquake in Central America came from the city of Douglas in the state of Arizona. There are modern scientific studies and catalogues that cite two important events in that period. The first of these was an event in the city of Granados in the state of Huàsabas, occurred in the north-east of Sonora on December 18, 1923 at 5 am, see Figure 3, with an intensity of $M = 5.7$, followed by

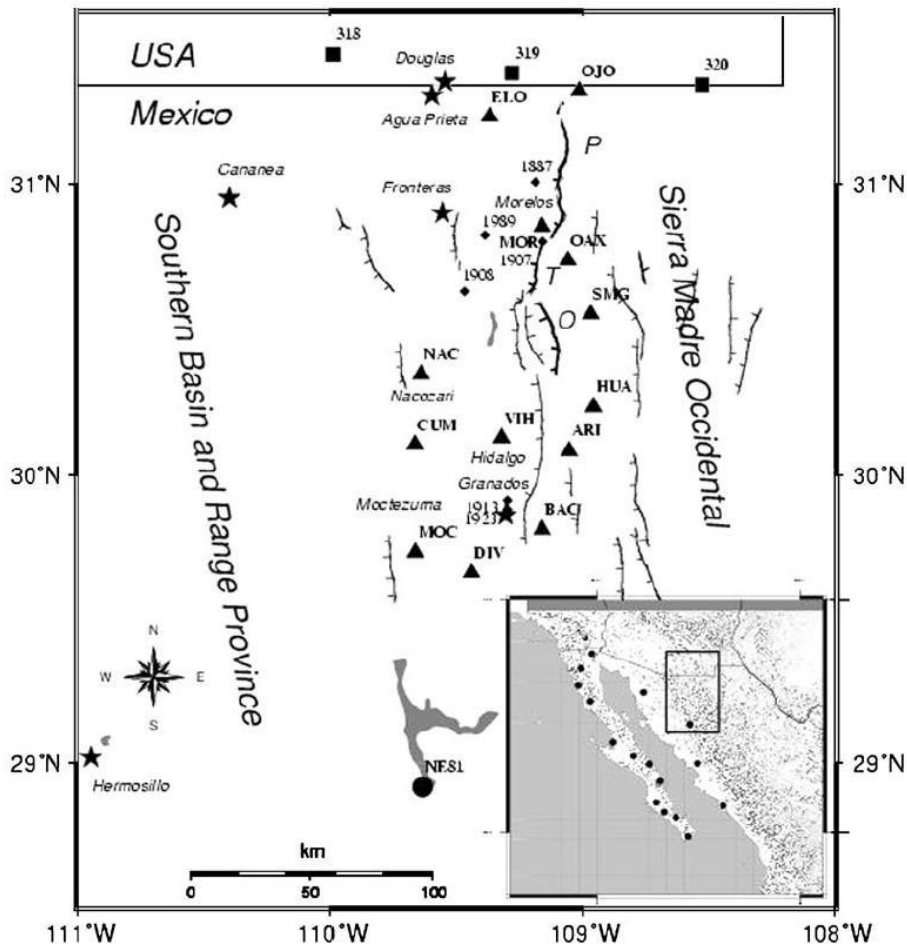


Figure 4. Mexican seismic activity in the region after the massive earthquake of 1887, the event of 1923 took place near Granados; from Suter, 2001.

another event with a lower magnitude, on December 19, 1923 at 6 am (Suter, 2001). The inhabitants of the Arizona neighbourhood felt a tremor at 9 pm on December 19, 1923 attributing that moment as the time of the quake in Mexico (Suter, 2001), this correspond to December 20th in Europe. However, the report reached Paris France on December 21, 1923 and this day could have been accepted as the date of the event, which was actually two days prior. Bendandi could not have known this because the report reached Italy on December 21 (LA NAZIONE, 1924).

The second event took place in Italy where the availability of devices for recording seismic waves was great. It was recorded that the earthquake hit Senigallia at 8:55 am on the second of January 1924, with an intensity of $M = 5.6$ (CPTI04, 2004), confirming the warning. This event occurred on the day that Bendandi indicated but it had a different epicentre, with an error of a few hundred kilometres. Months later, Bendandi stressed that his warnings were not yet resolved regarding the issue of location (Bendandi, 1924). It should also be noted that this earthquake was less intense than the first. However, there was a coincidence regarding time and space between these two earthquakes and the warnings. Additionally, the two earthquakes were the most important events of this period according to Bendandi.

From seismic archives, there is no information on events occurring in the Balkan Region in Europe with the same intensity in the weeks before or after January 2, 1924 (Catalogue, 1990). The two events closest to January 2 occurred in the Balkan Region in Chalkidiki, Greece, at 8:57 pm on December 5, 1923, with $M = 6.4$ (Catalogue, 1990), and in Sibenik, Croatia, at 8:39 am on January 29, 1924, with $M = 5.3$ (Catalogue, 1990, Herak et al., 1996). Regarding Mexico, strong shocks were not recorded for several years before or after 1923 (Suter, 2001). In Colombia, however, reports stated that major shocks took place on December 14, 1923 at 10:31 am, with $M = 7$, and on December 22, 1923 at 9:55 am, with $M = 5.5$ (Espinosa et al., 2004).

The last earthquake warnings

The Author chose to examine the last warnings instead of the others to contradict the recent May 2011 prediction (Cartlidge, 2011) erroneously attributed to Bendandi. For this reason, it was chosen to analyse the warning released to the media in 1977. These warnings were not very precise about dates, which were disclosed on March 3, 9 and 12, 1977 (Bendandi, 1977a). On March 3, Bendandi announced the beginning of a "*cosmic crisis*", of which large earthquakes are an aspect. On March 9, it was reported that: *Announced on 9 March (Bendandi, 1977a) for now no new ruinous shocks in Romania; shock of a certain intensity in the coming months in the Balkan region, in particular, will suffer under seismic centres of the Aegean and Ionian islands; repercussions in Smyrna and Asia Minor; outbreaks in Ochrid and the islands of Kefalonia will suffer significant setbacks, in Romania, before the autumn with shocks to Gallipoli, in the Sea of Marmara and on the coasts of Turkey.* On March 12 (Bendandi, 1977b) it was reported: *no serious problem for the region of Romania, shock sensitive enough to the Philippine Islands, endogenous tremors in the Ionian Sea between the islands of Zakynthos and Kefalonia, at the end of August on the Balkan peninsula.* These are the most recent earthquake warnings recovered from documents reviewed in the archives in Via Manara n. 17 in Faenza as well as the National libraries in Rome and Florence, Italy.

The confirmations to the last Bendandi earthquake warnings

On March 4, 1977 there was a devastating earthquake in Vrancea, with $M = 7.2$, **Figure 5**. With more than a thousand victims in the city of Bucharest, Vrancea Region, Romania. The earthquake was one of the most tragic in the history of Romania, but the American Geological Institute reported another possible strong earthquake that should have involved Romania (Bendandi, 1977c). Also in Italy, a year before, there was a strong earthquake in the Friuli Region, which was followed by another strong shock months later (Pondrelli et al., 2001). Four months prior to this, Raffaele Bendandi had published warnings on this phenomena (Il Resto del Carlino, 1976). To this regard, he wrote that "*a renewal of seismic activity was expected for the beginning of May 1976, in Northern Italy*", in December 1975. Indeed, a strong quake struck the Friuli Region of Italy at 9 pm on May 6, 1976, $M = 6.5$, which caused 965 deaths, while on the 11th and 15th of September, 1976, two quakes struck on each day in Friuli causing a total of 12 deaths: $M = 5.1$, 5.6 and $M = 5.8$, 6.1 respectively. For this, Bendandi wanted to guarantee that no great phenomenon would hit Romania

before the autumn. Consulting the catalogue of Central and South Eastern Europe (Shebalin et al., 1990), we can verify that indeed the next major earthquake having $M = 5.1$, struck the same region on January 1, 1978, and an earthquake of high intensity occurred only August 30, 1986, having $M = 7.1$. With regard to the Peninsula Balcanica, according to the catalogue of earthquakes in Central and South East (Shebalin et al., 1990), during the second half of July and the second half of September 1977 three significant events on the mainland occurred. On July 18, at 10:09:15 LT, in Albania there was an event with a magnitude of $M = 4.8$. On September 20th, 1977, at 20:28:18 LT, in Bosnia-Herzegovina there was an event with a magnitude of $M = 4.6$. On September 23th, 1977, at 02:58:02 LT, in Albania there was an event with a magnitude of $M = 4.6$. But it was between the Aegean and the Ionian Seas that the activity became more intense. In fact, from the seismic catalogue of Greece (Catalogue, 1999) it is possible to verify the existence important events on: August 18, with $M = 5.4$, September 11, with $M = 5.8$, and again October 22, with $M = 5.1$, near the island of Crete. While on July 30 and August 31 there were four shocks of moderate intensity in the Ionian Sea near the Zante and Cefalonia islands, $M = 4.5-4.9$. Finally, there were various shocks that hit the coasts of Turkey on October 5 and 27, having $M = 5.3$ and 5.0 , and on November 28 and December 16, having $M = 5.4$ and 5.3 (Catalogue, 1999; Tan et al., 2008).

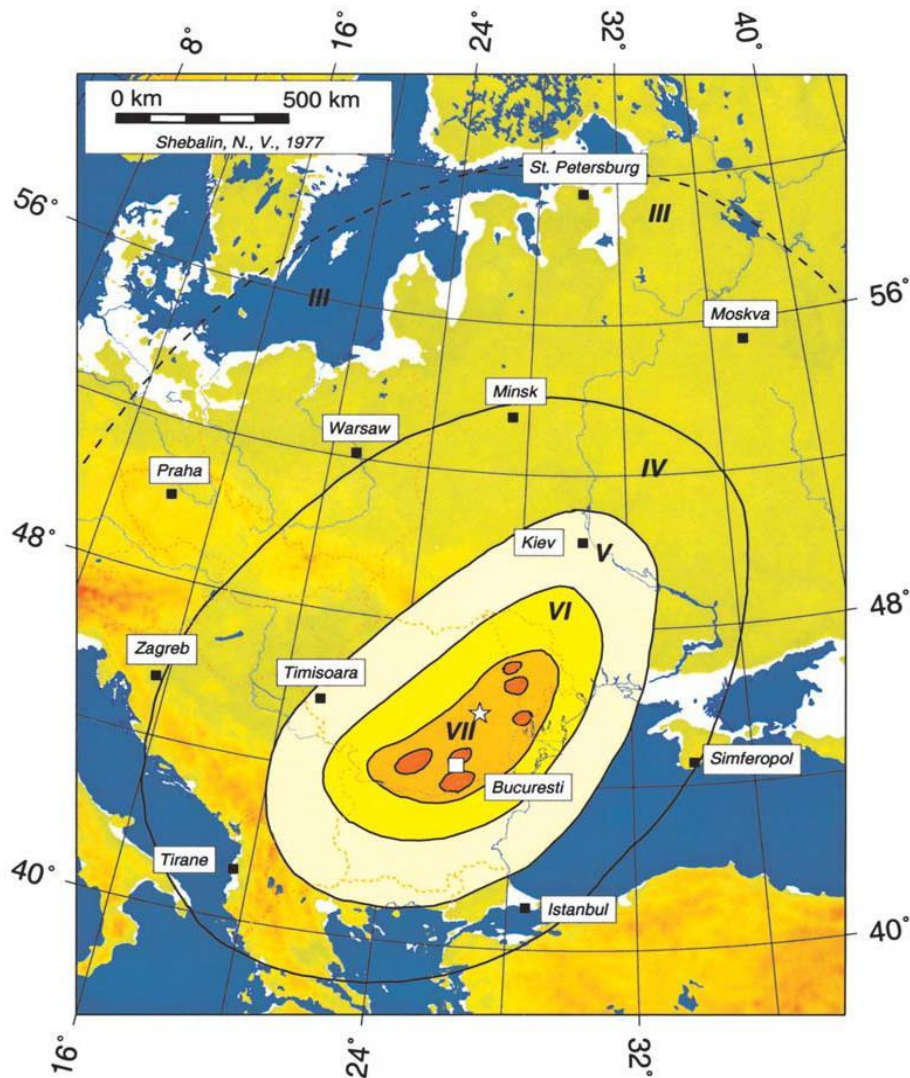


Figure 5. The considerable depth of the earthquake was felt in Vrancea and the effects of the event were felt in half of Europe. The Philippines were hit by a strong earthquake on March 18, 1977, with $M = 7$, as documented in many newspapers in that period, and an even stronger event on July 21 of the same year, with $M = 6.9$ (<http://earthquake.usgs.gov/regional/neic/>).

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ESSAYS

EARTHQUAKE AND VOLCANO “PREDICTABILITY” VS. CRUSTAL DIAGNOSIS

Space-time scale sizes & error bars
Societal information and moral responsibility issues

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Abstract and preface: Several phenomena have been reported to be possibly associated with a subsequent strong earthquake. No simple compilation appears, however, to be enlightening. In addition, since the mechanisms are largely not understood, it appears awkward, if possible at all, to make any structured review of this apparently unsolvable problem. On the other hand, the tremendous tragedies, which almost every few years affect a large number of people, is such that every mere academic debate appears nonsense and ethically unacceptable.

Either for clarity or for “simplicity” or for brevity purpose, the criterion that I followed has therefore been to attempt to assess some basic set of phenomena, which can be considered as a starting and reliable benchmark for a concrete subsequent discussion. I have therefore considered every candidate precursor, first of all, in terms of its *robustness* and of its *error bar*. *Robustness* is concerned with the amount of false alert that ought to be released if it relies on it. In other words, it is concerned with the number of events that occur and that are not followed by the expected seismic event. The *error bar* deals rather with the domain, in space and time, where the precursor is observed and that precedes a given earthquake. Indeed, this domain ought to be practically suited for societal needs.

Therefore, several seemingly promising and intriguing precursors, which at present are being investigated by authoritative Earth’s scientists, could not be included in the present treatment, as at present there is still need to collect additional case histories, in order to estimate their respective robustness and error bars.

In particular, the reader ought to refer to several recent impressive attempts, which are reported in several issues of the present electronic journal. In this respect, the present paper is supposed to be hopefully followed by additional studies also by other authors, inspired by some similar criterion, aimed to set order in this discipline, which at present appears certainly excessively dispersive.

Summarizing, the result of the present paper appears to be almost a concise “handbook” for the practical management of earthquake and volcano “prediction”. This study, however, is to be considered only as a first working document, to be improved as soon as additional findings appear in the literature.

At present, this discipline appears often confused, hence sometimes unduly debated. It is a moral obligation for Earth’s scientists to set order in this vaguely defined topic. Some hard thinking is certainly required. An operative and conceptual order can be achieved only by applying a screening of methods and arguments, by means of subsequent step-by-step methodological and critical improvement.

In the present paper, the meaning of “forecast” is first clarified, as it is the source of some basic - and very unfortunate - misunderstanding, mostly concerning communication between scientists, society, legislators, and decision makers.

In addition, the “myth” has to be destroyed of the existence of any “magic” phenomenon capable to “forecast” earthquakes, because every event is a different case history and it must be considered independent of every other earthquake: any two events are never strictly comparable each other.

The planning of the presentation which is here given is threefold, dealing separately with the “forecast” of either (1) *magnitude*, or (2) *epicenter location*, or (3) *occurrence time*. An appendix separately deals with some general methodological items that are largely shared by every kind of “forecast”.

Acronyms and definitions:

AE – acoustic emission

d.o.f. – degree of freedom

deontology – It is one approach of virtue ethics. “*Virtue ethics is currently one of three major approaches in normative ethics. It may, initially, be identified as the one that emphasizes the virtues, or moral character, in contrast to the approach which emphasizes duties or rules (deontology) or that which emphasizes the consequences of actions (consequentialism).*” [Stanford Encyclopaedia of Philosophy, March 8th, 2012].

e.m. - electromagnetic

ETS - episodic tremors and slips

GPS – global positioning system

HF – high frequency

InSAR - Interferometric Synthetic Aperture Radar

LF – low frequency

LFE - low-frequency earthquakes

LLR - lunar laser ranging

LY - light years

rms - root-mean-square

SFO - seismic free oscillations

SG - superconductor gravimeters

SHE – spherical harmonic expansion

SSE - slow slip events

SST - sea surface temperature

VLBI - very long baseline interferometry

VLFF - very-low-frequency earthquakes

1. - Introduction

The present paper is a concise discussion of the general strategy for seismic and volcanic “forecast”, including scientific methods, feasibility and costs, societal communication, legislative needs, and items concerning the duties of all people involved (i.e. concerning their deontology). It contains no original research contribution, but is a multidisciplinary synthesis referring to one specific focal problem. It aims to be a common-sense realistic assessment of the state of the art, on the basis of practically feasible and reasonably simple and well assessed tools, with no presumption for completeness, and leaving room for future inclusion of additional algorithms and methods, whenever they will arise. This is not a review of seismic or volcanic precursors (for this see e.g. Cicerone et al., 2009).

Owing to the very wide spread of different topics, methods, concerns, disciplines and techniques that are mentioned here, it is impossible to give extensive bibliographical references for every item. Pertinent quotations and references are given in the framework of a much longer study, which is currently in preparation.¹ The present paper is a summary of the conclusions of that much longer study.

I apologize to those authors who's studies are not fully acknowledged. I had to be very selective to focus on methods that appeared comparably more robust, hence more reliable. It will certainly be possible (and necessary) in the future to add new methods to the much simplified framework presented here.

In particular, at present a particularly vivid progress is ongoing, as reported in several recent issues of *New Concepts of Global Tectonics*. These alternative methods, however, at present are being developed, and a

¹ It is a monographic study I am carrying out since several years. A full draft has been completed and at present it is in the process of final revision. The title is “*Climate and the atmospheric electrical circuit - The electromagnetic coupling between solar wind and Earth*”. It contains over 6,000 pages, planned to appear 8 volumes. *Volume 1* deals with the magnetosphere and upper atmosphere. The *2nd* and *3rd volumes* deal with the internal voltage generator, including endogenous processes and geodynamics. The *4th volume* deals with the atmospheric condenser, with the atmospheric electrical circuit, and with the lower atmosphere. The *5th* and *6th volumes* deal with several specific climatological items. The *7th volume* (Appendices) is devoted to a few mathematical and physical technicalities. The *8th volume* contains reference list, and subject and author index.

statistics of case histories has to be collected before making any final assessment on their robustness and error bars.

If we want to begin to put order into this much debated and often controversial discipline, we must start from a “simple” screening, with no concern with the search for all-inclusive, very long and learned, reviews. We must begin from just a few seemingly reliable methods, and construct a basic framework, which can be shared by the international community of scientists and decision makers.

A few quite general premises are first specified - either for clarification, or to avoid basic misunderstanding, and to focus on some crucial key items. I do not want to be contentious, but to be humble, realistic, constructive and concrete.

- “*Ultimate truth*” is beyond human reach. The challenge of natural hazards and risks, which imply a potential large number of fatalities, must always be a primary concern, independent of every academic debate. It is just a matter of deontology (i.e. of moral responsibility) to allow for the possibility of different guesses, models, or interpretations, as nobody is depositary of “absolute truth”.
- *Feasibility and costs* must to be taken into account. In addition, *societal communication* (and also a correct science popularization) is fundamental. Popularization is concerned not only with the average man, but more importantly with legislators and decision makers: this is a key cultural challenge.
- “*Prediction*” in a strict sense is *never* possible,² when dealing with every kind of phenomenon, including seismic or volcanic forecasting. Even on a “probabilistic” ground, the longer the advance time of a “forecast”, the higher is the possibility that the physical system eventually changes its “reasonably predictable” trend.
- Since we cannot issue a “*prediction*” which is certain, it is more appropriate to claim that *we can* issue a reliable “*diagnosis*” of the physical system.³ For instance, no medical doctor can “forecast” the exact instant of time of the passing away of his patient. He can however, *diagnose* whether his health is improving or degrading etc. depending on several inputs, including the patient’s age, prognosis, environmental conditions, food, and other diagnostic parameters. *We cannot predict* catastrophes. But, in contrast with what is often claimed, *we can diagnose* the state of the Earth’s crust.
- The *reliability* of a “diagnosis” should always be clearly specified. For instance, society ought to be aware that the behavior of a volcano can be “forecasted” much more easily than a destructive earthquake.

² Astronomical movements are well-predicted, such as the phases of the Moon, etc. because some physical parameter (such as Earth’s or Moon’s mass or moment of inertia, etc.) overwhelms all unpredictable perturbations. However, when one considers the minor perturbations of the astronomical motion of the Earth (i.e. spin rate or pole motion), they cannot be predicted. And these apparently negligible phenomena have most relevant implications for catastrophe management. See below.

³ The term “*diagnosis*” is a common medical term. Several analogies are here mentioned between seismology and medical sciences. One might be concerned about using, for the present purpose, some different term (Martin Hovland, private communication). The term “*analysis*” is well known to have several meanings: it is a separation of any material entity into its constituent elements. It is opposed to “*synthesis*”. “*Prognosis*” (literally “fore-knowing”) usually means to consider the previous history of the health of a patient and of his family, in order to evaluate, on a statistical basis, the future evolution of his health and/or life expectancy. Therefore, in some way, “*prognosis*” is synonymous of “*prediction*”. But, if one wants to stress the misuse in seismology of the term “*prediction*” or “*forecast*”, no term better than “*diagnosis*” seems appropriate for this purpose.

- *Society* should be very well aware of the fact that every “forecast” always has some *chance to be incorrect*. For instance, if - owing to an expected heavy rain - a national Civil Protection releases a hydrogeological alert and the “forecast” later results to be wrong, nobody really minds. But a wrong alert for a volcanic explosion or for a strong earthquake triggers severe legal consequences etc. However, a forecasting mistake cannot be prosecuted only because it is associated with a great societal impact: at present, it is well known that a severe gap in legislation is a key bias in every country.
- In the final analysis, a crucial item of every “forecast” deals with its *multiparametric* character and its *error bars* [referring either (i) to space, or (ii) to time, or (iii) to the severity of the catastrophe].
- Contrary to what too often has been stressed in the scientific literature (and it is sometimes still stressed), it should be clearly emphasized that *no “magic”* parameter or phenomenon exists that can give a reliable and certain “forecast” of a catastrophe.

Every real professional and conscience driven Earth’s scientist must be well aware that there is need to monitor “all” possible diagnostic parameters. The system has a huge number of degrees of freedom (*d.o.f.*). We can observe only a very small fraction of them. Therefore, the state and evolution of the system must be diagnosed by taking into account “all” what can be realistically observed and objectively known.

- In general, scientists in every discipline like to deal with “*simplicity*” (e.g. Einstein, Dirac, etc.), i.e. simple rules, rules-of-thumb, intuitive arguments and models, etc. These rules enable us to match the complication of natural reality with the limited capability of human mind. In this way, however, during the development of science several *myths and paradigms* were generated. This often caused very harsh debates between different schools of thought. Also at present this contentiousness is a bias, and this drawback is naïve and – upon considering the severity of the societal impact of natural catastrophes – it is even deontologically irresponsible.
- In addition, while considering different parameters, their intrinsic *robustness* must always be taken into account.

Every quantity, which is either directly or indirectly measured or evaluated, has some intrinsic error bars, and eventually some unavoidable scatter. For instance, geoelectric parameters, soil exhalation measurement, hydrological data, etc. suffer by a large spatial scatter deriving from the uncertainties in the knowledge of subsoil structure that control fluid flow: hence, compared to other measured quantities, it has to be expected that in general their signal-to-noise ratio is relatively poor. That is, they are comparably less robust. Therefore, every precursor of this kind, whenever it is considered alone, must be managed with much care. It cannot be compared with other precursors that rely on comparably robust information.

Therefore, although these less robust precursors are certainly useful for a general assessment of the physical and chemical state of the system, they cannot be considered alone as a reliable source of information.

- While implementing some model for the interpretation of observations, it is sometimes convenient, or even unavoidable, to rely on the assumption of *scaling invariance* (such as it typically occurs when dealing with fractal or multifractal algorithms, which apply, however, only within well-defined and limited space-time domains).

In these cases, a warning deals with the distinction between *geometrical scaling* (i.e. when dealing with a repetition of the same behavior on different spatial scale sizes of the system), and *structural scaling* (i.e. dealing with the fact that every “simple” intuitive model is very often made of homogeneous material, which is much different from the heterogeneous structure of Earth’s crust, or of a volcanic system).⁴

A distinction ought therefore to be made between what is only a simple consequence of the nature of the physical laws that are shared by natural reality and by a different spatial scale model (i.e. deriving from *geometrical scaling*), compared to other effects, which are rather associated with the intrinsic peculiarity, composition and structure, of the system (i.e. deriving from *structural scaling*). This structural scaling is ultimately the most significant diagnostic information, because it focuses on the physics, rather than only on the size, of the system.

- When dealing with the physical nature of the process of a forthcoming catastrophe, it is well known that no phenomenon strictly occurs only at a “point”. Rather the *focal volume* is important for the generation of an earthquake, much like the *volume* of a volcanic edifice is important in the control of the pressure of the endogenous hot fluids, or the *volume* of a potential land slide, or the water *volume* for a flood, etc. That is, the storage of a given total amount of energy necessarily implies a physically discrete and *non-vanishing volume*, in order to store inside it the energy to be later released. This is just one example of a much general principle that can be expressed as “*principle of maximum density content of mass plus energy*”. That is, a physical threshold does exist that can never be overcome.⁵
- A key item, which at present seems to be generally forgotten by almost all Earth’s scientists, deals with fundamental and comparatively much different heuristic implications of *precursor* phenomena (i.e. which occurs *before* a catastrophe), compared to the information provided either by the occurrence of the catastrophe (earthquake or other) or of its *co-seismic*, or *aftershock* phenomena (which occur *after* the catastrophe).

That is, studying earthquake “prediction” by means of earthquake catalogues is, strictly speaking, *naïve and paradoxical*, for the same reason that medical sciences cannot progress by only relying on information provided by the autopsy of dead bodies, and from mortality statistics: rather they *strictly require* consideration of the diagnosis of sick but *alive* patients.

- The often harsh debate about *geodynamic models* appears to be more a matter of rivalry between different schools of thought, rather than a truly scientific discussion or an effective scientific concern.

Indeed, compared to the intrinsic complication of natural reality, every model or interpretation, which is suited for the intrinsically limited capability of human mind, is extremely oversimplified. Every model must therefore rely on a substantial amount of approximations, in order to reduce the huge number of *d.o.f.* of natural reality. Hence, different models can be simultaneously accepted, even when they appear contradictory, as they just rely on different assumptions and they describe different aspects of a multifaceted reality.

⁴ Note that, when dealing with time scaling (such as when an attempt is made to simulate the occurrence after a short time lag of a geological phenomenon), the kind of scaling is necessarily more of “structural” than of “geometrical” character, because the typical intrinsic time-rate of a natural law cannot be accelerated.

⁵ This item ought to deserve a much longer discussion, and it leads to unexpected consequences. But, for brevity purpose, it cannot be treated here.

In any case, it is deontologically unacceptable that the scientific community debates about these (often pseudo-)scientific academic competitions, while people die by severe natural catastrophes.

- A very frequent misunderstanding - very relevant to communication among Earth's scientists and also between scientists and society - is originated by a confusion between *global propagation* of crustal phenomena and *local* effects.

For instance, a seismic wave is well known to propagate through the whole Earth on the planetary scale. In contrast, ground vibrations of much higher frequency are rapidly damped off by the heterogeneity of soil composition and structure.

Higher frequency oscillations are, however, a very important diagnostic tool, which is very well suited to monitor some eventually very large *local* Earth's crust feature, such as the response of a huge block of limestone or granite, or of the outcrop of a pluton, or of solidified lava.

Indeed, the statics and *stress field* inside every such large body eventually changes with time. For this reason, these huge bodies act like real, much extended *natural probes*. They are considered to be an essential constituent of the entire instrumental monitoring device, as they are its long-range "probe" directly connected to the manmade monitoring device.

For instance, a lava outcrop is the effective terminal of a huge natural probe that monitors an unknown - although very large - percent of a whole volcanic edifice.

Claiming – as some writers have - that high frequency oscillations are useless for the study of the Earth is just nonsense.

- The lack of any distinction between *continuum* and *quantum effects* is an unfortunate bias that is shared by several present scientific discussions in Earth's sciences.

Classical physics and standard engineering relies on differential calculus, originated by Leibniz and Newton. Since the 1920's quantum mechanics has been assessed, and since that time we do know that at the molecular or crystalline scale-size we must rely on discrete, non-continuous, phenomena. The algorithm of continuous functions no longer applies. It appears almost unbelievable that in several disciplines of Earth's science this presently well-known fact is not taken into account.

In detail, according to solid state physics, no cleavage plane of a crystal can be explained by the continuum rationale. We must rather rely on crystalline bonds, on their geometry, on their different strength in different planes, etc. These items are fundamental for the understanding of *every fracture phenomenon*, that occurs in the Earth crust, whether an earthquake, or a landslide, or the collapse of a volcanic edifice, etc. The treatment of these phenomena by means of differential calculus results in a severe limitation for any realistic physical understanding.

In much the same way, an engineer is concerned with the macro-rheology of a material (Young modulus, breaking point, etc.), while the physics of phenomena involves effects that only solid state physics can explain. "Continuity" assumptions apply, and are very effective indeed, only in engineering problems. But, they are obsolete and sometimes misleading in Earth's sciences.

- When dealing with a natural catastrophe (seismic event, volcanic eruption, landslide, etc.) very few *d.o.f.* (degrees of freedom) are to be distinguished: *magnitude*, *location*, and *occurrence time* (with their respective error bars). Every “forecast” *must* clearly distinguish whether it is concerned with either one or another of these *d.o.f.*

Natural reality is concerned with some physical system, which is unavoidably characterized by a much larger number of *d.o.f.* Therefore, no two real case histories shall ever be identical; and no two precursors shall ever be the same. This is the famous Heraclitus adage: “*no man ever steps in the same river twice, for it's not the same river and he's not the same man.*” This is the same as stating that the arrow of time steadily moves in one direction, or also stating that entropy is steadily increasing.⁶

For instance, any two earthquakes are always a different phenomenon, because either their epicenter is located in different areas, or – if they hit the same site – because different events have a different crustal environment and trigger.

Neither can one obviate to this inconvenience by means of statistics. Indeed, strictly speaking, statistics makes sense only when - unlike in the case of earthquake data series - the data base is composed of elements that are physically comparable with one another.

Statistics is not to be conceived like a “Great Mother” (Neumann, 1949) or like a “Linus cover”⁷ in order to get rid of our ignorance about a huge number of unknown *d.o.f.* The formal computation of a mean, or of a root-mean-square (*rms*) deviation, may always be formally carried out. One should be aware, however, of the real logical significance of such a computation (e.g. sometimes a median has to be used instead of a mean, etc.).

- While releasing every kind of alert – whether it is associated with a “diagnosis” of Earth’s crust or with a “forecast” - this can be practically helpful only when the *advance time* is reasonably large and when it fits with societal needs. But, the longer is the advance time of the alert, the higher is the possibility (or “probability”⁸) that the physical system eventually changes, by which the former extrapolation no longer holds - which was the motivation for issuing the alert. This is a physical matter of fact, just a challenge that every scientist (and also every conscience driven legislator) must take into account.

The present discussion deals separately with the *magnitude*, with the *location in space*, and with the *location in time*, when dealing with a possible forthcoming natural catastrophe of any kind.

Some methodological items, which are shared by every kind of monitoring, are illustrated in the *Appendix*, which is therefore an essential component of the present paper.

⁶ The role of time for fundamental gnoseology is a classical and very debated item of theoretical physics. An extensive literature exists. Refer e.g. to Gregori (2010), or also to Gregori (2005) and Gregori et al. (2006) and references therein.

⁷ Linus is a character of the popular [Charles M. Schulz's comic strip Peanuts](#), and his “Linus cover” is supposed to hide his pranks.

⁸ “Probability” is a concept that, strictly speaking, applies only to a statistical population of *homogeneous* elements, such as it typically occurs in games (cards, lottery, etc.). In contrast, when dealing with natural phenomena, the elements of an ensemble in general are not homogeneous. Hence, their treatment by means of the algorithms of probability theory implies a severe arbitrary assumption on the nature of the database, and this assumption may eventually result to be misleading. This basic epistemological warning is apparently usually neglected in several disciplines, even outside Earth’s sciences. The result is an often occurring misuse of the “probability” concept by average man, decision makers, and legislators.

2. - Magnitude

To the best of my knowledge, three different approaches are suited to issue a “forecast” of the magnitude of a possible future earthquake. In addition, a fourth and older approach, which maybe provides us with a lesser space-time definition, sometimes can be useful, and perhaps also improved.

Concerning other kinds of natural catastrophe, such as landslides, floods, snow avalanches, etc., one must rely on their respective trigger, and on soil morphology, on atmospheric precipitation, temperature, winds, etc. Much different is the case of spontaneous forest fires, which require consideration of the electromagnetic (e.m.) coupling between soil and ionosphere, in addition to air conductivity which depends on the space-time variation of soil exhalation, etc. (see section 3.1.2). But, these items ought to require a much different discussion compared to the arguments treated in the present paper.⁹

The four *earthquake* precursors that can be indicative of the magnitude are: (i) slow (or silent) earthquakes; (ii) seismic lull; (iii) fractal analysis (in space) of faults (observed at Earth's surface) briefly called “Cello's analysis”; and (iv) maximum “seismicity” preceding the main shock.

2.1 - Slow (or silent) earthquakes

Silent or slow earthquakes, tremors, stick-slip and creep processes, episodic tremors and slips (*ETS*), slow slip events (*SSE*), non-volcanic tremors, low-frequency earthquakes (*LFE*), very-low-frequency earthquakes (*VLF*), etc. are almost synonymous phenomena, or they refer to observations that are different upon considering some subtle distinction concerning their respective primary driver or mechanism. The best available distinction in their respective definition is perhaps given in **Figure 1**, borrowed after Ide et al. (2007) who also give (not shown here) a detailed table with references, etc.

A so-called “slow” earthquake is a discontinuous event, which releases its total energy (of the same order of magnitude as the energy of a standard earthquake) over a period of hours to months, rather than of seconds to minutes such as a typical earthquake. “Slow” earthquakes can be detected either by strainmeters, or they may be accompanied by fluid flow and its related tremor, typically in the 1 - 5 Hz band. Originally they were also named “silent” earthquakes.

They are probably associated with several kinds of primary mechanisms, such as stick-slip and creep processes, such as in the so-called subduction areas, or associated with fluids of any kind moving through “porous” rock, hence associated with volcanic non-eruptive activity, or also deriving from ice sheet melting and reduction of its corresponding load.

They can be episodic, and in this case a phenomenon is sometimes called “episodic tremor and slip” (*ETS*). They can be either precursors or aftershocks.

In general, the investigation of this huge realm of phenomena has been carried out only sporadically, although the number of published papers is steadily increasing.

When a permanent planetary array of *AE* stations (see sections 3.1.2 and 4, and the Appendix) which monitor acoustic emission becomes available, a much more systematic and easier investigation of slow earthquakes will be possible - also including seismic free oscillations (*SFO*) and Earth's hum.

⁹ The discussion of these items is closely related to the physics of ionospheric or atmospheric earthquake precursors (e.g. either in terms of VLF e.m. propagation, or of airglow anomalies, or of earthquake clouds, etc.). That is, these phenomena deal with the very complicate nature of the coupling between upper atmosphere and underground phenomena. Understanding these phenomena, however, at present is very severely biased by several unproven paradigms, which are only conventional assumptions aimed to define and distinguish different disciplines, to be conceived like realms of different specialists and schools of thought. This unfortunate conventional choice results into a fundamental limitation of our knowledge. But, these items, which are extensively discussed in the aforementioned 8-volume set, should strictly require a separate long paper. They cannot be included in the present paper. Only some related items are here partly discussed in section 3.1.1.

As stressed in section 1, monitoring ultrasound *AE* is not a direct way to monitor any very-high-frequency phenomenon that crosses through whole Earth. Rather, *AE* monitoring is concerned with the stress while it crosses through some huge solid crustal body, normally of unknown extension underground, which operates like a real "natural probe" embedded into the Earth crust. These "natural probes" are real and much effective extensions - an essential component of every single *AE* station, i.e. of the composite detection-device composed of electronics through this huge natural probe.

Figure 1 is self-explanatory: the duration of a slow earthquake displays a clear relation with the seismic moment of the future earthquake that hit that area. These very curious and still poorly studied phenomena are a reliable diagnostic tool aimed to assess the seismic hazard of a given area in terms of the maximum expected potential earthquake to be expected.

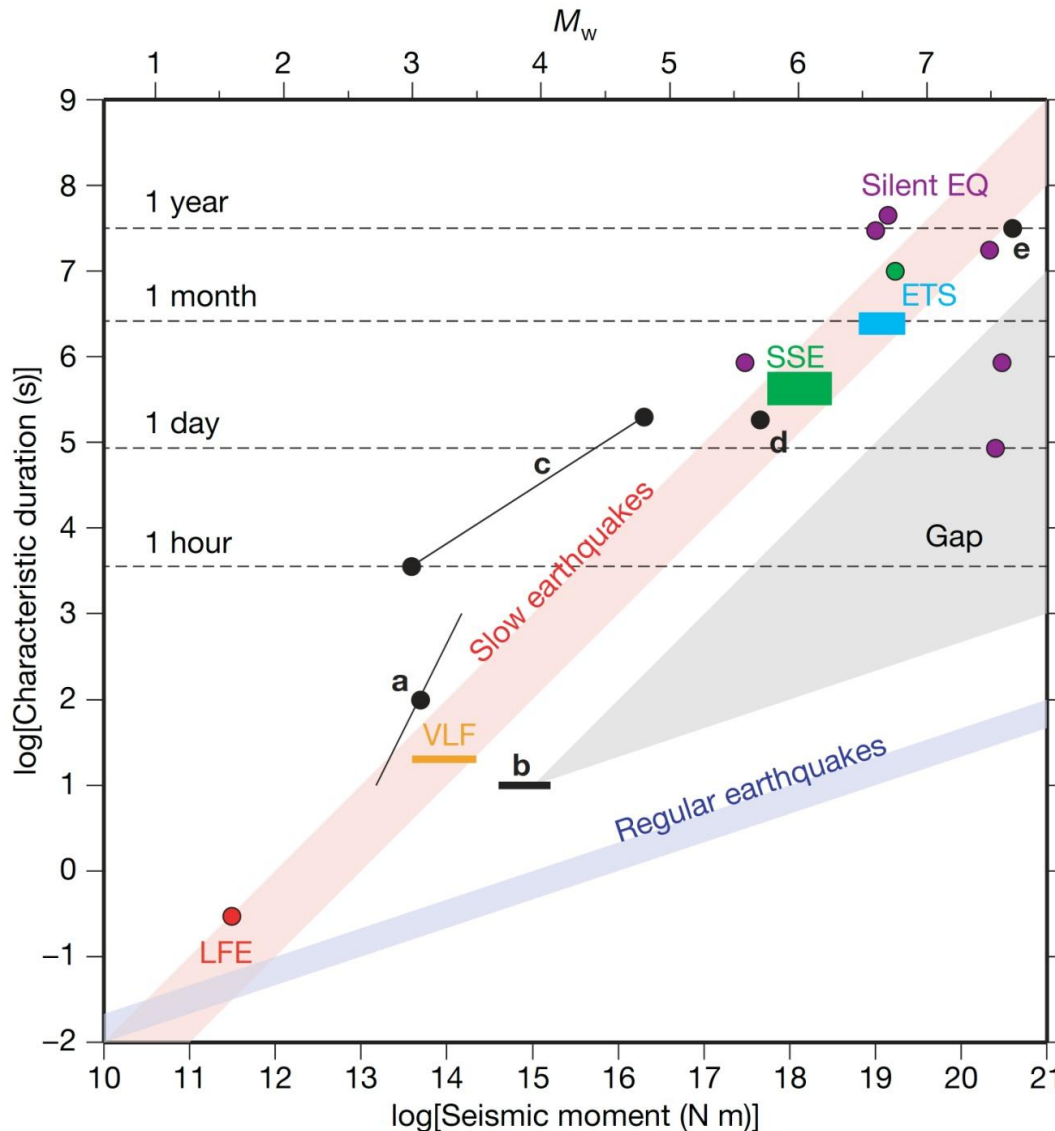


Figure 1. "Comparison between seismic moment and the characteristic duration of various slow earthquakes ... LFE (red), VLF (orange), and SSE (green) occur in the Nankai trough while ETS (light blue) occur in the Cascadia subduction zone. These follow a scaling relation of $M_0 \propto t$, for slow earthquakes. Purple circles are silent earthquakes. Black symbols are slow events ... (a), Slow slip in Italy ... representing a typical event (circle) and proposed scaling (line). (b), VLF earthquakes in the accretionary prism of the Nankai trough ... (c), Slow slip and creep in the San Andreas Fault ... (d), Slow slip beneath Kīlauea volcano ... (e), Afterslip of the 1992 Sanriku earthquake ... Typical scaling relation for shallow interplate earthquakes is also shown by a thick blue line." Figure and captions after Ide et al. (2007), who also give references (here omitted), and where " M_0 " is the seismic moment.

It is likely that a somewhat different detailed law applies to different regions. Therefore, additional investigations are required.

Maybe, when it becomes possible to improve by a substantial amount the capability to monitor slow earthquake by means of suitable arrays of *AE* stations, the error bar of the “forecast” of the seismic magnitude will be reduced.

Slow earthquakes appear to be a definitely promising possibility, and they are also a useful by-product of *AE* station arrays (see sections 3.1.2 and 4, and the Appendix).

2.2 – Seismic lull

The so-called “*seismic gap*” method is an old-fashioned and well known concept. It relies on the statistics of the presumed storage of elastic energy in a given area, which is supposed to be of relatively small-size. Some lesser and apparently irrelevant seismic activity is sometimes observed to occur vs. time within some given and comparably broad area. Sometimes a “curious” and small spatial gap is observed inside this broad area. For a while, no minor activity is monitored inside that small area, which is called seismic-gap. This means that an accumulation of elastic energy is in progress, and the next relevant shock is therefore going to have its epicenter located inside that area. This “law” has been well known for decades (e.g. McNally, 1983). It is reported to have been observed in several case histories.

The concept of “*seismic gap*” applies either in space or in time. In space it happens that a small area, inside some wider region, displays a gap of seismic activity. In time, within a given area, crustal activity of any kind is in progress, but for a while it fades off. In this case the gap is called “*seismic lull*”.

Some recent papers discuss general statistical features of space-time distribution of seismicity, which are likely to be characteristic of specific regions. They use very involved and clever algorithms, such as pattern recognition, multifractal analysis (see the Appendix), etc. But, these items are outside the simple framework of the present paper, which is focused on almost intuitive operational methods that have already been practically proven to lead to some clear, regular, and well assessed earthquake precursor. This is not a criticism of other methods. Indeed, every less “simple” and less intuitive method still requires additional hard thinking, before any final assessment of its practical operative effectiveness can be assessed. Particularly interesting laboratory investigations on different specimens were carried out by Chen et al. (2002) (for space gaps) and by Botvina et al. (2001) (for time gaps, i.e. lulls). For brevity they cannot be reviewed here in detail.

Botvina et al. (2001) also investigated the dependence of the maximum magnitude of an earthquake on its seismic lull. They show **Figure 2**, where they plot both phenomena observed either in the natural crustal environment by means of data provided by some earthquakes (i.e. the seismic lull T_S), or also some analogous observations carried out on steel specimens stressed by a notch mouth (i.e. the acoustic lull T_{AE} , as they rely on *AE* monitoring although they are not really concerned about *AE* frequency).

For steel specimens, they computed the values of M^* by means of a relation analogous to the Gutenberg-Richter relation, i.e.

$$1.5 M^* = 11.8 - \log E$$

where the energy E is expressed in *erg*.

By this, they showed that the magnitude of an earthquake, which is to be expected to occur in a given area, is linearly related to the logarithm of the duration of the seismic lull. Also in this case, it should be pointed out that an array of *AE* stations certainly improves the capability to monitor in real time the seismic lull, thus improving error bars and the reliability of the final “forecast”.

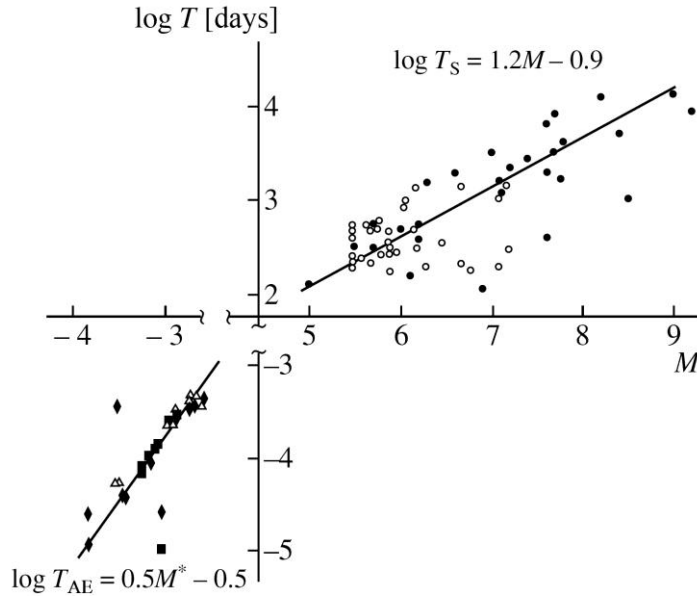


Figure 2. "The duration of the period of seismic T_S and acoustic T_{AE} lull (the first and third quadrants, respectively) as functions of the magnitudes of earthquakes (M) and metallic specimen failures (M^*). ● Data of Rikitake (1975); ○ data obtained by Botvina et al. (2001) for the earthquakes in North California; ■ steel 45; △ steel U8; ◆ steel 17KhG2SAF." Figure and captions after Botvina et al. (2001).

2.3 – Fractal analysis of faults - Cello's analysis

The seismic gap (in space) is indirectly, although much better, investigated maybe by means of the fractal analysis (in space) of the fault distribution observed at Earth's surface, which are reported on every standard conventional detailed geological map which is available in several countries. This method was applied by Cello (1997 and 2000), Cello et al. (2000 and 2002)¹⁰ both to a large seismic area in central Italy, and to a smaller seismic area in southern Italy.

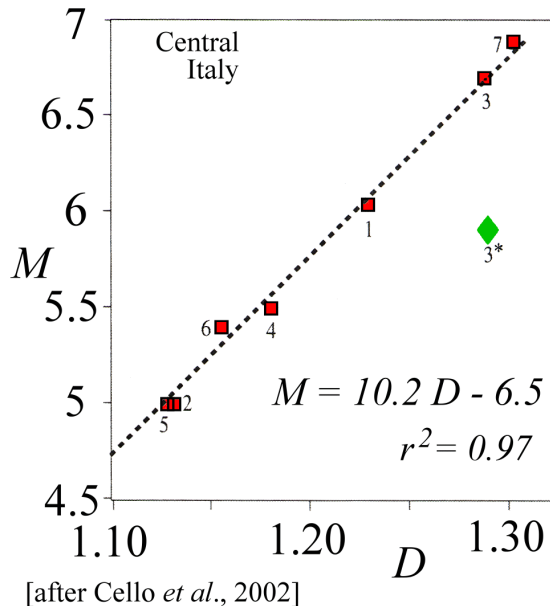


Figure 3. Maximum recorded M vs. D_s for the historical earthquakes of the axial Apennines. Numbers denote different seismogenic zones. One point (no. 3, dealing with the town of Norcia) is plotted twice, reporting a 1979 event with $M = 5.9$, and another with $M > 6.5$, which struck the same area in 1703. Figure after Gregori and Paparo (2004), redrawn after Cello et al. (2002). The same figure, slightly different, also appears in Cello (2000).

He made straight application of the well-known "box counting method". That is, he completely covered every given area of investigation (defined as a 2D approximate rectangle between geographic parallels and meridians) by means of several smaller non-overlapping boxes of a pre-chosen and given size. Then, he

¹⁰ I am indebted with the late Prof. Giuseppe Cello for discussion, and for providing with his reprints, shortly before his premature passing away.

counted the number of boxes which contain at least one fault. By the tilt angle of the log-log plot of number of boxes vs. box size (Richardson's plot) he computed the fractal dimension (in space) D_s and he finally plotted the maximum magnitude M of an earthquake that struck that area vs. D_s (**Figure 3**). One point was found to fall out of the remarkable alignment. But, upon a closer inspection of the historical database, he found that an older earthquake can fit the general trend, solving this apparent paradox.

Cello (ibid.) exploits an extensive discussion (not here reported) of the robustness of the estimated parameters, of error bars, etc. But the limitation of this clever and much effective data handling relies in the fact that it requires a detailed geological map, and a wealthy historical seismic database. Unfortunately, however, this information is not available everywhere.

2.4 - Maximum "seismicity" preceding the main shock

Keilis-Borok and Malinovskaya (1964) investigated the preparation process of a strong earthquake in terms of its preceding weaker earthquakes. The total number of earthquakes represents only the weakest shocks, while their total energy represents only the strongest ones. Hence, they introduced a weighted sum $\mu(t)$ where various earthquakes had suitable weights depending on their energy. The long discussion of the definition of $\mu(t)$ is not pertinent in the present paper.

They show plots that refer to different case histories, occurred in central Asia, in the eastern Mediterranean, and in the Himalayas. The seismic catalogues available to them were incomplete, particularly concerning the less strong shocks. But they found remarkable regularities.

They found that $\mu(t)$ has a sharp peak of approximate amplitude P_M before - and only before - an earthquake with a magnitude of M . A few minor deviations from perfect regularity could be a reasonable consequence of their uneven catalogues. But the significance of their analysis is shown by the following evidences.

The time interval - between the moment when the left side of a $\mu(t)$ peak reaches $(1/2)P_M$ and the time of the main shock - increases with its magnitude M (**Figure 4**). The difference between main shock instant, and the time of the $\mu(t)$ peak maximum, is less regular, but always positive.

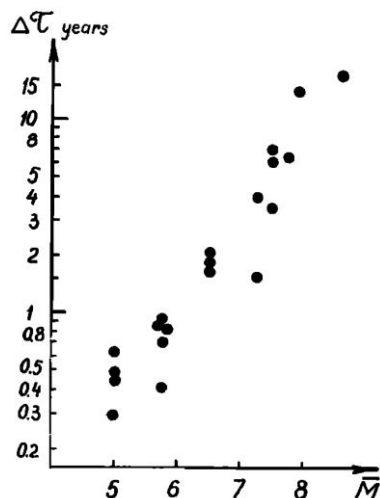


Figure 4. Time interval between main shock instant and the time when the left side of the $\mu(t)$ peak reaches $(1/2)P_M$. After Keilis-Borok and Malinovskaya (1964).

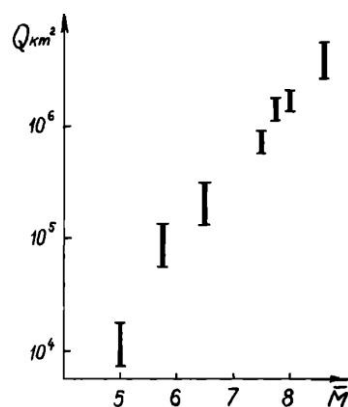


Figure 5. "Area of preparation" Q vs. M . After Keilis-Borok and Malinovskaya (1964).

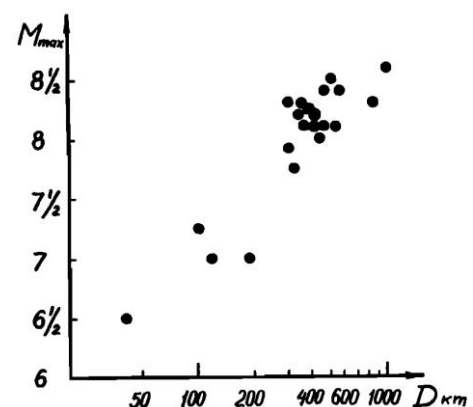


Figure 6. "The maximum magnitude M_{max} possible in various seismic belts of the world. D = the width of the belt." Figure and captions after Keilis-Borok and Malinovskaya (1964).

They computed the “*area of preparation*” Q where the smaller shocks occurred. Q increases with the magnitude M of the main shock (**Figure 5**). Moreover, the maximum magnitude, M_{\max} , which is possible in a given belt, is roughly determined by the width of this belt D (**Figure 6**; based on data after Gutenberg and Richter, 1954).

Summarizing, their analysis was based on some “reasonable” although arbitrary assumption aimed to estimate some significant quantitative gauge of seismicity in a given region. They found clear correlation between the cumulated seismicity observed a few years in advance, and the magnitude of the earthquake that struck that region.

This shows that the occurrence of a strong earthquake, somewhere inside some suitable large region, requires a preparation time, which is manifested as an observed increased seismicity preceding the main shock by a few years.

That is, a strong earthquake is not the result of a local accumulation of elastic energy. Rather it reflects the response of a large crustal region. The location of the epicenter at a given site is determined by the local presence of an active fault, which is suited to cause the release of the elastic energy, which in reality is however accumulated over a very wide area.

This means that every investigation on earthquake precursors *must unavoidably* deal with a twofold perspective. On the one hand, we must focus on large scale perturbations that affect crustal stress and cross through the globe. On the other hand, whenever we are concerned with the hazard of a specific active fault, we must monitor its area with great space-time detail, in order to envisage what local process are in progress that might eventually respond to a critical enhancement of crustal stress crossing through it.

3. - Location

Owing to practical purposes, there is need to consider first (section 3.1) a large-scale planetary “forecast” of the propagation through Earth’s crust of some huge “crustal storm”, i.e. of a large perturbation of crustal stress crossing through some given region and typically lasting a few years. “Crustal storms” are then intercalated by “quiet” periods (see the Appendix for details).

Different monitoring arrays and data handling are required (section 3.2) in order to assess with a much better precision the areas that are comparably more prone to the occurrence of a possible earthquake.

3.1 – Location in space – Planetary scale phenomena

The “large-scale” location of an area, which is prone to a seismic event of some conspicuous magnitude, can be assessed by means of almost every kind of precursor in terms of every kind of suitable information. It is essentially impossible to list all possible potentially measurable effects, which in any case can eventually result much different in different areas and on the occasions of different earthquakes (e.g. refer to Cicerone et al., 2009).

For instance, the *seismic gap* (see section 2.2) is, maybe, one of the oldest and best known methods. But also the *seismic lull*. They are monitored by one pre-chosen technique, normally over a region having a linear size of several hundred kilometers. For instance, the size of the lull area depends on the density of the available monitoring array.

Another example is represented by *water wells* anomalies. As mentioned in section 1, in general their information (anomalies of water level, or of its temperature or turbidity, or gas bubbling, etc.) *per se* is not robust. But, on peculiar circumstances, this is not a real bias: the crucial item is rather the space density of wells, and the availability of a steady monitoring.

For instance, this information was used in one of the former successful case histories of earthquake “prediction” in China. That interested region was densely populated, with no aqueducts, hence it contained

several wells, which were permanently monitored by the local inhabitants, due to their daily water needs. They had also been instructed to inform a suitable center about any kind of anomalous phenomenon observed in a well. Upon screening this (non-professional but very dense and steady) monitoring, statistically it was thus found that the epicenter area resulted to be identified inside a much limited spatial range, with a precursor of only a few days advance. The plot of well anomalies (shown by black dots) looked like a leopard skin, and the epicenter occurred where the black dots were denser.

Note that this does not mean that an identical response has to be expected in every other case history. In addition, one single well can eventually result unsuited to monitor a reliable signal, as it could be supplied by a much anomalous aquifer. Only a large number of wells can be effective.

Let us here distinguish two wide categories of precursors: (i) electromagnetic (e.m.) phenomena, and (ii) crustal stress phenomena.

3.1.1 – Location in space – Electromagnetic phenomena

A premise is needed about magnetostriction and electrostriction phenomena. They have often been appealed to in the literature as a source of seismic precursors. But they are very local and very much scattered.

Indeed, one can eventually observe a relevant effect at a site, while no analogous effects is observed at some very close location, depending on the heterogeneity of the underground crustal structure. Hence, these phenomena are definitely non-robust, and result therefore a little practical use (if any, unless an unrealistically very dense array of monitoring sites can be available).

From a more general viewpoint, a key concern deals rather with the e.m. coupling between ionosphere and ground. The discussion of this item involves both planetary scale phenomena and local features.

Our living environment (i.e. our “climate”, which can be formally defined as the space-time domain of “environment” where life can develop and survive) is an electrical condenser [see Gregori (2002, 2006 and 2009) concerning this and several other concepts mentioned here below].

The upper plate is the ionosphere. It is powered by an electric current generator, identified with the solar wind.

A paradigm - which is generally accepted also by ionospheric physicists although they agree on its incorrectness - is that the ionosphere is an electrically equipotential surface. The ionosphere is, rather, a very bad conductor, or a gently conducting insulator. Hence, it is likely that, as a response to the rapidly time varying composition of solar wind precipitations (as it is testified e.g. by the much different location of proton polar auroras with respect to electron polar auroras, or by several incoherent scatter measurements), much different electrostatic charge density can well temporarily exist in different subvolumes of the ionosphere.

The lower plate is generally underground. But, soil is not composed of horizontal layers. The Earth is not structured in terms of concentric layers, e.g. reminding about an onion. Much like at Earth's surface some large anomalies can be observed (such as typically fumaroles or volcanoes, etc.), the underground structure of the electrical conductivity σ reminds about a sea-urchin pattern, with several spikes.

The electric currents inside these spike-shaped σ structures are powered by the deep Earth dynamo (see Gregori, 2002, 2006 and 2009). “Climate” phenomena occur inside this “atmospheric” condenser. The top point of every spike is the site of release of Joule's heat. In general, the top point of a spike terminates underground at a suitable depth. That is, an effective e.m. coupling occurs between the upper plate of the atmospheric condenser and every spike, which acts therefore almost like an antenna, or like a lightning rod.

The Caronia phenomenon (dramatic spontaneous fires inside a house spreading from electric power sockets, or water pipes, etc.) was caused by St. Elmo fires on top of a σ spike.

Only very seldom a spike emerges from ground: this typically occurs inside volcanic plumes. Wonderful photographs are available of volcanic plumes with lightning discharges, which can be explained upon considering that volcanic plumes contain electrons, positive ions, and negative ions.

Electrons promptly move towards the ionosphere, leading to formation of the lightning discharges that are always released from the outer boundary of the plume (but never inside it, because the plume is very conductive). These lightning discharges are normally vertical above the plume, except in Iceland, where the electrostatics of the ionosphere is strongly affected by the auroral electrojet.

Positive ions are rapidly pushed downward to ground, and are spread over some large area. They cause no visible discharge.

In contrast, *negative* ions “float” in air, as they are subject to gravity and to the electrostatic field originated by the positive charge in the ionosphere. They move with wind, and eventually cause very intense lightning discharges but far away from the volcanic edifice. They are very intense and sometimes killed people. These peculiar kinds of lightning discharges are often clearly distinguishable on several photographs of volcanic plumes that appear in the literature.¹¹

But, the e.m. coupling between ionosphere and ground is a ubiquitous phenomenon, although it eventually causes no visible discharge.

However, a severe bias in the general interpretation of these phenomena, according to what is reported in the literature, derived from the discussion of the so-called *air-earth currents*. Following a much preliminary order-of-magnitude estimate of one century ago, it was finally agreed that air-earth currents are negligible, at least as a planetary average. This had an important implication, as it allowed for a treatment of the geomagnetic field by means of the classical Gauss analysis of the potential by means of spherical harmonic expansion, thus permitting the separation of internal and external origin field, etc.

But, upon a critical re-consideration, it appears that this assumption, which is very useful to handle the geomagnetic field, indeed is not supported by adequate evidence.

Thus, much like the incorrect hypothesis of an equipotential ionosphere introduces an unrealistic Faraday screen between magnetosphere and atmosphere, this hypothesis of negligible air-earth currents introduces an unrealistic Faraday screen between e.m. phenomena above and below Earth’s surface.

These “paradigms” eventually originated some unfortunate misunderstanding, by which ionospheric and airglow precursors were formerly considered as unrealistic and unreliable, and some controversy was sometimes raised by the fact that somebody observed them, while others did not. In reality, every case history has to be considered independent of others, and all results can be significant and equally reliable.

An e.m. coupling certainly does exist between ionosphere and subsoil. Therefore, it is not surprising that during the precursor stage of an earthquake some anomalies are eventually observed. This is well known to have been observed on several occasions, in terms of different e.m. phenomena, or of airglow (which is just a manifestation of some kind of ionospheric disturbance). The results of the satellite *DEMETER* ought to be recalled, etc.

¹¹ This explanation of lightning discharges in volcanic plumes is original, and it is more extensively discussed in the aforementioned 8-volume set in preparation.

In general, however, any two different earthquakes, either with close epicenters or not, are to be expected to be eventually associated with much different e.m. effects, essentially because the general e.m. environment, which depends on the instant state of the solar wind etc., is much different in different case histories.

A related concern deals, however, with the spatial resolution of an ionospheric or airglow precursor. The possibility to detect some effect depends on the features (i) of the lower and (ii) of the upper plate of the atmospheric condenser, (iii) of the medium between the plates, plus (iv) on how dense is the monitoring array.

However, since phenomena are observed which are originated in the ionosphere, the geometry of the lower plate is less relevant. Another drawback is the sparse location of ionospheric or airglow observatories.

It is well known that no anomalous feature in the ionosphere can be detected with a spatial detail more precise than the order of magnitude of the height of the ionosphere, i.e. a few hundred kilometers (see **Figure 7**).

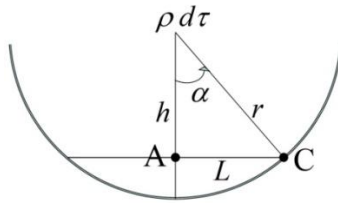


Figure 7. Estimating the linear distance L at Earth's surface where the ionospheric signal has significantly changed. See text.

An electric charge $\rho d\tau$ is located at a height h over an observer located at a point A at Earth's surface. Another observer is located at C at a distance L from A on a flat Earth. By formal computation, with the symbols defined in the figure and by calling V_A and V_C the electric potential at A and C , respectively, and p the percent V_C/V_A , it can be shown that $V_C/V_A = h/r = h/\sqrt{h^2 + D^2} = p$. Hence, $L = h \sqrt{(1/p)^2 - 1}$. Therefore, if $h \sim L$ it is $p \sim 1/\sqrt{2} \sim 70\%$.

Therefore, some consistent change of the ionospheric signal can be observed at Earth's surface only over a distance L of the order of magnitude of the height h of the ionosphere.

Therefore, ionospheric precursors are certainly an important hunch, as they can monitor a wide region at Earth's surface (i.e. they are robust, they have a negligible scatter in space, and the location of the ionospheric observatory is not critical). However, the spatial detail is limited of the definition of the expected epicentral area.

From a different viewpoint, it has to be considered that a planetary pattern of crustal stress, and of its propagation, can perhaps result important in order to monitor the performance and ageing of Earth's crust through wide regions. This is not a "forecast". But it gives an important indication on the large- and long-range hazard space-time domain. These items are discussed in section 3.1.2.

As far as the trigger mechanism is concerned, which can be associated with planetary (or large-scale) e.m. phenomena, a relevant - and as yet non-monitored - phenomenon deals with the anomalous stress caused by stray currents (or "Foucault" currents, or induced telluric currents) inside the Earth lithosphere, which are caused by the time-varying e.m. fields originated by the solar wind.

The resultant total force and total 3D torque, which are applied to the Earth, can be monitored, almost in real time, by means of the induced electric potential within the global network of submarine communication cables (Lanzerotti and Gregori, 1986) combined with the geomagnetic records, which are permanently collected by the international network of geomagnetic observatories.

Note that, in principle, this identical information could also be attained by means of geomagnetic records alone, with no use of transoceanic communication cables. But, the sparse and uneven network of the observatories is such that the error bars result very large. Long transoceanic cables detect an effect which is integrated over huge distances, and this information is a constraint that is very likely to be decisive in order to keep contained the drawback of error propagation in computations.

This network of communication cables can therefore monitor, on an instant basis, the moment and torque exerted on the planet Earth by the e.m. interaction with the solar wind, with its implications on Earth's spin rate and on pole motion.

But, at this point it is important to get a monitoring *on an instant basis* of the anomalous variations of the astronomical motion of the Earth, i.e. of its spin rate and pole motion.

At present, this monitoring is achieved mainly by means of a few techniques: astrometric measurements, *VLBI* (very long baseline interferometry), *LLR* (lunar laser ranging), and occasionally a few specific space geodetic experiments.

The oldest classical method is *astrometry*. A picture of the zenith nighttime sky is taken every day, at the same astronomical station and at the same instant of time. Time is measured by an atomic clock, which is assumed to be the most stable, hence most reliable, time-recorder: Just by definition, it is the reference pace for every other observed phenomenon. Then, the displacement is measured of the observed stars with respect to their expected position. A network of devoted astronomical observatories is used, in order to get rid of overcast conditions, etc. and to manage error bars, etc.

Until a few decades ago, astronomers released one average datum every 5 days and specified a few different parameters. They claimed that they wanted to smooth the scatter *vs.* time which they observed, and which appeared unacceptable to an astronomer who is acquainted to deal with much regular and smoothly varying observations. However, maybe also due to the strong complains by geophysicists who considered the scatter as a most interesting information, astronomers later started to release one datum every day.

The *VLBI* technique relies on the Doppler effect of a celestial radio source, which is simultaneously observed from two observatories located at a relative large longitudinal span.

LLR relies on the time spent back-and-forth by a laser impulse between Earth's surface and a reflector which was posed on the Moon by astronauts.

These three techniques are presently applied on a permanent basis by different groups, and their results appear well correlated one another, inside their respective error bars. But, the focus is always on daily average values.

To the best of my knowledge, it appears difficult to envisage whether and how the monitoring of the astronomical motion of the Earth can be achieved providing with a much shorter time resolution, or even on an instant basis.

In addition, in principle, the instant Earth tide ought to be much different on different continents etc. depending on their relative location with respect to the Moon and the Sun (e.g. refer to the effect of the Pacific loading tide on the Eurasian shelf, mentioned here below; see **Figure 14**).

One new technique - which however apparently has not yet been implemented in any specific Earth's astronomical monitoring - relies on the Josephson effect that can monitor instantaneous effects, at every different site, and in real time.

Consider that, following the elastic/plastic response of Earth's crust, depending on its varying structure and morphology, in principle, the measured effects are to be expected to be very different at different sites at Earth's surface. This information could therefore (perhaps) result much important for an effective and crucial assessment of the time-varying local seismic hazard.

In any case, the paramount importance ought to be stressed of an instant monitoring of the astronomical motion of the Earth, in correlation with the aforementioned monitoring of the total force and torque originated by stray "Foucault" induced telluric currents. These ought to be permanently monitored by a combination of spontaneous electric potentials in the planetary network of transoceanic communication cables plus geomagnetic records from the international network.

The knowledge of the trigger of relevant crustal stress perturbations could result, perhaps, much important in order to assess the time instants during which the crust is relatively more stressed, either in terms of a planetary average, or of continental or regional scale concern, or for local "forecast" in specific seismic-prone areas.

Concerning the anomalies of the astronomical motion of the Earth, a well-known phenomenon, which was observed on several occasions, is the apparently erratic correlation of the effects that are sometimes in association with the occurrence of large earthquakes. A proposal for an explanation and for the study of this unexplained item is mentioned in section 3.1.2.3.

In this same respect, it ought to be recalled that Poscolieri et al. (2006) reported on a crustal stress effect, that has been simultaneously and synchronously observed in central Italy and in Greece (in the Ionian islands). They were able to tentatively interpret this observation only in terms of a regular time-varying crustal stress, originated by the varying push of the loading tide of the Pacific water on the Eurasian Pacific continental shelf (see **Figure 14**).

Although this finding ought to be confirmed by records carried out at some intermediate longitude between China and the Mediterranean area, it appears beyond any reasonable doubt that the Earth crust is crossed by periods of "crustal storms", measured by its stress or other parameters, and other "quiet" periods. See the Appendix for details on this item.

3.1.2 – Location in space – Crustal stress monitoring

Three techniques are here mentioned. Two of them are suited for the deployment a conspicuous (either permanent or temporary, planetary or local) monitoring array: they are *AE* and *shallow geotherms*.

Another technique, which has been implemented only in comparably recent time, deals with superconductor gravimeters (*SG*). They are much expensive and therefore suited for the operation of a limited array, although they provide with a pertinent and valuable geophysical information.

In addition, *GPS* and *InSAR* (Interferometric Synthetic Aperture Radar) techniques are well known and much efficient tools, suited for a successful monitoring of the time variations of soil deformation, applied either to volcanic areas, or to tectonically active regions. *InSAR* appears to be more sensible, compared to *GPS* monitoring (Furuya et al., 2010).

In general, however, satellite methods, such as *InSAR*, have the drawback of a limited time resolution, because the available monitoring of a given area is discontinuous in time and/or in space coverage. In addition, these methods need to compare observations of the same area carried out at different instants of time, delayed by a small time lag etc. Sometimes the use of an expensive cluster of identical satellites is available, and this mitigates somewhat this drawback.

These techniques can give some important indirect hunch also for the location in space of a possible future epicentral area. But, owing to brevity purposes, no additional mention is here given about these very important items. The interested reader may easily find several related papers.

3.1.2.1 – Acoustic emission (AE) monitoring and arrays

Every object behaves like a “solid” when its crystalline bonds (between atoms and/or molecules) overwhelm other forces.

The concept either of “elasticity” or of “plasticity” are however (see the Appendix) mere abstractions defined by human mind, much like in Euclidean geometry the concepts of “point”, “line”, “surface” etc. are abstract definitions that never exactly exist [e.g. even the Milky Way can be likened to a plane, as it is a few 100,000 LY (light years) of diameter, and a few 100 LY thickness (except in its central region). That is, every “plane” in natural reality always has a non-vanishing thickness, etc.

Similarly, no perfectly “elastic” medium exists, likewise no perfectly “plastic” or “viscous” medium (i.e. no “Newtonian fluid”). Therefore, every real “solid” medium, when it is subject to a stress, *must* always experience the yield of a few of its crystalline bonds.¹²

When at any subsequent time the same material is subject to a new applied stress, additional crystalline bonds yield, and the probability of their rupture is higher were the medium is already weaker, i.e. close to the sites where other bonds previously yielded. Therefore a process occurs that reminds about a chain reaction.

The rupture of a bond determines the trigger of a vibration of the “solid” medium. The vibration is eventually transmitted through the “solid” body, and can be possibly detected like an infrasound, which is called “acoustic emission” (AE) at a given frequency.

The smaller is the size of the micro-flaw of the medium, the higher is the AE frequency, and every given frequency may be realistically depicted by stating that it is typically associated with micro-flaws of some typical average size: this is called “*flaw domain*” associated with that given frequency.

Note that in general we may lack the knowledge of the real physical size of this flaw domain: we just know that this is the feature that must be reasonably expected to occur.

Thus it is reasonable that one can eventually monitor some anomalous behavior of the medium which is associated with the observation of AE of some given frequency. For brevity purpose, let us briefly call them “high frequency” AE, or *HF AE*.

But, comparatively smaller flaw domains, which are associated with *HF AE*, are to be expected to coalesce into flaw domains of increasingly larger size, as a result of implosion of several small flaw domains into one larger flaw domain, etc. This implies that the crystalline structure progressively deteriorates, and thus the mechanical performance of the medium consequently worsens.

The former *HF AE* release are thus going to be progressively damped off altogether with the progressive coalescence of smaller flaw domains into larger one. Therefore, lower frequency AE (simply denoted as *LF AE*) become more intense: the anomalies that were observed by *HF AE* are now observed by *LF AE*, etc.

The possibility to detect these mechanical vibrations of the medium depends on whether a sufficient transmission exists of the AE signal, between AE source and its detector. As mentioned in section 1, in general ultrasounds do not propagate through Earth’s body, as they are rapidly damped off through loose

¹² This is the same as the steady increase of entropy, or of the steady flow of time. See a previous footnote.

or heterogeneous material (unless it contains water). In any case, however, when a large “solid” body exists underground (such as a huge monolithic block of limestone, granite, dolomite, etc. or a pluton, or of solidified lava, etc.) this body acts like a “natural probe”, which has to be considered as an intrinsic component of the recording device from electronics through the sensor, through the natural probe. [The sensor is located on an outcrop of the “natural probe”.]

From the viewpoint of the physical analysis of the *AE* record, three items are to be considered, as explained in detail in the Appendix: *lognormality*, *fractality*, and “*flaw hierarchy law*”.

Lognormality refers to a property shared by every phenomenon, in every case history when the occurrence of an event is proportional to the number of similar events that are already occurring. For instance, typically it applies to a public service, where it provides with the correct explanation of rush hours.

It can be shown that a phenomenon of this kind is associated with a *lognormal distribution*, hence its name.

In the *AE* case history, the number of yielding crystalline bonds is proportional to the number of bonds that are already breaking. But the same concept or abstraction is shared by several other phenomena.

It applies to the classical sand pile problem, where the location of a sand grain is proportional to the number of sand grains that are already at that level (as they have to support the newly added grain). Hence, it applies to the hypsometric curve of a planet, or to topography over a more or less extended region, etc.

It applies also to every phenomenon controlled by psychological factors, such as in commerce, or in financial events, etc., or to several biological phenomena. For instance, in urodynamic testing, uroflowmetry is the measurement of urine speed and volume. The amount of urine and its flow rate are monitored and plotted vs. time. The plot looks just lognormal: the amount of urine flow is proportional to the urine that is already flowing, and the process stops when the urine reservoir has exhausted.

This example appears closely pertinent to explain the morphology of a *geomagnetic storm*, because a storm is the result of the macro-structure of a “plasma cavity” in the solar wind (see Gregori, 1998). That is, a temporary relevant decrease of particle flow (“plasma cavity”) sometimes occurs inside the solar wind. The magnetosphere responds to it. But the amount of lack of particle supply from the Sun is proportional to the ongoing reduced flow of particles. Hence, the phenomenon displays a lognormal distribution, and it lasts as long as the “plasma cavity” persists. Its duration (typically a few days) depends on a physical driver that affects the release from the Sun of solar wind. Indeed, the typical classical shape of a geomagnetic storm, represented by the *H* component of the geomagnetic field, appears just like a lognormal distribution, although it is conventionally represented with a reversed ordinate axis (Campbell, 1996).

Lognormality applies also to a *magnetospheric substorm*, although through a different physical control. In fact, a “plasma cavity” inside the solar wind causes a lack of current supply to the electric current system, which is typical of the magnetosphere. While this gap - of the particle supply from the solar wind - propagates along the magnetospheric tail, the particles that are stored inside the plasmashet are used to supply - and to reduce as much as possible - the effects of the solar wind lack. During this time (typically 2-3 hours) the magnetospheric substorm develops: it is characterized by a violent inflow of particles in the plasmashet, and by the development of a spectacular “*auroral substorm*”. The time duration of 2-3 hours depends on the length of the tail of the magnetosphere. Since the temporary amount of particle supply from the plasmashet is proportional to the amount of already supplied particles, the typical pattern must be lognormal of the geomagnetic record (with reversed ordinate axis) associated with a magnetospheric substorm (although a magnetospheric substorm is well known to be much better recognized by means of polar auroras).

Therefore, as long as a “plasma cavity” is observed inside the solar wind, a magnetospheric substorm will be triggered. But it will fully develop only as long as particles are available inside the plasmashet. Hence, a

storm (lasting a few days) appears like a disordered overlapping of several substorms (everyone lasting 2-3 hours), while the particle reservoir inside the plasmashet is progressively depleted. A storm is therefore the representation of the macro-pattern of the overall effect of a “plasma cavity” in the solar wind.

It appears difficult to understand why lognormality, which is a very general mathematical property shared by different amounts by every phenomenon, and which was discovered in the very first years of the XX century, is still only very seldom assessed in its several much effective applications for understanding much different phenomena, including aftershocks and the Omori-Utsu law.¹³

In contrast, *fractality* has already been well assessed in several phenomena, although its mathematical discovery occurred much later compared to lognormality, i.e. only during the last decades of the XX century. It is associated with the fact that some phenomena often occur according to an identical morphology displayed on much different space-time scale sizes (this regularity applies, however, only inside space-time domains that are defined by physical constraints). This property is generally denoted as “*self-similarity*”.

As far as rupture phenomena are concerned, self-similarity occurs on scale sizes that cannot be either smaller than the atomic range, or larger than the size of the object which is breaking.

Self-similarity (as already mentioned in section 1) may also be conceived in terms of a twofold concern. It can deal with geometrical features, i.e. similar phenomena occur on different spatial scale sizes. Or it can be concerned with structural aspects, such as when experiments are carried out on steel specimens (or of other materials) aimed to mimic the behavior of Earth’s crust, etc.

Geometrical similarity refers to intrinsic properties shared by the identical laws that apply to different materials. *Structural* similarity refers to different physical properties associated with the structure and composition of the medium.

The fractal properties of a medium are depicted by means of the so-called “fractal dimension”.

In the case of *AE* records (of a given frequency), the raw signal is first treated in terms of an rms average over a pre-chosen elementary time interval. Then, the time series of these *AE* values is handled in some way in order to single out a point-like process (i.e. a series of “yes” events, independent of their amplitude). This time series is analyzed by means of fractal algorithms (typically e.g. by means of the “box-counting method”; see the Appendix). Thus, the fractal dimension D_t is promptly computed, where the index “*t*” denotes that it is computed in the *time* domain, in order to distinguish it from the fractal dimension D_s in the *space* domain, such as it is used by the Cello argument mentioned in section 2.3.

In general, it can be easily shown that, owing to definition, a mere, ideal, perfect, random series of events formally leads to $D_t = 1$. Whenever every given event has some “memory” of other events - which occurred either before it, or are going to occur after it - it is formally found $D_t < 1$, and the lesser is D_t the greater is the “memory”. In the extreme case of a “total” “memory”, i.e. in the case that all events occur at the same instant of time, and it is $D_t = 0$. See the Appendix for additional details.

The interpretation of the observed D_t is according to a twofold *physical* rationale, i.e. whether the inferred physical information refers to the trigger of the observed phenomenon, or rather it refers to a response of the medium while it searches for its new equilibrium after having suffered by a stress.

¹³ The Omori-Utsu law refers to an approximately exponential decrease of the aftershock sequence after a strong earthquake. In reality, this is the tail of the lognormal trend of the mechanical vibration of the crust. The identical rationale applies (Paparo and Gregori, 2003) either to *HF AE* or to *LF AE*, until the lowest frequency, including seismic frequency (~0.5-1 Hz). The raising stage of the lognormal trend corresponds to the time interval when precursors occur. But seismologists are seemingly only concerned with the decreasing trend of the lognormal distribution, which they represent as an exponential decay, and forget about the precursor stage of the earthquake.

Consider first the second case, that is the response of the medium. An internal response of the medium triggers some comparatively lesser-intensity effect, which causes some release of *AE* from the medium. The progressive degrading of the performance of the material is monitored by a progressive decrease of D_t until the final rupture of the “solid” body. This was observed e.g. in experiments carried out on steel sample-bars, or on concrete sample-cubes stressed until final disruption etc. This is also the rationale that explains, on a physical ground, the well-known classical phenomenon of cleavage plane of a crystal.

Instead, consider the case history of a material which is stressed by a progressively increasing prime trigger agent. Typically, consider a volcano, with a time-varying (either increasing or decreasing) pressure by its endogenous hot fluids.

The *increase* of the endogenous pressure causes a widespread 3D diffusion of hot fluid through the porous medium of the volcanic edifice. That is, *AE* monitoring refers to the time variation of the external perturbation which is applied to the medium.

It will be thus found $D_t \sim I$. Whenever D_t is found to increase, it is claimed that the volcano is “inflating”. Whenever it is found that D_t decreases, it is claimed that the volcano is “deflating” (Paparo et al., 2004).

It has to be pointed out that during “inflation” a large number of instrumental seismic shocks is recorded by standard seismometers. In contrast, during “deflation” the number of shocks is much smaller, although they are stronger and even non-instrumental. This is consistent with the fact that, when the volcanic edifice misses the former support by the endogenous fluid pressure, it “recovers” towards its former geometrical shape due to gravity, while isolated cracks occur. The crack size is comparatively larger, and they occur along cleavage planes etc. In contrast, as mentioned above, during “inflation” a much greater number occurs of smaller micro-cracks, due to the diffusion of endogenous hot fluids. Vesuvius displays a few months of inflation followed by a few weeks of deflation.

A much enlightening case history was represented by the paroxysm that hit Stromboli during the last months of 2002. The Stromboli volcanic edifice is almost ~3000 m tall above sea floor, but it emerges from the sea only by <1000 m. On September 23rd, owing to some unknown environmental accident, our *AE* station located on the island interrupted its operation. On December 28th 2002 Stromboli had an unusual violent paroxysm, followed also by a local tsunami. **Figure 8** shows the results.

During this period of time the endogenous fluids continued to increase their pressure. The raw *AE* signal displayed some irregular variation. In contrast, D_t steadily increased. It displayed some oscillations, not strictly periodical, with a typical duration of ~5-7 days (maybe, they were associated with a time variation of atmospheric pressure, but this guess ought to be confirmed by meteorological data).

Note the steady increase of the *maximum* of the oscillation displayed by D_t in **Figure 8b**. It is reasonable to guess that also after September 23rd its trend was still increasing, until December 28th, when it reached the value $D_t=1$. Then, the plumbing line collapsed, and a new boca explosively opened at some lower height above sea level on the slope of the volcano.

In the subsequent days a tsunami wave was observed, and the phenomenon was recorded by TV images by a professional observer who had expressively been sent on the islands to watch the volcano after the paroxysm. The interpretation given by Gregori and Paparo (2006) was that an event occurred similar to the aforementioned opening of the new boca: a large and abrupt landslide was triggered, below sea level, along the slopes of the volcanic edifice, and it triggered a tsunami that hit the coast of the island.

This interpretation of the tsunami event may be confirmed, perhaps, by the apparent similarity with the response of the compression, until final rupture, of a concrete cube (**Figure 8c**).

The similarity is noteworthy between **Figures 8b and 8c-left side**. The plot (not here shown) analogous to figure 8a, but referring to the concrete cube experiment, looks much different compared to **Figure 8c-left side** (in fact, the raw *AE* signal rapidly increases when a new load is added, but it also decays very rapidly, unlike D_t which keeps a high value for a few minutes as shown in figure 8c-left side).

The concrete cube experiment may therefore be considered a laboratory-scale model of the Stromboli paroxysm. This may be considered as a case history of “structural” self-similarity.

This Stromboli paroxysm shows therefore the heuristic potential of D_t (**Figure 8b**) compared to simple and straight reference to raw data alone (**Figure 8a**).

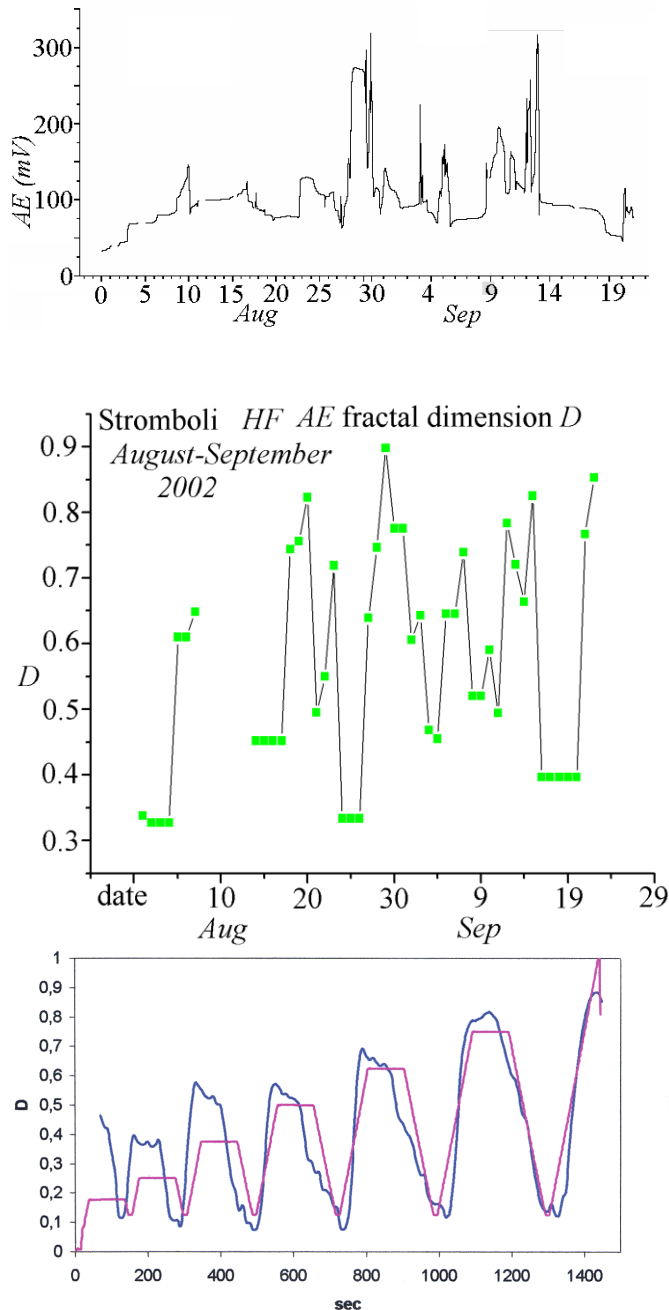


Figure 8. [top to bottom] (a) Raw HF AE record, weighted mean over 24 h (by triangular weight). After Gregori and Paparo (2006). (b) D_t after subtracting the 24 h running-mean from the unsmoothed raw data set (every raw datum is an average over 15 min). Every D_t was computed for one day. But, whenever data were insufficient, several subsequent days were considered, and are plotted like several days with the same D_t . When the volcanic edifice is “deflating” and D_t is low, the AE events more seldom occur, due to a temporary reduction, or lack, of any prime energy supply to the volcano. After Paparo et al. (2004). (c) Average D_t (in blue) measured on two sets, of 10 elements each, of concrete cubes (15 cm side). All specimens are identical, and of identical concrete. Every specimen was stressed (red line) by adding progressive loads, (everyone 50 kg, with unconfined uniaxial compression). The specimens were stressed until final rupture. The left and right diagram refers to HF AE (200 kHz) and LF AE (25 kHz), respectively. HF AE is representative of the beginning of structure deterioration. After Guariniere (2003).

Suppose to have available a planetary network of *AE* stations. According to the presently available previous measurements, two frequencies may be recommended, ~200 kHz, and ~25 kHz, but even a few other frequencies can result eventually useful, although not strictly necessary.

The importance ought to be stressed of making reference to *simultaneous* records of both *HF AE* and *LF AE*.

The crustal stress on the planetary scale - and also its space-time variation and propagation through Earth's crust (which is to be discussed in section 4) - can thus be effectively monitored almost in real time (this reminds about a much similar information provided by a planetary-scale meteorological service).

Whenever suitable, an additional comparatively denser *AE* array ought to be implemented in order to monitor local crustal propagation, inside crucial and restricted areas (as discussed in section 3.2). This can provide with the needed information about local hazard (much like micro-meteorological information can be used for every local concern, on the basis of the boundary condition information provided by a planetary meteorological datum, etc.).

The “*flaw hierarchy law*” is a much general concept, appealed to by several authors (although they call it by no specific name). It relies on the principle that some hierarchy must exist during every rupture process, by which one has to expect to monitor first some kind of phenomena, and subsequently another type, etc.

A practical confirmation and observation of this effect has been investigated in several laboratory experiments on various specimens (steels, granites, concrete, etc.) reported in the literature. Owing to brevity purposes, only two results are here recalled.

The first remind is about the number of hierarchy levels which can be observed and distinguished. This number strictly depends (*i*) on the intrinsic structure and composition of the natural system which is investigated, and also (*ii*) on the kind, and on the spatial and temporal resolution, of records and on their error bars.

For instance, in the case of seismic activity, Lei et al. (1993) recognized in China (by means of multifractal analysis; see the Appendix) a 3-level hierarchy, which they show is in close correspondence with specific tectonics features and with crustal morphology of China.

Concerning experiments on granite specimens (e.g. Lei et al., 1992 and 1993), a coarse grained granite reveals a 2-level hierarchy, unlike a fine grained granite which occurs only according to a 1-level effect: it is very likely that this difference ought to disappear if the temporal resolution of the detector could to be increased, etc.

The second related remark deals with an evidence that was found by means of the aforementioned granite specimens. But it also applies to concrete specimens (Xu et al., 1997). Referring to a granite, when it is brought to total collapse under tri-axial constrained compression, the intra-grain bond yield first. When, at a later stage, also single grains collapse, the whole granite rapidly breaks down. In the case of concrete, which contains some hard inclusions, micro-cracks form a belt, until a micro-crack gap occurs around every hard inclusion.

This means that intra-grain bonds (or cement/inclusion bonds) are comparably weaker. The granite (or concrete specimen), under strong pressure, first displays a less “elastic” and more “plastic” behavior. By this, the intra-grain bonds (or cement/inclusion bonds) yield, and the granite (or concrete) attains a new structural configuration. In some way it adapts to the stress which is applied. But, when also single grains (or hard inclusions) collapse and also their stronger bonds yield, the entire structure of the whole medium rapidly collapses, and it experiences an abrupt total loss of performance.

As far as cement is concerned, it is a mixture of several different components. Every interface between contiguous different components has its typical strength. Hence, these differences imply some typical flaw hierarchy law. However, the chemistry of different components changes *vs.* time, due to very slow diffusion processes. This explains the ageing of cement, and of concrete, which at present is a great concern.

AE monitoring permits to assess the “flaw hierarchy law” much better than every other method: the key advantage is that it provides with a distinction of *HF AE* and *LF AE* and these results to be a much effective way to recognize the direction of the arrow of time within observations (see section 1, and also section 4).

In this respect, a key remind has to be given about previous papers that are found in the literature and that deal with *AE* measurements, carried out either in geophysics or in laboratory experiments.

In general, experimenters apply a piezoelectric transducer, and often they don’t even specify the frequency at which it operates. Or, if they specify the frequency band, they don’t mind about the dependence of the effect simultaneously observed at different frequencies.¹⁴

In contrast, a key and fundamental item of the rationale which is here envisaged is the concern about the frequency dependence of the phenomenon. Indeed, this feature gives the information of paramount importance about the direction of the arrow of time inside the medium (see section 1). We know that, owing to sound physical arguments, the same phenomenon has to be observed *first* to involve smaller flaw domains (i.e. *HF AE*) and only subsequently an analogous phenomenon must involve larger flaw domains (i.e. *LF AE*). This feature is fundamental in order to get rid of the well-known and otherwise unsolvable dilemma of the distinction between precursors and aftershocks.

That is, the aforementioned argument that is here adopted - which begins from micro-flaw-domains that coalesce into larger flaw-domains, etc. - relies on a *physical* model. Its discussion finally leads to the explanation of a cleavage plane, etc., and to associate a physical significance to the value of D_c , etc.

In the case of the Earth crust, the possibility (see the Appendix) has been shown to clearly recognize periods of “*crustal storm*” and “*quiet*” periods in between them. A “*crustal storm*” is characterized by a violent crustal stress activity, which is monitored by intense *AE* signals. In the Italian peninsula, a “*crustal storm*” seems to last several years, and “*quiet*” periods also last years. Earthquakes seem to occur only during a “*crustal storm*”, although no regular lognormal trend seems to be recognizable in a “*crustal storm*”.

Inside every “*crustal storm*”, however, it seems possible to recognize “*crustal substorms*”, everyone lasting in the order of, say, two weeks. A strong earthquake seems to occur at the completion of a “*crustal substorm*”. The trend of a “*crustal substorm*” seems approximately to remind about a lognormal trend. A tentative proposed interpretation is that a “*crustal substorm*” is a cycle during the crustal rupture process. In general, however, this cyclic process is interrupted and no final “catastrophe”, i.e. total rupture, occurs. The likely reason is that the boundary conditions continuously change.

At present, all this is only tentative and speculative, as several additional case histories are to be collected. Nevertheless, the unquestionable observational assessment of “*crustal storms*”, composed of an apparently erratic superposition of shorter lived “*crustal substorms*”, is suggestive to be an example of the flaw hierarchy law, as every “*substorm*” is a minor detail of the major process of a “*storm*”.

The capability to recognize a detail inside our records depends on our monitoring facilities, and on our capability to interpret them. That is it depends on the empirical constraint. The discussion in the Appendix

¹⁴ To the best of my knowledge, the distinction of two different simultaneous *HF AE* and *LF AE* records was made by Gabriele Paparo in his Gran Sasso experiment, and later on he asked for my help for interpretation. This was the beginning of our investigation of *AE* monitoring.

highlights the present state of the art, although subsequent improvements are likely to occur when the database will get richer and more varied.

For completeness sake, it has also to be mentioned that several approaches are very different, which rely on some much accurate and clever mathematical tools (such as typically it occurs with multifractal analysis or others; see the Appendix). They display much intriguing features and dependences. But it appears as yet sometimes difficult to assess a physical understanding and explanation, or any formal “protocol” to be applied to different case histories. That is, sometimes it appears that no final agreement seems to have been achieved concerning their practical application. Some harder thinking is likely to be needed, before their inclusion in the present “handbook”.

3.1.2.2 – Shallow geotherms

A “geotherms” is called every temperature profile vs. depth in ground. By “shallow” I mean that it refers to a layer down to ~3.5 m depth. An array of “shallow geotherm” stations is in operation in the Chinese meteorological network since over half a century (although the station number increased gradually in time). Note, however, that the term “geotherm” was not used by Chinese scientists.

These remarkable studies were carried out by Prof. Tang Maocang and his school, from the *Institute of Plateau Atmospheric Physics*, Lanzhou (Gansu Province, People Republic of China). They even afford to issue - yearly and on a permanent basis for the Chinese government and with a skill of ~65-70% - a climate forecast (atmospheric precipitation) on a middle space-time scale, i.e. on a scale of several 10 km to a few 100 km range, and a few to several weeks’ time lag.¹⁵

Every station is composed of a hole drilled into ground, where temperature is simultaneously measured at different depths, i.e. respectively at 0, 40, 80, 160, and 320 cm depth. The datum at 40 cm depth appears to be essentially unreliable, due to erratic and unpredictable disturbances originated from Earth’s surface. The data at greater depths permit to estimate the thermal gradient between different levels.

The data handling is then carried out by rejecting the days affected either by rain or by snow cover. Other periods of time are used to estimate the geothermal flux and its variation in time.

It seems likely that the former rationale was perhaps focused on earthquake precursors, because a temporal change of release of endogenous heat is to be reasonably associated to heat advection associated with the dynamics of endogenous fluids. A micro-fracturing of the crust favors the escape of geogas, hence it affects the geotherm, etc. and this could be, perhaps, a seismic precursor.

In reality, their records resulted much more effective for climatological applications (see below), although also the tectonic implication were relevant.

Compared to other monitoring devices, this technique is comparatively very cheap. The largest part of data were collected manually twice a day, at two pre-chosen and fixed instants of time. Present facilities make much less expensive to collect data automatically, even in real time whenever needed.

¹⁵ The following information relies on the scanty material that can be found, mostly only on the English abstract of Chinese papers, that sometimes have no English translation. In addition, I had the privilege to host and cooperate with two much valuable scientists, who had been former students of Professor Tang Maocang. They are Dong Wenjie and Gao Xiaoqing, wonderful persons and friends. I acknowledge several discussions with them, and also some material that they gave me. A more detailed amount of information is contained in the 8-tome study mentioned in a previous footnote.

But their study remained constrained among Chinese Earth's scientists and it found almost no acknowledgement in the western world.¹⁶ This depended on different sound reasons, which are here briefly mentioned (being however my personal evaluation).

A first concern deals with the significance of measurements. In this respect, let us recall three schools of thought that interpret a geotherm by means of much different and apparently irreconcilable ways.

The standard well-known viewpoint of a *geothermal scientist* assumes that the observed temperature gradient derives only from heat *conduction* alone from a deep heat source. Fluid advection underground is considered to be only an unwanted and supposedly approximately negligible perturbation. Hence, whenever some inconsistency is found in observations, the anomalous datum is rejected.

Instead, a *meteorologist* assumes that the observed temperature gradient derives from the previous time history of the thermal exchange soil/atmosphere (either by conduction, or by radiation, or by thermal advection through water or air flow into ground). No concern is allowed for any endogenous heat source, which is believed to be negligible.

A *hydraulic agronomist*, or a *hydrologist*, considers rather only *thermal advection* by fluid dynamics. Hence, a geotherm is a way to monitor the effects of water flow underground, while either the time variations of geothermal flux or the meteorological effects are supposed to be negligible.

In addition, these last specialists are very much - and often harshly - concerned by the perturbation that can be introduced in the environment by the probes that are posed into ground in order to monitor temperatures. More specifically, they are much concerned with the *percolation* water that runs along the probes inserted into soil.

In every case, whatever technique is used to pit a probe into soil, an environmental perturbation is unavoidably always produced, even when a trench is excavated and probes are inserted horizontally, etc.

One can get rid of this drawback by attempting to measure the different records, which can be collected at supposedly strictly identical sites, by means of probes put into ground by different methods. For instance, the effect of water percolation can be tested as in **Figure 9**, etc.

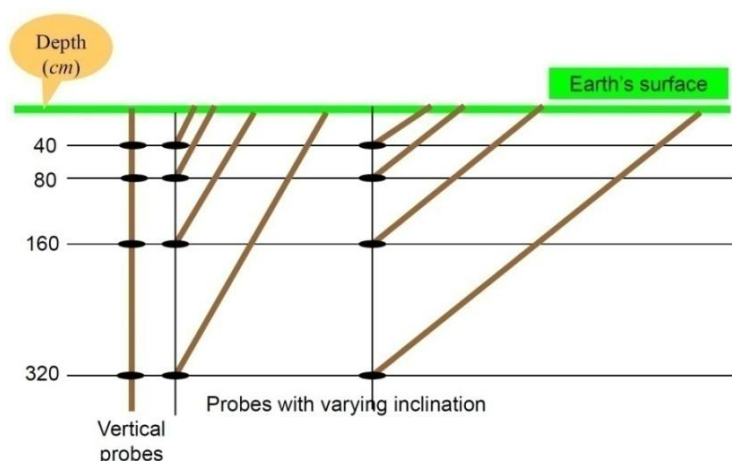


Figure 9. Calibrating the role of percolation by using simultaneously operated probes, every one with a different inclination relative to vertical direction. See text.

¹⁶ For instance, the *Research Branch of Agriculture and Agri-Food Canada*, in the framework of an environmental monitoring program in Northwest Territories managed by *ABEKC (Arctic Borderlands Ecological Knowledge Co-op)*, since 1997 established at two sites (Eagle Plains, and Old Crow) soil temperature records at 20 and 50 cm depth. But it appears that they were not aware of the large amount of data collected by, and of the related studies made by, the Tang school.

This controversial item certainly played a role for keeping specialists skeptical about shallow geotherms. Nevertheless, it is much reasonable to guess that one single geothermal record can eventually be unreliable. But, whenever we deal with a huge number of geotherms, statistically the largest number of them is very likely to be physically significant, and not largely affected by water percolation or by some other unwanted disturbance.

Owing to brevity purposes, it is strictly impossible even to mention here a few of the Tang school findings.¹⁷ Consider also the uncertainties that affect these records and derive from the often unknown varying environmental conditions. The Tang co-workers rejected records following periods of rain, or biased by snow cover etc. Therefore, compared to these unknown environmental biases, maybe, water percolation is the least concern. In any case, an analogous drawback is shared, in general, by several other kinds of environmental monitoring. Hence, only the final multiparametric check can help to discriminate between significant and non-significant results.

Indeed, Tang and co-workers found convincing results that appear to be very likely to be significant. A few additional circumstances contributed to the success of Tang's school investigations (and perhaps no equivalent success had been possible in other countries).

Indeed, they had available a monitoring network that spans a sub-continental-size region. In addition, it simply relies on the national meteorological service of one country alone. Hence, they had no problem of coordination between networks operated by different administrations. They could collect records for decades, and get an observational database suited to carry out a significant study.

In addition, a maybe paramount advantage was that they had to manage observations dealing with a much varied territory including the Tibet Plateau. This plateau resulted to be climatically (and unexpectedly) very interesting. This was not due only to its elevation above sea level. In fact, it was found to be a relevant anomaly of geothermal flow. According to my interpretation, this anomaly derives from the huge amount of friction heat, which is caused by the presently ongoing orogenic process underneath Himalaya.¹⁸

That is, the Tibet Plateau acts like a real time-varying “stove” that contributes, by some relevant amount, to atmospheric processes and to energy balance, by means of its time varying thermal input into the atmosphere.

The Chinese Earth scientists describe the Tibet Plateau as the “Third Pole” of the Earth, as they consider it as one singular feature, similar to the North and South Pole.

Hence, the success of the Tang school derived both from their great skill and far-looking perspective, and also from the particularly lucky environment and circumstances where it was implemented.

In general, however, it is not to be expected that when the same method is applied in other regions, the result ought necessarily to be equivalently successful. Every region has to be calibrated, depending on its specific environmental morphology and its different climate drivers.

In any case, it should be stressed that a combined dense network of multiparametric stations, including *AE*, shallow geotherms, and local meteorological parameters, can provide with a composite data set which is

¹⁷ They are reviewed and discussed - as far as it was possible to me, due to obvious language difficulties - in the aforementioned 8-tome set.

¹⁸ The Joule heat distribution evaluated by means of standard geomagnetic measurements, and which is expected to occur at the lithosphere/asthenosphere boundary, displays a maximum just underneath the Tibet Plateau (unpublished map, drawn by Xiaoping Gao, on the basis of the formalism that I envisaged). The reason is that a hotter medium, due to local friction heat, has a higher electrical conductivity, thus implying a higher concentration and channeling of the planetary-scale induced telluric currents.

suited to carry out a self-consistency check of the different collected records, of the state of the crust, and mostly of the interaction soil/atmosphere.

By the way, this information appears to be fundamental also in order to test every proposed mechanism dealing with the coupling between atmosphere and soil, including atmospheric or ionospheric seismic precursors.

Indeed, *AE* records monitor the time variation of soil porosity. Hence, the thermal control, by advection of endogenous fluids, ought to be correlated with *AE* variation. In contrast, the thermal interaction soil/atmosphere ought to be monitored by means of the observed correlation of meteorological parameters and shallow geotherm records, etc.

Summarizing, I recommend to set up a planetary array of composite stations (meteorological, *AE*, shallow geotherms) in order to collect a primary and long-lasting data base suited to monitor the variation of crustal stress, including its spacetime propagation through the globe, and its relation and impact on the energy exchange between soil and atmosphere.

3.1.2.2 – Superconductor gravimetry (*SG*)

At present, a network of 25 *SG* stations is operated in the world. They are extremely sensitive (and expensive) gravimeters, which require a very great care and concern while they are operated. They were implemented only during comparably recent times.

According to the comparably limited number of papers that appeared, at present they seem to be in the stage of assessing the dependence, of their time-varying measured gravity, on the variation of water amount in subsoil following rain. But, even when they have subtracted all unwanted effects, they display some varying signals that as yet cannot be physically interpreted (Iginio Marson,¹⁹ private communication).

They also recognized (see Crossley et al., 1999; Rosat et al., 2009) that western Europe (which is the region with the densest number of *SG* observatories) moved up-and-down on one occasion, reminding about the membrane of a drum, while a station in Ukraine did not move. That is, regions of continental size can oscillate.

These observations appear to be a very powerful tool that provides with unprecedented and very accurate observations. Their monitoring of the time-varying gravity field, carried out at fixed locations and with a very great precision, is likely to give information that no other technique could provide.

Since March 2002 the satellites *GRACE*²⁰ are operative, and they monitor the time variation of gravity on the planetary scale. But *SG* stations represent a key and very sensitive ground-signature at a fixed point and at every instant.

A combination of *SG* monitoring with a local array of *AE* recorders, and also shallow geotherms, could prove decisive for the interpretation of presently unexplained *SG* observations.

In this respect, let us mention a guess for the interpretation, and for the investigation, of the apparently erratic correlation of the observed impulsive changes either of the spin rate of the Earth, or of pole motion, occurring in coincidence with some strong earthquake (although not for every strong earthquake).

¹⁹ I am indebted with Professor Iginio Marson for stressing the role of *SG* techniques.

²⁰ *GRACE* is the *Gravity Recovery And Climate Experiment* - being a joint NASA – German Aerospace Center. *GRACE* is a pair of satellites that orbit Earth at ~500 km height, one close behind the other. Through constant interchange of microwaves the satellites very precisely measure the distance between them, and that distance changes as massive objects below tug at the leader and the follower in slightly different ways at any given instant. The small discrepancies so produced can be used to calculate a gravity map. As masses move around, that map will change. Refer e.g. to Knudsen et al. (2001) and references therein.

The well-known difficulty is that there should be a dramatic change of the moment of inertia of the Earth, which cannot occur by means of any realistic and sufficient amount of mass displacement inside the Earth body.

A possible interpretation is as follows. Let us begin by considering the great tsunami caused by the Sumatra-Andaman earthquake of December 26th 2004. A huge tsunami wave crossed the Indian Ocean and it later hit Africa, which is known to be the most firmly rooted continent on the mantle. This huge wave determined some kind of “sail” effect, and a consequent recoil that affected the astronomical motion of the Earth.²¹

Consider now a general strong earthquake, which causes no tsunami.

The inner core is generally represented as an approximately spherical object, although there is no reason to believe that it is really spherical. It is possible, and even very likely, that it displays some bumps. But their location and relative radial extension are unknown.

When a strong earthquake occurs, the most relevant percent of its energy is injected inside the Earth body. For instance, in the aforementioned case history of the Sumatra-Andaman tsunami, the earthquake occurred on December 26th 2004, with magnitude between $M_w = 9.1 - 9.3$, and a duration between 8.3 - 10 min (it is reported as the longest earthquake ever observed). The hypocenter was in the Indian Ocean ~ 160 km off the western coast of northern Sumatra, at a depth of 30 km. The Sunda megathrust ruptured for a length of ~ 1300 km. It caused, maybe, over 275,000 casualties.

The tsunami was caused by a sudden vertical rise of the seabed by several meters. According to Bondevik (2008), the earthquake “*within a few minutes . . . drove the Indo-Australian tectonic plate an average of 13 m beneath the Burma-Sunda plate*”.

Its energy was equivalent to $\sim 2 \times 10^{16} J = 20. PJ$ [PetaJ] (Pearce and Holmes, 2005) a couple of orders of magnitude less than the energy released in its trigger earthquake. According to USGS estimates, altogether earthquake and tsunami released at Earth's surface $M_E \sim 110. PJ = 1.1 \times 10^{17} J$ (which caused the damages), and a total work spent through whole Earth of $M_w \sim 4.0 \times 10^{22} J = 40. ZJ$ [ZettaJ]. A seismic oscillation at Earth's surface was observed up to 20-30 cm. A 0.02 mm complex harmonic oscillation of Earth's surface was still detected by February 2005. Its effects faded off > 4 months after the earthquake (Virtanen, 2006).

Therefore a strong earthquake generates a wave that crosses through the fluid outer core, and that finally hits the inner core. If the bumps of the inner core are suitably located in space relative to the hypocenter location of the triggering earthquake, a “sail” effect occurs on it (similarly to the aforementioned “sail” effect on Africa). Hence the total inertia vector of the Earth is changed. This effect can be observed at Earth's surface only as a change of the astronomical motion of the Earth.

This is speculation, but it can be checked by observations. In fact, describe the figure of the inner core by means of a spherical harmonic expansion (SHE) perfectly analogous to the algorithm used in geodesy to describe the figure of Earth's surface. Consider a set of several strong earthquakes, and of their respective corresponding perturbations, observed on the astronomical motion of the Earth. By means of a least square fit, compute the coefficients of the aforementioned SHE.

By this, the figure of the inner core is actually measured altogether with its unknown (although at present very speculative) motion relative to Earth's surface.

²¹ This implies a conspicuous impulse of crustal stress. This is consistent with the effect, mentioned in section 3.1.1, which is seemingly originated by the loading tide of the Pacific Ocean water on the Eurasia shelf, and that triggers a crustal stress that is later observed by HF AE in central Italy and in the Ionian Islands (Greece).

At this point, the *SG* records, measured with great precision at a few (at present 25) selected points at Earth's surface, ought to monitor and check the time variation of bump locations on the inner core, hence its rotation relative to Earth's surface.

3.2 – Location in space – Local “forecast”

An earthquake is the result of a strictly local release by an active fault, as a response to a crisis of crustal stress, which always involves a much larger region. Hence, we must focus on local crustal morphological features, if we want to guess any kind of realistic local alert.

In principle, a local “forecast” can be released by means of the information similar to that used for the large-scale “forecast”. The concern is about the detail and spatial resolution that can be provided by every given monitoring technique, in addition to its error-bars, and to its feasibility and management.

On a practical basis, the best and most detailed space-information about the local seismic hazard is given by the geological and tectonic knowledge of every given site, and by the historical time series of seismicity. That is, a detailed knowledge ought to be achieved of the different minor crustal blocks of a given hazard area. For instance, although on a very large spatial scale, Wang et al. (2011) successfully afforded to implement a model of several different blocks that compose the Chinese crust. They relied on multiparametric information and mostly on the historical data series. By this, they concretely afforded to envisage what areas have a greater hazard etc.

In the case of much smaller areas, suitable monitoring local arrays must to be implemented.

Therefore, a convenient procedure is to rely on a preliminary alert to be issued by a global monitoring system. Then, local authorities, on the basis of the local concern dealing with specific areas which are believed to be more prone to an eventual seismic activity, implement a dense network of monitoring stations in the area of concern and in its immediate surroundings. This local array is expected to monitor the evolution of the local crustal stress, in order to locate the most likely position of the epicenter.

As far as the choice is concerned of the monitoring technique, upon considering costs, feasibility, and management (prompt installation and data base availability, plus data analysis that can be carried out in real time), maybe *AE* arrays appear most convenient. In addition, by a limited extra cost, shallow geotherm monitoring can be combined with *AE*, thus providing additional information, which improves the quality of the physical interpretation of ongoing phenomena.

One may also claim that, in the final analysis, this kind of monitoring is a much more effective way suited to manage the same kind of information that, indirectly, gives rise to the sparse occurrence of anomalies of hydrological and fluid exhalation phenomena.

4. - Time

In principle, the “forecast” of the time of an earthquake can be carried out by several different techniques, which are more or less reliably used for global monitoring.

Global *AE* monitoring can provide with the information on the stress propagation through the planetary crust, thus giving the alert whenever a crustal storm (see Appendix) is crossing through some large-scale region.

When a local authority is concerned with a potential seismic hazard, they may implement a local *AE* array (eventually supplemented with shallow geotherms) that can monitor the “crustal substorms” (see section 3.2 and the Appendix) thus providing the information needed to issue a local and more precise time alert.

This applies both to seismic-prone areas, and also to volcanoes. A volcano, however, can also be effectively monitored by means of precursors associated either (i) with a likely large change of ground temperature, which can be monitored by satellite remote sensing, or (ii) with a relevant and “rapid” topographic variation, that can be monitored either by GPS techniques or by satellite altimetry, or *InSAR* observations.

But a “simple”, and maybe very reliable, information can be inferred from photon emission from ground due to micro-fractoluminescence.

Fractoluminescence, i.e. photon emission when a solid structure is fractured, was successfully investigated in the laboratory by V. I. Vettegren' and coworkers, at the *A. F. Ioffe Physico-Technical Institute of Russian Academy of Sciences*, St. Petersburg, Russia. Vettegren' et al. (2012) state that “*under the impact, the Si-O-Si bonds are broken and SiO free radicals and SiO centers are formed. Fractoluminescence appears as a series of flashes with a duration of ~10 nsec. Each flash is assumed to correspond to the initiation of a microcrack. The linear sizes of the microcracks estimated from the intensity of the flashes and the velocity of elastic waves range from ~7 μm to ~40 μm, with an average of ~10 μm. The microcracks are grouped in microseries with a duration of ~4 μsec, which causes modulation of strong AE oscillations by weak oscillations with a period of ~8 μsec. The formation of microcracks with a linear size exceeding ~30 μm causes discontinuities in the time dependence of e.m. emission.*” They do not specify the frequency of their recorded AE.

A related crustal observation is reported by Persinger et al. (2012). They used a photomultiplier to monitor, in a totally dark environment, the photon emission released from soil. They operated their instrument in a dark basement at the Laurentian University, Sudbury, Canada, and found an impressive correlation of an increased photon emission in coincidence with two very strong and very far away earthquakes (**Figure 10**).

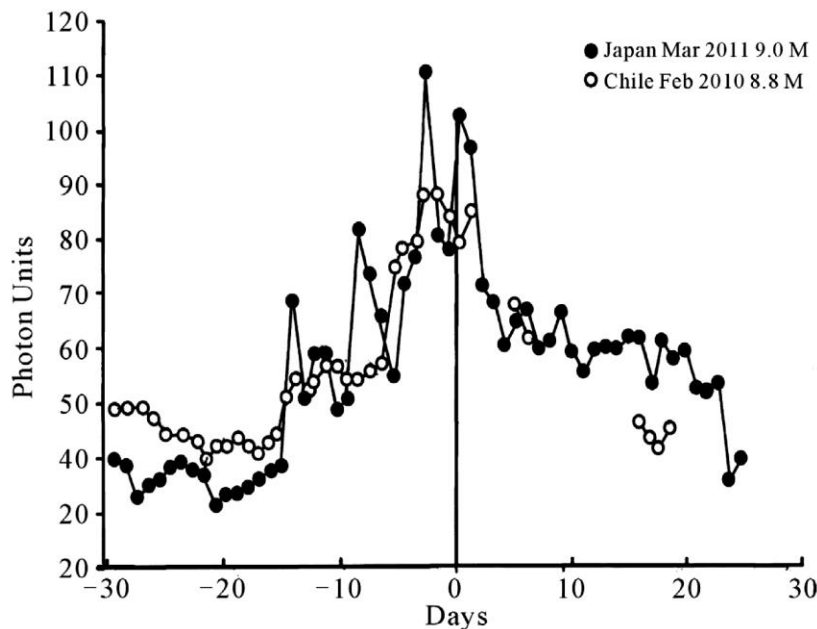


Figure 10. “Median daily numbers of photon units ($1 \text{ unit} = 5 \times 10^{-11} \text{ W m}^{-2}$) recorded by our photomultiplier tube system ($1 \text{ sample min}^{-1}$, $24 \text{ hours day}^{-1}$) during the days before, during, and after the Japanese (closed circles) and Chilean (open circles) very strong earthquakes.” Figure and captions after Persinger et al. (2012).

They comment that “the peak, which would be equivalent to about 350 times the photon density over our background reference range, occurred 7-11 days before the major shock. The return to baseline ranges occurred about 15-16 days later.”

They also stress “the conspicuous antecedent increases in continuous photon emissions for days before the quakes were ~9,200 km and ~9,700 km (surface distance) away from the Chilean and Japanese events,

respectively, and suggest that very energetic seismic events may be preceded by ground photon emissions at a global level."

However, as they emphasize, several additional case histories are to be investigated before claiming that a new "law" has been discovered.

A few items are to be pointed out.

The typical aforementioned time delays, either before or after a very strong shock, may depend also on the recording location, because the rheology of the crust may be different at different sites.

If such a planetary phenomenon is confirmed, it implies that a huge crustal stress paroxysm involves anywhere the entire globe during ~7-11 days (or other suitable time lag) before a major earthquake. This effect ought to be easily detected by a planetary array of *AE* (plus shallow geotherm) stations, and eventually it could monitor (if it exists) a space-time variation of the propagation of such a strong crustal paroxysm.

As far as the "forecast" is concerned of the time of a major shock, the maximum in **Figure 10** (i.e. some ~80-110 *photon units*) maybe could result to be different on different occasions and at different recording sites. Hence, a corresponding uncertainty exists on the predicted time.

In any case, the indeterminacy in the case histories of figure 10 is less than the sum of the time lags before and after the major shock, i.e. it is altogether less than ~22-37 days, which is of practical usefulness in order either to issue an alert and to decide to issue an all clear.

In any case, a local and dense suitable array of *AE* (plus eventual shallow geotherm) stations deployed in the area of some fault, which is known to be in hazard of seismic activation, can effectively monitor the time evolution of the local ongoing crustal paroxysm. Thus, the local authorities can decide whether the crustal stress eventually approaches some pre-chosen threshold and thus they have to issue an alert.

Fractoluminescence (recorded somewhere all over the globe) plus local monitoring of crustal storms and/or crustal substorms can be very helpful in order to decide when to release an all clear.

It appears that, at present, this is the best that can be done in order to match, on a realistic operative basis, the societal needs with the error-bars of scientific understanding. Scientists also have the responsibility to transfer the correct scientific information to decision makers. But legislation still appears to be the most serious problem, because in every country it is definitely inadequate.

Considering the seriousness of this great hazard, it must be stressed that this gap of legislation has a profound deontological implication.

5. – Conclusions

It should be stressed that the synthesis given here is only a very partial and temporary assessment of a discipline that is likely to experience a rapid evolution, as soon as several present hunches are progressively better understood, both in terms of a collection of a richer observational data base and of the improvement in the understanding of local and planetary crustal phenomena.

On the other hand, the present literature very often appears to be affected by a substantial amount of confusion, by which several very different approaches are methodologically unrelated one another. Hence, they raise serious problems of lack of clarity in their respective interpretation, potential usefulness, and effectiveness.

The present paper aims only to attempt to begin to put some order into these much disordered issues.

Consider also that the solar influence in Sun-Earth relations is such that it affects phenomena that deal with the interaction between soil and atmosphere/magnetosphere, including climatic effects that eventually thus result, in general, to be somewhat correlated with seismic activity.

For instance, let us recall the correlation between *SST* (sea surface temperature) and seismic activity: some authors suggest that this is a manifestation of friction heat released from the crust into the sea. A similar concern deals with earthquake clouds. Other remarkable investigations are concerned with soil temperature variations monitored by satellite born radiometry. But, radiometric records have to challenge the disturbance originated by vegetation etc. No references can be here given.

In general, all these items are hampered by the present poorly understood coupling between atmosphere (both upper and lower) and subsoil. This understanding is severely biased by a sum of paradigms. But this item requires an independent and long critical discussion to be given elsewhere.

These phenomena are however in any case much indirect effects, much like it occurs also for every biological precursor. It is therefore often difficult to interpret their observed correlation. Their detection is generally much occasional, as it applies only under suitable general conditions. Sometimes it is even difficult to assess what case histories display an actual correlation, while apparently others, even being similar, show no correlation at all. Hence, at the present state of the art, these items appear to be still a topic for hard thinking and research, rather than a really useful tool for actual practical application. But, in the future, every topic can result worthy of greater practical consideration.

Instead, a few key deontological items are to be here strongly emphasized.

It is quite unacceptable that - while tremendous tragedies hit a large number of people and countries - the scientific community is concerned with debates and controversies that, upon a deeper analysis, often appear to be real nonsense. A few key points are to be explicitly mentioned.

- One nonsense discussion is between opposing partisans, who claim that earthquakes can be “predicted” or “not”. Nothing can be “predicted”. But everybody *must* admit that the state of the crust can be diagnosed. Denying this (as it is often done) is equivalent to claim that it is useless to carry out research in medical sciences, just because nobody can forecast when a patient will die.
- Suitable multiparametric monitoring is strictly needed in order to issue a reliable diagnosis. This means that no “magic” rule-of-thumb or index or quantity alone can exist, which is capable to issue a reliable “forecast” of an earthquake.
- It is nonsense to pretend to investigate seismic precursors, by consideration of shocks that occur either when an earthquake occurs or after its occurrence. This means that seismometers are useful for a statistical *a posteriori* analysis of phenomena, but *not* for crustal diagnosis and for precursors. Medical science cannot proceed only by means of anatomic analysis of dead bodies, or by statistics of mortality: observation and diagnosis is strictly required by means of observation of patients *before* death.
- It makes nonsense to discuss whether plate tectonics is “the correct” model, rather than expansionism, or any other model. Natural reality is multifaceted. Every model relies on much oversimplifying assumptions, and by this it can explain only very few facets of reality. Very different geodynamic models can coexist, even when they may appear contradictory with one another. They just rely on different, often unrealistic, assumptions. And often they derive from much learned and extensive investigations. Every model deserves therefore full respect for the hard thinking and research which is behind it.
- A prevailing theory is generally upgraded to a “paradigm”. But no paradigm should exist. The discussion of “paradigms” is academic, fruitless, and often irresponsible when it is of no help for dramatic societal needs.

The scientific community must be aware of the moral implications in maintaining an eventually fierce competitive discussion on nonsense controversies, while great tragedies are often occurring somewhere.

“Humility” is strictly required to explain natural phenomena. We must avoid to want to impose to natural reality our pre-selected “simple” paradigms (Showstack, 2011).

Scientists must transfer the correct information to mass media, to decision makers, to legislators and governments, so that they can issue suitable laws that allow for an effective management of natural catastrophes. At present a great legislative gap exists in every country. Every official authority, in the case of a false alarm, is at present at risk of very severe legal consequences in terms of civil and criminal liability. Therefore, there is an often serious concern, as nobody wants to challenge any even very small probability that an alert is eventually not followed by the “predicted” catastrophe. Hence, a disquieting feeling is that some authority prefers not to be informed, as in this way it has no obligation to decide.

APPENDIX

Methodological items shared by every kind of monitoring

Three key items are to be briefly stressed dealing, respectively, with (i) abstractions and algorithms, (ii) fractal and multifractal analysis, and (iii) “storm” and “substorm” concepts.

A.1 - Abstractions and algorithms

Human mind has a limited capability. Hence, it requires “simple” or “beautiful” (Einstein) models, schemes, rationale, etc. This is a basic premise for every cognitive process.

Simplification requires abstractions in order to simplify the proposed model, and to construct, by means of abstractions, algorithms suited to exploit a rational interpretation of observations.

Elementary and well known abstractions are e.g. numerability, or “point”, “line”, “plane” in Euclidean (or non-Euclidean) geometry, or specific spaces in abstract algebra, etc.

But even the Newton fundamental laws of classical dynamics are just a matter of abstraction, as well as any axiomatic formulation of every physical theory, including general relativity, or quantum mechanics in its various formulations, and also every most advanced hypothesis of theoretical physics, etc.

Concerning the rheology of Earth’s crust, the pertinent abstractions are a “solid” medium, or ideal “elasticity”, or ideal “plasticity” (i.e. the so-called “Newtonian fluid”), etc.

In natural reality, however, nothing exists which is exactly in agreement with any abstraction. Therefore in particular, no “solid” object is perfectly “elastic”, no “solid” object is perfectly “plastic”, perfectly “conducting” or perfectly “insulating”, etc.

In addition concerning the algorithms that are mentioned in the present paper, three items are to be recalled.

- 1) *Lognormality* – This property is shared by almost every system, as explained in section 3.1.2.1. It appears almost unbelievable that a concept that was clearly assessed in the early years of 1900 - and which has several applications in very different disciplines, from natural sciences (including biology and medicine) through financial and psychological sciences, etc. - was never clearly assessed as a basic abstract and heuristically much effective property and algorithm.

Its axiomatic definition shows that it is a case history of the so-called Kapteyn class distributions (from the renowned Dutch astronomer of that time). Refer to Kapteyn (1903), Kapteyn and van Uven (1916), Arley and Buch (1950), or to Paparo and Gregori (2003) for details.

- 2) *Fractality* – This property is shared by almost every kind of phenomena. Or, at least, it applies to every discipline that deals with some phenomena that behave like a fractal. Other phenomena do not. It is presently being used in several disciplines (unlike lognormality), although only since the 1970's fractality has been clearly assessed as a common abstract property, with its associated algorithms.

Indeed, every abstraction, and the exploitation of its algorithms, responds to a primary logical requirement, aimed to match and explain some observations. The primary leading idea behind fractal analysis has been the repetitiveness of a natural property on different scale sizes: this property is conventionally called “*self-similarity*”. This property however, holds only inside a given and finite space-time domain. For instance, a Roman broccoli (which is indicated in every textbook of fractal theory as the best visible natural example of a fractality) shares self-similarity requirements while ranging from the geometrical volume of the broccoli, until the molecular level, while self-similarity no more exists outside this space domain. Refer to section A.2 for a brief mention to a simple and elementary fractal algorithm.

- 3) *Flaw hierarchy law* – It was already defined in section 3.1.2.1. It may be conceived as a much general property. A key role in its practical definition in every observational case history is played by the empirical constraint, represented by the fact that we can measure and monitor - always with a given but limited precision and sensitivity - only a much reduced set of *d.o.f.* of the system. This implies that we can distinguish only some kind of phenomena, but not others.

Inside this logically constrained gnoseologic scenario, we can distinguish a sequence of different stages in the evolution of a physical system,. For instance, in the case of the evolution of a fracturing process, one can detect and recognize the evolution of flaws of different size etc.

The possibility to detect an effect of this kind intrinsically relies therefore also on the composition and nature of the system. For instance, the application to the historical earthquakes of China, mentioned in section 3.1.2.1, led to the distinction of three stages, closely associated with morphological features of Earth's crust that can be effectively recognized in that region, etc.

A.2 - Fractal and multifractal analysis

Fractal analysis has now become a classical and standard approach, and several textbook are readily available. Only for the reader who is not yet acquainted with fractals, one very simple algorithm is here mentioned, which ought to be known by every Earth's scientist. It is the so-called “*box counting method*”.

Let us begin and consider a *time* series of “yes” events, i.e. independent of the amplitude of every event. Only its time coordinate is of interest (i.e. this is a 1D variate, but this applies to every other 1D variate other than time). This kind of data series of “yes” events is called in mathematics a “*point-like process*”. Let the time series to span a total time lag of duration L .

Arbitrarily choose a “ruler” of length μ , and cover the time lag L by a sequence of contiguous and never-overlapping rulers μ . Define a counter $N(\mu)$ and state that $N(\mu)$ is the number of rulers μ that contain at least one “yes” event of the given point-like process.

Repeat the same procedure for different choices of μ . Plot $\log N(\mu)$ versus $\log \mu$ and this is called “Richardson plot”. A decreasing plot is thus found. If it is found to be linear (inside some interval on abscissas, say for $\mu_1 \leq \mu \leq \mu_2$), it is said that in this interval the variate is a fractal.

The tilt of the line (with reversed sign) is called “*fractal dimension*” D_t (where the index t denotes that a time series of “yes” events was considered, although the same procedure applies to every series of events, everyone associated to one parameter, which in general can be denoted as t).

The reader should check that a perfectly random time series of “yes” events strictly leads to $D_t=1$ (check it!). This is in fact one rigorous way by which an ideal perfect “random” time series can be defined: it is tautological with “random”.

If the distribution is not random, this means that every event has some “memory” of the occurrence of other events (occurred either before or after it). The greater is this “memory”, the lower will be found $D_t < 1$. When every event has total “memory” of all others, all events occur at the same instant of time. In this case it is found $D_t=0$ (check it!).

The same procedure applies in a 2D space, such as e.g. in Cello’s analysis of faults (see section 2.3) on a geological map, represented as a Cartesian coordinate plane with latitude and longitude axes. The “ruler” μ is some pre-chosen fixed rectangle. The Richardson plot is always $\log N(\mu)$ versus $\log \mu$ etc. The (reversed sign) tilt of the line gives the fractal dimension D_s (where the index s denotes that fractal analysis is carried out in a 2D space, instead of the 1D case of D_t).

It is thus found that, in the case of an ideal perfect random distribution of faults, it is $D_s=2$ (check it!), and that in the case of ideal reciprocal “memory” it is $D_s=1$ (check it!).

That is, this very simple and intuitive argument, which directly relates to some given physical features of the observed system, directly leads to a much specific quantitative gauge, which measures the self-similarity, i.e. the fractality, of the observed phenomenon, inside a suitable space-time domain.

The theory of fractals has now become a well-established “mathematical” theory, including several different algorithms that lead to the same estimate of the fractal dimension, although by means of different approaches.

It should be stressed, however, that unlike every classical mathematical formulation, fractal theory appears somewhat anomalous (although perfectly rigorous in its definition) in the fact that it does not start from some axiomatic definition with subsequent logical implications. Rather, it makes reference to some data series of some observations. Its purpose is to single out some kind of unprecedented “statistical” properties displayed by the given series. Therefore, compared to standard mathematical analysis, its methods and rationale appear somewhat “unusual”.

For the sake of completeness, it ought to be mentioned that a remarkable generalization has been envisaged - and it is already frequently applied in the literature - called “*multifractal analysis*”. The fractal dimension is one case history of the parameters that are defined by multifractal algorithms. This analysis applies also to case histories when the simple fractal analysis does not exhaust the information that is contained inside observations.

However, different applications of multifractal analysis often rely on very different, although equivalent algorithms. The final set of parameters is finally evaluated according to much specific assumptions (for instance dealing with different asymptotic approximations, etc.). There appears to be as yet no general agreement on the most convenient algorithm to be used, and on the way by which every computed parameter can be “intuitively” interpreted in terms of its physical implication.

Therefore, it appears that some hard thinking is to be expected before attaining some final assessment of the real heuristic possibility of this remarkable theory. For brevity, no additional details can be here given.

A.3 – “*Storms*” and “*substorms*”

As mentioned in section 3.1.2.1, the terms “*storm*” and “*substorm*” are borrowed from geomagnetism and magnetosphere. But, these concepts express a very general behavior of several phenomena, and they deal with almost every discipline.

The concept of “*storm*” applies whenever a given physical system displays a strongly perturbed period of time, compared to other periods during which it displays quietness.

Such a definition, however, is certainly excessively vague. In fact, a “*storm*” of a system often is the response to a specific input or trigger either by its boundary environment, or by internal processes. Its general morphology often appears to evolve according to the requirements of lognormality.

As already mentioned in section 3.1.2.1, a classical geomagnetic storm, when the sign is reversed of the geomagnetic horizontal component H , displays an approximately lognormal distribution (Campbell, 1996), although with some relevant scatter. This scatter reflects some lesser intrinsic details or minor processes, which specify some features of the ongoing evolution of the storm.

These lesser details are indeed the magnetospheric *substorms*, which however are better evidenced by means of the breakup of polar auroras. Also every substorm displays a trend that reminds about a lognormal distribution.

Therefore, in geomagnetism, both storms and substorms respond to the logical implications of lognormality. A substorm reflects the timing of the propagation of a lack of particle supply inside the system of the electric currents that flow through the magnetospheric tail. The consequent gap of electric current affects the magnetosphere. But this holds only as long as the lack of current supply flows inside the current system along the tail of the magnetosphere, i.e. typically during *~2-3 hours*.

Owing to a similar argument, the storm persists long as the large-scale plasma cavity in the solar wind persists, i.e. *~ a few days* etc.

Therefore, in general, one can recognize a “*storm*” of a system from a clear and evident alternation of strongly perturbed periods, and of quiet periods of time. In addition, if a lognormal distribution is eventually observed - even though more or less approximately - then one may envisage a process that responds to the requirements of the abstraction of lognormality. But this additional requirement is not a strict condition, as it is an optional feature to be eventually observed.

In addition, inside one “*storm*”, one may eventually recognize some scatter that can be possibly interpreted as the manifestation of some internal process that occurs, thus explaining a minor detail of the ongoing macro-process of the “*storm*”. In this way, a “*substorm*” has been recognized. And the process can continue as long as the observed scatter displays some hunches that can envisage some better detailed physical mechanism, thus eventually envisaging a *sub-sub-storm* etc.

In the case of a rupture phenomenon, this is just what has been called a “*flaw hierarchy law*”. That is, substorms, sub-sub-storms, etc. are subsequent stages of the hierarchy of observations that describes the process. These details depend on the empirical constraint, as they reflect the human capability to detect and recognize the timing of the evolution of the ongoing phenomenon.

In the final analysis, one central logical key is the assessment, inside a higher level of the hierarchy and apart some lesser scatter, of an approximately lognormal trend. This means that some kind of an (even unknown) process is ongoing, which is the sum of several events, every one of which happens with a probability proportional to the number of the same events that are already occurring.

This means, however, that this kind of (unknown) events is eventually going to exhaust. That is, the physical system is not in equilibrium: it is steadily evolving towards some final state or event. In the case of the Earth magnetosphere, the final target is a new state of equilibrium. The magnetospheric storm or substorm thus represents the physical time-delay required by the magnetosphere to reach its new equilibrium state, as a response to an eventual change of its environmental boundary conditions, which are represented by a change of the solar wind flow.

In the case of a rupture process, the final target is the achievement of a new equilibrium state. That is, the physical system requires a finite time-lag in order to attain its new equilibrium state. It is evolving. It must evolve towards a target, and this target eventually implies that the “solid” structure must finally collapse (or, on other occasions, maybe the target does not imply a collapse).

Differently stated, we may recognize a lognormal distribution inside some parameters that monitor the ongoing formation of micro-cracks inside a “solid” object. But, we cannot know whether, in general, that given specific parameter that we are monitoring - and which refers to one specific (eventually unknown) internal micro-process of the “solid” structure - eventually leads (or not) to a catastrophic collapse of the physical system.

Let us refer to crustal processes. The best way to explain concepts is to refer to an actual case history. As an example of practical application of these concepts to a specific seismic event (see Gregori et al., 2010 and 2012), let us refer to the l’Aquila earthquake (main shock on 6th April 2009, magnitude 5.8 on the Richter scale, 6.3 on the moment magnitude scale; it caused a severe destruction of the old historical capital of Abruzzo, with 297 fatalities).

Figure 11 shows *LF AE* records carried out during 2002-2009 at the Raponi site, in the fraction Orchi (which means “Ogres” due to sounds that often come from underground). It is located close to the town of Foligno in Umbria, central Italy.²² This site is very close to the epicenter of the Colfiorito earthquake, which during September–October 1997 stroke central Italy between the villages of Nocera-Umbra and Sellano. It was a seismic sequence with three main shocks ($M_w=5.6$, 5.9, on September 26, and $M_s=5.5$ on October 14).

The impressive spike in **Figure 11**, which can be briefly called “crustal impulse” is not an instrumental failure. It is real, as it is shown in the detail of **Figure 12** (note, however, that **Figure 11** is a plot of daily weighted averages “*F*”, while **Figure 12** deals with raw *LF AE* data). This very large anomaly preceded by ~32 days the strongest l’Aquila shock. This is a very likely precursor. However, the time lag ~32 days is not necessarily a “universal” law.

In fact, on previous occasions, while studying either peninsular Italy or the Ionian islands (Greece), we observed (with co-workers) strong precursors either in *HF AE* or *LF AE* (either in raw data or in D_t series) with a time advance widely ranging between *a few days* through *10 months* (see also **Figure 15**). Therefore, the advance time lag is likely to be much different in different regions, and even much different on different specific occasions of earthquakes striking the same area. Therefore, no rule-of-thumb can be defined.

²² I am deeply indebted (together with my coworkers) to the Raponi family who generously hosted the experiment.

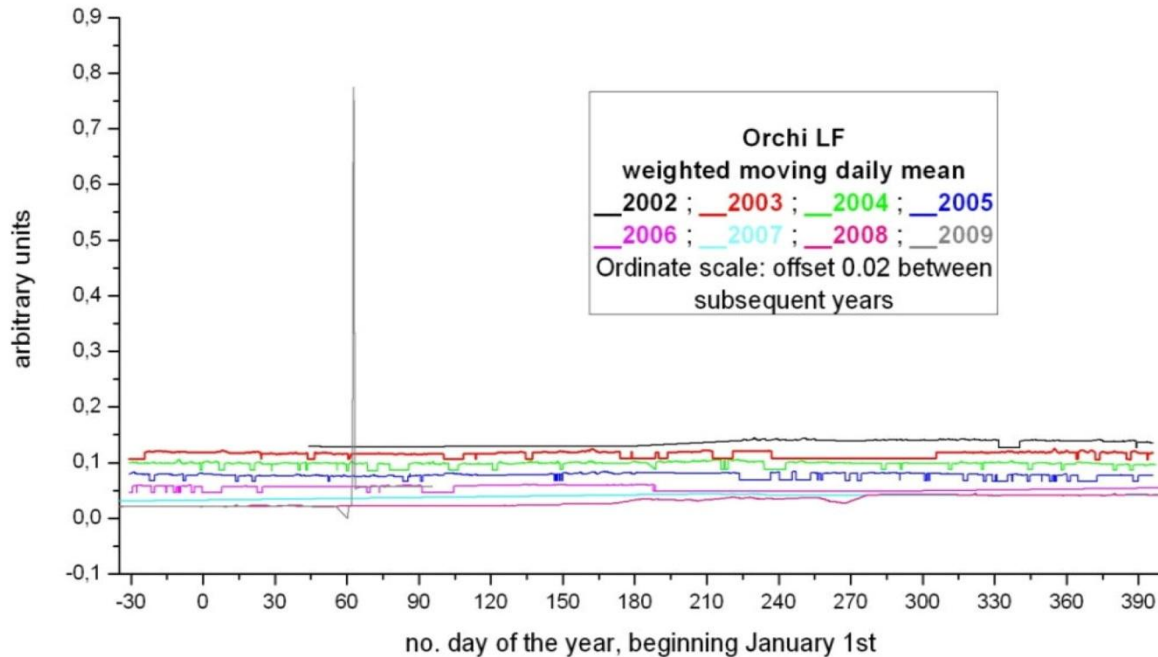


Figure 11. "Superposed LF AE records at Orchi. All strings of data, shown with a slight offset between different years in order to avoid overlapping, begin from 1 January of every respective year. See text." Figure and captions after Gregori et al. (2010).

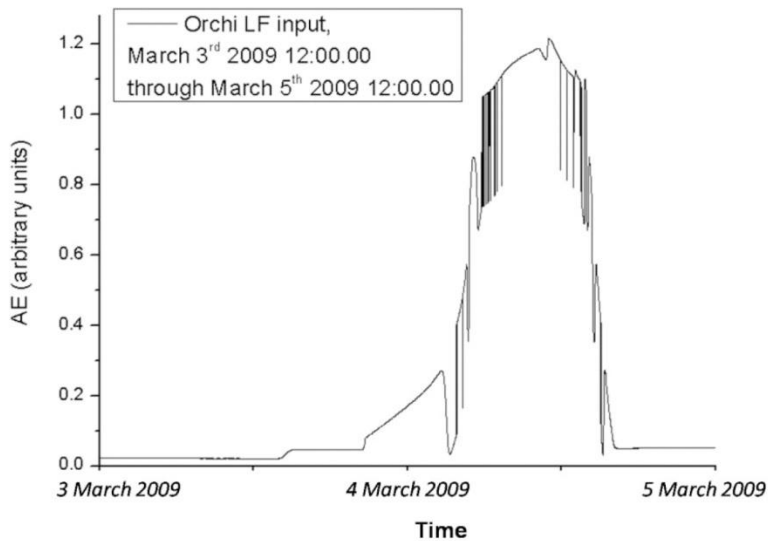


Figure 12. "Detail of figure 11 (but raw AE data, not "F"), showing the internal structure of the "crustal impulse" lasting ~12 h and preceding by ~32 days the l'Aquila earthquake ..." Figure and captions after Gregori et al. (2010).

Figure 13 shows a detail of **Figure 11**, referring to raw data, and by using a different unit on ordinates. The appearance of a "storm" is clearly displayed, which is better evidenced in **Figure 14**, where also the records at Valsinni (see below) are plotted in addition to Orchi's (note the different units on ordinates). Valsinni is located close to the Ionian coast - roughly at the central point of the "sole" of the Italian "boot" - and the station was operated by the Civil Protection of the Region Basilicata (capital Potenza).

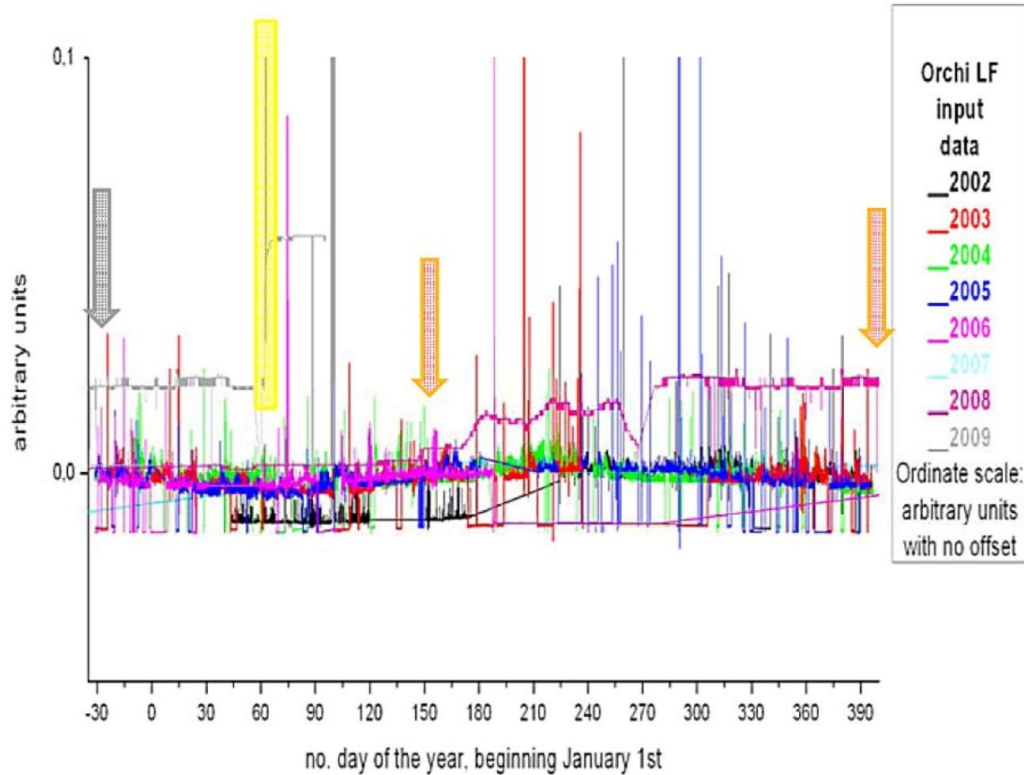


Figure 13. "Detail of figure 11, referring however to raw data, with no outliers rejection, and no smoothing. Note the gentle seasonal variation, and the "crustal impulse" (yellow rectangle) ..." Figure and captions after Gregori et al. (2010).

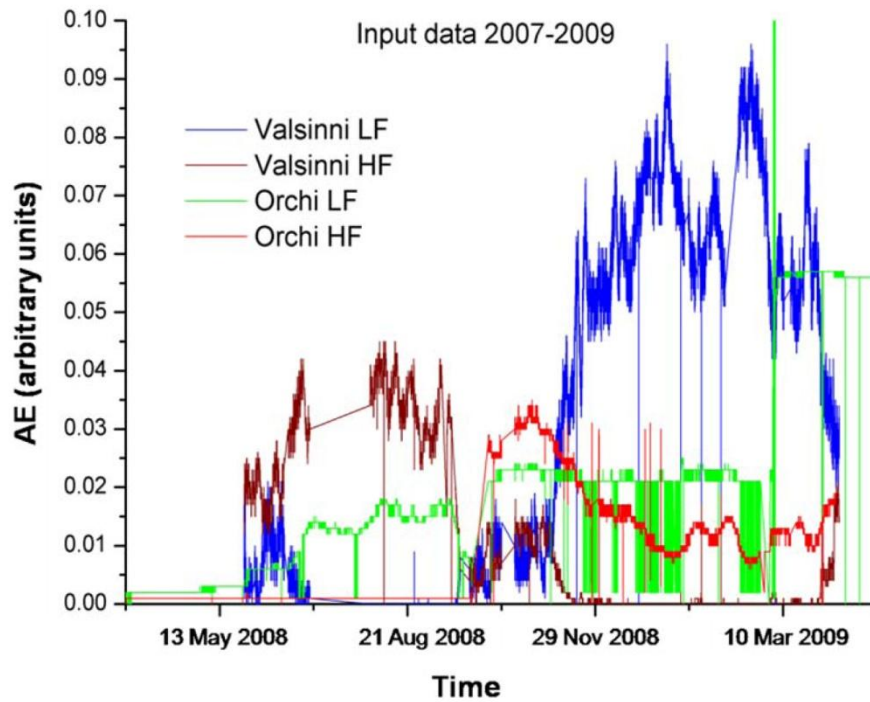


Figure 14. "Raw AE records at Orchi and Valsinni, showing the onset of the "crustal storm" that preceded the l'Aquila earthquake. The "crustal impulse" is also clearly shown (in green)." Figure and captions after Gregori et al. (2010).

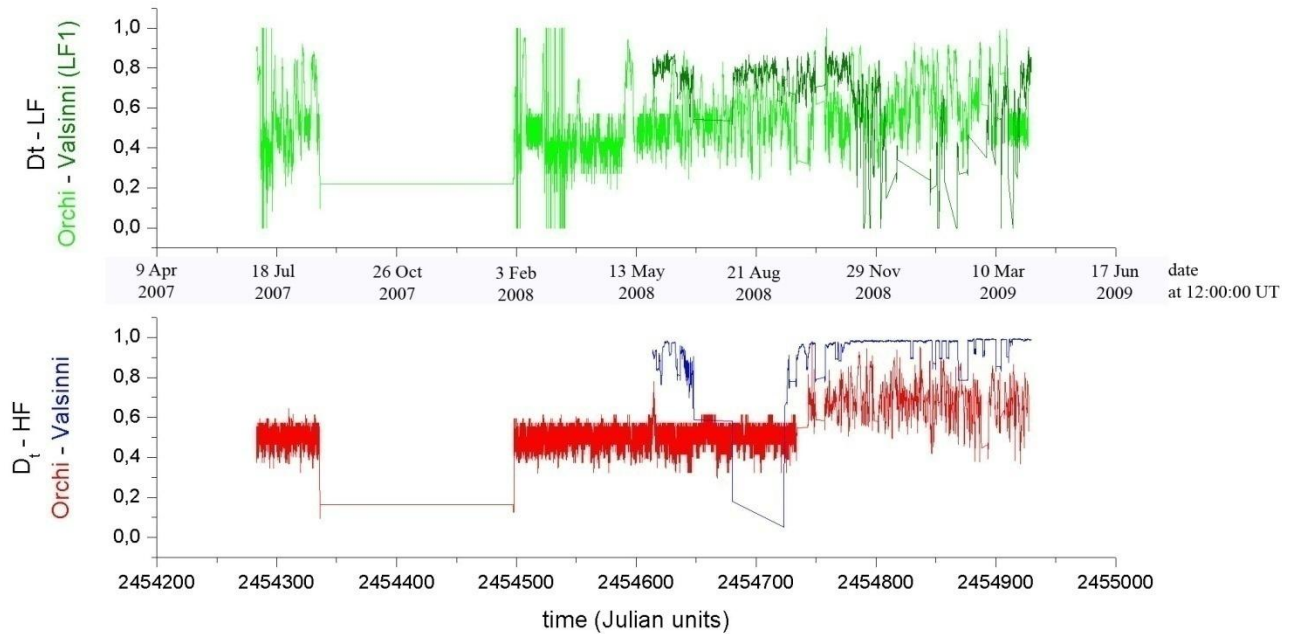


Figure 15. Plot of fractal dimension D_t at Orchi and Valsinni during 2009 ($HF\ AE \sim 200\ kHz$, $LF\ AE \sim 25\ kHz$). The main shock occurred on 6th April 2009 at the end of this diagram. A “crustal substorm” is displayed at Valsinni, and (as expected) it occurs first in $HF\ AE$ (in blue; begun in the first decade of June 2008), and later on also in $LF\ AE$ signal (in black; begun at the end of October 2008). See text.

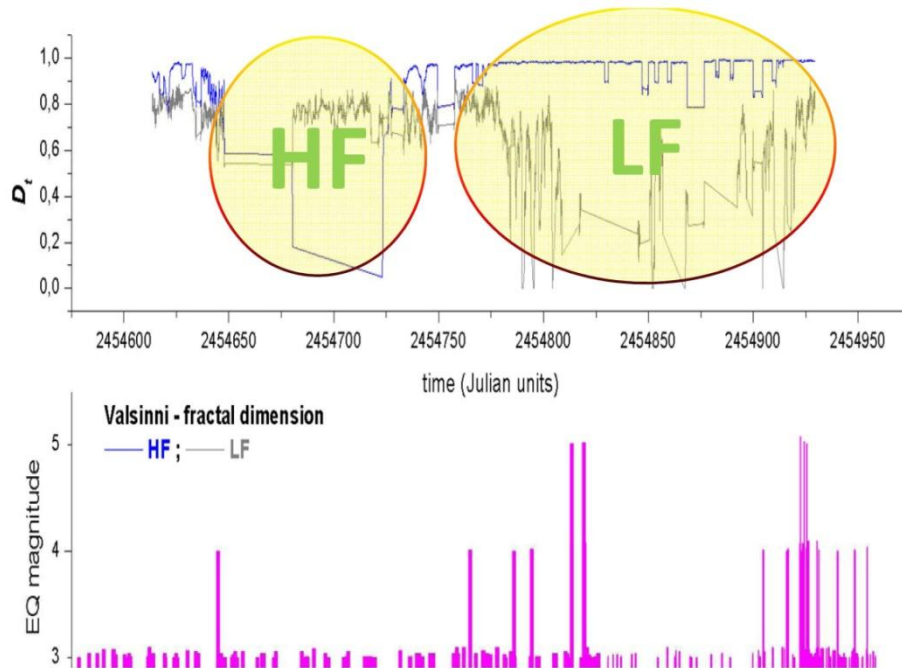


Figure 16. "Fractal dimension D_t of both $HF\ AE$ and $LF\ AE$ records carried out at Valsinni, at $\sim 354\ km$ from the epicentre of the l'Aquila earthquake. The 'stress substorm' at either $HF\ AE$ or $LF\ AE$ is denoted by a large ellipse. The l'Aquila earthquake occurred at the completion of the $LF\ AE$ 'substorm', although in general different earthquakes can have a different speed of evolution in time ..." Figure and captions after Gregori et al. (2010).

Note also the gentle (with this scale units) seasonal variation, which appears very clear and regular by using a suitable unit on ordinates (not here shown) and that was tentatively interpreted as the consequence of the time-varying stress originated by the loading tide of the Pacific ocean waters on the Eurasia shelf (see section 3.1.1).

A geomagnetic storm is better indicated by means of the horizontal component H of the geomagnetic field, while a magnetospheric substorm is better detected by means of polar auroras breakup. Similarly, in the case

of crustal stress, a “*crustal substorm*” is better revealed by the fractal dimension D_t . **Figure 15** shows D_t both for *HF AE* and *LF AE*, and it shows that the substorm feature can be distinguished from the background scatter, and this “*crustal substorm*” is observed *first* in the *HF AE* signal (as it must be expected) and shortly *afterwards* in the *LF AE* signal. **Figure 16** is the same, with a reduced time span on abscissas, where the two *HF AE* and *LF AE* substorms are shown by two closed ellipses.

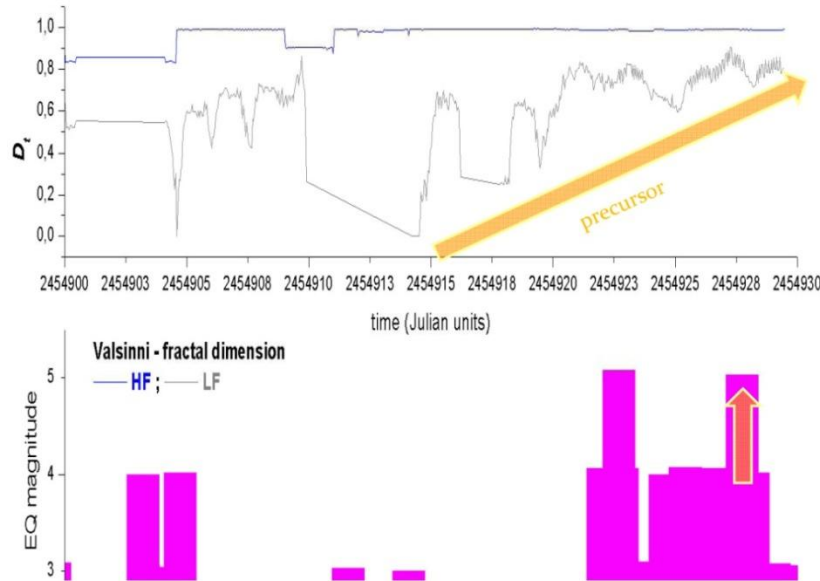


Figure 17. Detail of the last few days of the large “reversed” lognormal trend that in Figure 15 is indicated as an ellipse “*LF*”. The lesser oscillations are tidal effects. The bottom diagram shows the seismic shocks, and the red arrow the main l'Aquila shock. The orange arrow in the upper diagram denotes a guessed precursor: the main shock occurred when the recovery was completed of the *LF AE* crustal substorm. See text. After Gregori et al. (2009).

Figure 17 represents a detail during the few days that preceded the main destructive shock, which occurred when the substorm was completed. This means that a fracture process was in progress, as it is displayed by a lognormal trend. That is, a crustal substorm was ongoing. At the end of this process, the crust was certainly going to attain a new final equilibrium configuration. In this case, the final target was a dramatic crustal fracture.

Differently stated, when we do observe a crustal substorm, we *never can know* whether the final target will be a dramatic fracture of the crust, or not. But, in any case, we do know that, as long as the substorm is in progress, we cannot claim that the system has attained a temporarily “quiet” state: it is quite possible that at the end of the crustal substorm a dramatic shock can occur. Note, in the lower plot of **Figure 17**, the swarm that preceded the main shock. Several local inhabitants were frightened, and they decided to sleep in caravans. On the other hand, the panel of experts - which is permanently in charge and is appointed by the national Civil Protection - officially stated that no scientific reason could allow them to issue any alert for a possible forthcoming strong shock.

According to mass media reports, however, some expert of the panel unduly and unfortunately apparently released some clearly much reassuring statements: but the shock occurred, and the expert panel was later sued.

However, if *AE* monitoring had been available in real time during those days, the trend of the upper plot of **Figure 17** could effectively envisage that the state of the crust was experiencing a rapid evolution towards a new equilibrium state. This, maybe, could even imply a conclusive catastrophe of the system. This is certainly not a “forecast”. Nevertheless, this is information about the fact that something dramatic might occur just at the expected end of an observed and ongoing crustal substorm. That is, only when the crustal substorm is over, can one issue an all clear.

Figure 15 requires some comments. The data gap during the last months of 2007 was caused by lack of records. The *HF AE* substorm occurred 300-200 days before the main shock, and the *LF AE* substorm some ~200-0 days before the main shock. A perturbation in the *LF AE D_t* also occurred simultaneously with the *HF AE* substorms.

The earthquake struck the city of l'Aquila, which is much closer to Orchi than to Valsinni. But the crust of the Italian peninsula is not a homogeneous "solid" body. It is well known that geologists envisaged the existence of a deep sinistral transcurrent fault crossing through the entire peninsula from Anzio to Ancona. But the evidence is not fully convincing. L'Aquila is south of this fault, hence it is on the crustal slab of Valsinni.

The crustal substorm was observed at Valsinni, not at Orchi. At Orchi, however, *D_t* displayed a permanently much scattered trend in the *LF AE* (green), while *D_t* in the *HF AE* (red) abruptly change its trend at the end of August 2008, with a much increased scatter. An attempt to interpret these features could be carried out only if an array of *AE* stations were available through the Italian peninsula.

As a summary of the inference drawn from several investigations on the seismicity of the Italian peninsula, the following facts seem to be shown by observations. A warning, however, is that every reliable conclusion ought to rely on an array of at least a few *AE* stations, rather than on single-station records.

During 1996-1997 a crustal storm was ongoing. During this period of time two strong earthquakes occurred: Potenza, April 3rd, 1996, M=4.9; and Colfiorito, September 26th, 1997, M=5.7, followed by several intense shocks.

During 1998-2001 the available *AE* records are insufficient for any tentative assessment.

During 2002 the Molise earthquake occurred (October 31st, M=5.8). At present, it is impossible to envisage whether it occurred during a continuation of the 1996-1997 crustal storm or not. During the period of time 2002-May 35th, 2008 a "quiet" period occurred.

Since May 26th, 2008 a new crustal storm started (as shown in **Figures 13 and 14**). On April 6th, 2009 the l'Aquila earthquake occurred (M=6.3). On August 4th, 2009 a strengthening occurred of the *HF AE* storm, and on August 23rd, 2009 of the *LF AE* storm. No *AE* records were available after December 2009.

But also the use of *AE* and *D_t* can be misleading. During September-December 2009 systematic *AE* records were collected, both at Orchi and at Valsinni. Data were regularly analyzed every two days. For brevity the plots are not here shown. Only their evidences are here reported.

The simultaneous *D_t* behaviour at Orchi and Valsinni result uncorrelated.

HF AE D_t appear comparatively less scattered than *LF AE D_t*. Perhaps, this was a consequence of the fact that during those months the crustal storm period was manifested in the *LF AE* frequency band, while the *HF AE* was already experiencing a "quiet" period. This speculation, however, could be confirmed only by carrying out a much longer *AE* records, while data collection was interrupted after December 2009.

HF AE D_t display an almost steady sequence of seemingly "crustal substorms" of various duration, although every "substorm" never fully completed its trend. If one had applied the same criterion, by which the crustal substorm of **Figures 15, 16 and 17** is interpreted as the "correct" precursor for the main l'Aquila shock, an alert had to be issued on several occasions (in the order of one every week or even more frequently).

But, in any case, the epicentre location was unknown on the basis of the records at two *AE* stations alone. It was only known that, since every crustal "substorm" was observed at Valsinni, a possible shock had to strike the Italian peninsula somewhere south of the Anzio-Ancona fault.

This is speculation. On a sound and realistic basis it appears possible, or maybe likely, that a “crustal storm” period was in progress. The Italian peninsula - and maybe mostly its part south of the Anzio-Ancona fault - was permanently shocked. Hence, several crustal components were suffering by fracturing processes. The phenomenon was monitored by *LF AE* better than by *HF AE* as *LF AE* refer to a comparatively more advanced stage of the ageing of crustal structures.

That is, the fracturing processes were ongoing at various sites, although luckily none never reached a threshold sufficient to generate a destructive shock. In this case, one might claim that *LF AE D_i* apparently resulted suited to “forecast” this kind of fracturing, although this is evidently of no societal concern.

It should be stressed that, on the basis of this observational evidence alone, all this could be mere speculation, devoid of any actual relation with natural reality.

In principle, this dilemma cannot be solved upon relying on *AE* records carried out simultaneously at two stations alone. One should rather rely on a suitable array of both *HF AE* and *LF AE* stations, and one should match the resulting diagnostic information inside the general geological framework of the knowledge of the tectonic setting and faulting of every given area.

A realistic final assessment of the hazard and risk of every given area can therefore be finally assessed only when all diagnostic information can be implemented into a realistic crustal model in that given area, and *AE* monitoring certainly appears to be a leading tool according to this perspective.

Mostly, one should envisage the specific active fault that might be the site of the epicentre, and should implement a dense array of *AE* stations etc. (as per section 3.2).

Summarizing, this shows that precursors are *never* identical in different case histories, and one must always be extremely careful before claiming to have made a fully reliable diagnosis of Earth’s crust.

Much like in medical sciences the knowledge of a pathology is improved by wealthier statistics of investigated case histories, it appears fundamental to collect a large number of case histories dealing with earthquakes (or even better, with the “crustal storms” and “substorms” that are not followed by an earthquake) that strike the same area. The purpose ought to assess whether one given precursor can be more or less reliable, or how frequently it is repetitive or not. That is, the assessment of the reliability of a precursor relies on an expert-research on the morphology of the “seismic” behaviour, and on the rheology, of the tectonic structures in every given area.

No simple rule-of-thumb can be envisaged that relies on one parameter alone. Multiparametric monitoring is fundamental, and it should be as detailed as possible.

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THE TETHYS CONFIGURATION AND PRINCIPAL TECTONIC FEATURES OF THE MIDDLE EAST: A WRENCH TECTONIC SURVEY

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“To achieve anything really worthwhile in research, it is necessary
to go against the opinions of one’s fellows”

Sir Fred Hoyle, in: *Home Is Where the Wind Blows*

Abstract: During the reign of plate tectonics, the tectonic evolution of the Middle East has been turned into a never ending ad hoc situation – without trustworthy phenomenological coherence. In an attempt to get out of this deadlock, the geological evolution of the region – stretching from India in the east to Turkey in the west – is interpreted within a new global evolutionary scheme: Global Wrench Tectonics. In working out the new geological development pattern, we start with the pre-plate tectonics notion of the Tethys – an extended E-W running epicontinental seaway along the southern fringes of Eurasia, including the Middle East. During the Alpine tectonic revolution, the Tethyan axis was close to the time-equivalent palaeoequator; and as the palaeo-equatorial zone is a crucial geographical belt for inertia-based wrench deformation of the lithosphere, the Middle East Tethys sector underwent a tectonic cataclysm during which the epicontinental Tethys disappeared completely. Lithospheric Alpine age wrenching led to significant overall transpression of the Tethyan basement giving rise to marginal thrust belts, transcurrent faulting, ophiolite formation, and tectonic rotation of both externally and internally located continental blocks. For example, palaeomagnetic evidence, fault plane solutions, GPS velocity vectors, along with structural data suggest that the Central Iran micro-continental assembly – including the Lut Block – were subjected to a significant counter clockwise rotation in response of Upper Cretaceous-Lower Tertiary transpressive deformation. Furthermore, evidence suggests that the many kilometers thick salt accumulations of the Middle East – including the major Infra-Cambrian Hormoz sequence, the Neogene basins of Iran, the Red Sea and the Dead Sea depressions – are unlikely to be of evaporitic origin; instead, they are much more likely precipitates of episodic ejections of high concentration brines from the upper mantle. The upward surging of asthenospheric material – including magma, solid state upper mantle material (building up surface ophiolites), and transport of the whole diversity of metal compounds – is tightly associated with changes in Earth rotation.

Keywords: *The Middle East Tethys, Alpine tectonic revolution, transpressive deformation, tectonic rotations, formation of major salt basins.*

The classical Tethys seaway; dynamo-tectonic and environmental implications

Like other prominent mountain ranges on Earth, the Alpine-Himalaya chain has long been referred to as an *orogenic belt* – driven by tectonically-produced crustal thickening and related buoyancy. However, all mountain ranges are apparently newcomers in Earth history – having been uplifted primarily during the last 5 million years (e.g. Sonnenfeld, 1981; Stoneley, 1981; Gansser, 1991; Ollier, 1992; Ollier and Pain, 2000), regardless of the tectonic history of their underlying crust. Hence, the old and still popular term of *mountain building*, based on the principle of isostasy, is apparently no longer rooted in facts (cf. Storetvedt, 1997, 2003 and 2010). On the other hand, the buoyant forces behind crustal uplift are most likely associated with deep lithospheric fault zones along with associated segments of anomalous and buoyant upper mantle – a growing fact that call for radical changes of many inbred opinions about the working of the Earth (Storetvedt, 2003 and 2011).

It is an old recognition that long before the late Cretaceous-early Tertiary tectonic upheaval along the Alpine-Himalayan axis, this crustal belt was the site of an extensive east-west running shallow epicontinental seaway – the Tethys, a notion originally conceived by Neumayr (1885) and subsequently elaborated in tectonic terms by Süss (1893 and 1901). In its classic version, the northern shores of the Tethys followed along a shallow ridge which delimited the seaway from another extensive epicontinental sea – Paratethys (cf. Sonnenfeld, 1981 for extensive bibliography) which covered larger areas of Central Europe and western Asia (see **Fig. 1**). Because of its repeated isolation from the world's water masses, the stratigraphy of the Paratethys is difficult to correlate with the depositional records elsewhere. A similar situation was apparently the case for the Tethys. In an extensive review volume, Sonnenfeld (1981) states that throughout Palaeozoic and Mesozoic times the south and north shores of the Tethys were in the same climatic belts; the fossil record shows a much greater variability along the length of the seaway than across it. Already at an early stage of investigation, it was conceded that the Tethys frequently developed a persistently closed-in palaeo-geography characterized by fauna endemism – described as distinctly different from that of the Paratethys. The largely endemic nature of the Tethys, as well as of the Paratethys, was probably aided by intermittent development of shallow 'intra-basin' transverse ridges (Sonnenfeld, 1981). For longer periods of time, the two epicontinental seas covered major parts Eurasia.

Due to the occasional presence of mafic-ultramafic metamorphic rocks of late Palaeozoic and Jurassic-Cretaceous ages, often forming discontinuous sinuous belts within the Tethyan tract (e.g. Ernst, 1972; Ghazi et al., 2004; Shirdashtzadeh et al., 2010; Torabi, 2011), suggests that also in pre-Alpine time tectonic activity along the Tethyan axis had led to diapiric remobilization of low-density serpentinized upper mantle material – to form surface mélanges of ophiolites. During the Jurassic, for example, the Tethys Basin became tectonically disrupted, giving rise to a horst-and-graben topography with resulting diverse water depths (Trümpy, 1965 and 1971; Falcon, 1967; Stöcklin, 1968). At that time, the Sea seems to have advanced as far west as the Caribbean, depositing widespread layers of salt in Central America and the southern United States (Aubouin et al., 1977) – an accumulation that was superseded by basement rupture and rapidly subsiding depressions filled with shale and turbidities (Schmidt-Effing, 1977). The depositional conditions were governed by stagnant water masses and development of faunal endemism, but a passage to the Pacific may have been open at times (Hallam, 1977). Thus, the Mesozoic basin of the proposed Caribbean Tethys seems to correlate well with its mega-scale Eurasian province. However, the Tethyan basin had had a long pre-Mesozoic history – forming a protracted geosyncline that developed along a fundamental tectonic fracture zone implanted into the brittle crust already by late Archaean time.

It is traditionally thought that by the late Archaean a certain outer layer of the planet – heated primarily by an original surface concentration of radioactive elements (see Storetvedt, 2011) – had cooled sufficiently to acquire brittle conditions; thus, it was hypothesized that a certain surface (lithospheric) layer had been subjected to a minor degree of shrinking thereby occasioning two relatively deep near-perpendicular great-circle contraction fractures (cf. Wilson, 1954 and references therein). Inferentially, one of these deep dislocations circumscribed the present Pacific, while the second mega-scale fracture followed along what is now the Alpine-Himalaya axis. The trans-Atlantic and trans-Pacific branches of the second deep fracture (Benioff Zone) were thought to have been submerged and somehow disrupted by late Mesozoic crustal breakdown processes. Wilson apparently followed the classical view of a relatively narrow east-west trending Tethyan geosyncline, and from his global tectonic reasoning this epicontinental sea represented an original world-encircling (great-circle) basin – ultimately broken up in pre-Alpine times. From present rock evidence deep oceanic basins of any significance did not exist prior to the Cretaceous, so for most of its lifetime the epicontinental Tethys apparently extended uninterrupted across the Atlantic – following along the hypothesized 'E-W' running contraction fracture. As for Wilson's most predominant great-circle dislocation – represented by present-day Pacific Benioff Zone sections – the original great-circle fracture has subsequently been tectonically deformed, notably in the SW Pacific, by Alpine age wrench forces (Storetvedt, 1997 and 2003).

In consequence of the dynamic instability responsible the Archaean-Proterozoic boundary (around 2.5 billion years ago), inferentially caused by redistribution of internal mass (Storetvedt, 2003), the Earth finally

settled in a new spatial position (relative to the ecliptic). The planet's new orientation – specified by its inferred palaeoequator, probably representing most of the Proterozoic and part of the early Palaeozoic, is sketched out in **Fig. 1**. Consistent with this ancient relative equator (see Storetvedt 1997, 2003, 2005 and 2011), the corresponding palaeomagnetic poles define reasonable clusters in antipodal positions at ca. 65°E, 25°N and ca. 115°W, 25°S respectively. In fact, the late Proterozoic palaeoequator of Kreichgauer (1902), defined by a combination of fossil palaeoclimate evidence and the late Precambrian global tectonic arrangement, fits surprisingly well with that based on modern palaeomagnetic data.

According to the palaeogeographic setting of **Fig. 1**, it follows that in late Precambrian and early Palaeozoic times there must have been significant latitudinal variation along the Tethys: thus, Iberia and NW Africa were situated in the sub-tropics, while the palaeolatitudes increased eastward towards a polar setting of the Iran-Pakistan region. According to Wolfart (1967), the ancient Tethys of the Middle East was at all epochs experiencing shallow water continental deposition. But despite the region's palaeo-polar location, accumulation of a considerable thickness of Infra-Cambrian halogenic deposits took place: the Hormuz salt basin – extending from the Persian Gulf region to the Salt Range of western Pakistan. In Pakistan this high latitude salt series, consisting of alternating sequences of gypsum, anhydrite, red marl, and rock salt, have estimated thicknesses exceeding 1000m (Zharkov, 1981 and references therein). But in the Persian Gulf Basin the Neo-Proterozoic Hormuz salt series have thicknesses ranging from 1.5 to 4 km (Edgell, 1996). Salt deposits of any thickness are traditionally referred to as evaporates, despite the fact that modern salt deposits rarely exceed aggregate thicknesses of 20 metres (Schmaltz, 1969). According to Sonnenfeld (1984) it is difficult (or impossible) to envisage major thicknesses of layered salt deposits in terms of an evaporitic origin – owing to the multitude of unlikely environmental requirements to be fulfilled in such cases. This would be even more problematic in a polar setting – such as in the case of the thick Hormoz salt sequence (see below).

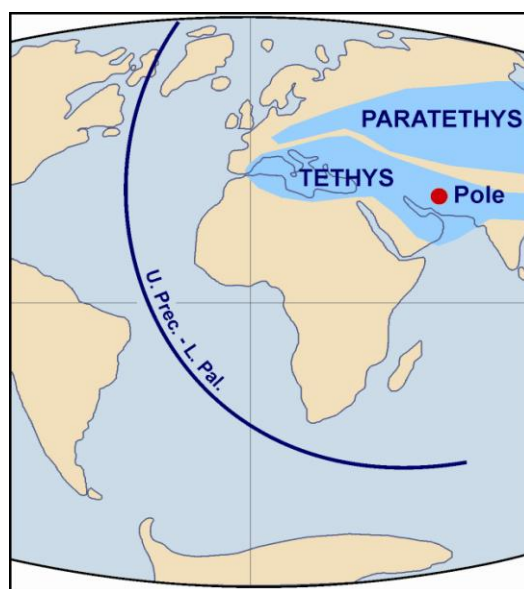


Fig. 1. Diagram shows the western branch of the Tethys and Paratethys seas (medium blue) in present geography. During the Palaeozoic and Mesozoic history of the Tethys, the Earth made a number of spatial reorientations (re-settings of the globe relative to the ecliptic, see Fig. 3). The diagram shows the Infra-Cambrian palaeo-geographic situation during which the palaeoequator passed across Arctic Canada with further continuation along the Central and South Atlantic – with corresponding geographic poles in the regions of Pakistan and SE. Pacific respectively (cf. Storetvedt 2003, 2005). In other words, the major Infra-Cambrian sequence of the Middle East salt deposit formed under polar conditions (approximate polar location marked in red) and is very unlikely therefore to have formed by evaporation.

In general, major salt basins often show linear outline suggesting that they are fault-controlled. To cite Sonnenfeld (1984, p. 398): “The tectonic instability is frequently controlled by normal faults that can and do

act as conduits for the basaltic lavas so often associated with thick salt sequences. The continuity of facies over wide areas without any significant deformation corroborates such vertical subsidence of blocks of great areal extent". Following from this line of evidence, it is likely that the major Arabia/Iran/Pakistan salt pan evolved as products of planetary degassing – i.e. the salts are precipitates from high-concentration brines (of time-varying chemical composition), expelled from the Earth's interior, rather than being products of surface evaporation. Thus, basin subsidence caused by degassing-related sub-crustal loss to the mantle, would naturally cause hydrostatic pressure increase in the volatile-rich upper mantle – periodically setting off surface 'exhalation' of an assortment of volcanic gasses, high concentration brines and occasional magma (cf. Storetvedt, 2003, 2010a and 2011). It seems reasonable to conclude therefore that the major salt deposits of the Tethyan Middle East stems from Earth's internal degassing – and are therefore without any palaeoclimate significance.

From studies of the length of day – by evaluation of sedimentary rhythms caused by the ebb and flow of the tides, and counts of growth rings in fossil shells – it is inferred that in the distant geological past the Earth rotated a good deal faster than now (e.g. Wells, 1963; Creer, 1975; Rosenberg, 1997). For example, Rosenberg (1997), discussing the fossil clocks provided by tidal depositional rhythms, concluded that in the latest Precambrian (some 900 m.y. ago) there were as many as 440 days per year – as compared with the estimated ca. 420 days per year during the Ordovician and 400 days in the Devonian year. It follows that the Earth seems to have experienced an overall slowing at least since the late Precambrian. However, changes in Earth rotation – by variation in spin rate as well as through events of true polar wander (spatial re-orientation of the planet with associated resetting of the equatorial bulge) – have been episodic phenomena. These changes in the Earth's moment of inertia, triggering hydrostatic pressure variations in the asthenosphere, seem to be intimately associated with revolutions in Earth history. Hence, shifts in planetary rotation are likely to have triggered latitude-dependent lithospheric torsion (wrenching) giving rise to tectonic belt formation – besides being the dynamic rationale behind the relatively distinct geological time boundaries (see Storetvedt, 2003).

More than 100 years ago, Kreichgauer (1902) argued for a close link between tectonic belt formation and changes in Earth rotation, and Global Wrench Tectonics – a theory that came to light through quite different sets of observation than that of Kreichgauer – has arrived at the same conclusion. It follows that tectonic belts have formed in two palaeo-geographical settings; they have developed as inertia-driven shear belts either (1) along the time-equivalent palaeo-equator, or (2) in rifted zones at steep angles to their corresponding equator. For example, the progressive southward shift of Acadian, Hercynian and Alpine fold belts across Europe is in harmony with the corresponding shift of time-equivalent palaeo-equators and fall in category (1). On the other hand, the Oslo Rift and Ural Belt have developed in near-perpendicular orientation versus the relative late Palaeozoic equator, while structures like the Rhine Graben and Bress Graben have formed as rifted basins perpendicular to the Alpine equator (which ran along the Mediterranean region, see below). This simple inertial principle explains why the Tethyan belt, particularly on its northern shores, shows segments of Hercynian tectonics, in addition to the much more strongly developed Alpine deformation; as wrench forces have their strongest effect along equatorial belts, this difference in tectonic intensity is simply explained by the fact that the Hercynian equator (cutting across Central Europe) was a bit north of the main Tethyan basin and the Alpine equator.

Due to the relatively fast rotation rate during Infra-Cambrian time, the Earth was prone to develop mega-scale rift structures in near-perpendicular orientation vs. the corresponding equator (**Fig. 1**). Thus, major tectonic structures like the Grenville Belt of North America, the Pan-African Belt, and the East-African/Red Sea Rift system are examples of mega scale ruptures that broke away from the Proterozoic-early Palaeozoic equator. Also, the major structural alignments of the Gulf Region (in their original 'N-S' orientation, see below) most likely formed during the same rifting process, paving the way for the expulsion of high concentration mantle brines from which the regional Infra-Cambrian salt sequence precipitated. A geological profile across the Persian Gulf, with the Hormuz salt sequence capping the crystalline basement, is depicted in **Fig. 2**. Salt plugs are very widespread in the Persian Gulf – and many regional diapiric islands owe their origin to the extrusion and remobilization of the thick Infra-Cambrian salt layer. These elongate salt domes

apparently followed reactivated tectonic discontinuities in the Precambrian basement (e.g. Edgell, 1991; Nasir et al., 2008).

According to Ala (1974) Infra-Cambrian salt began to mobilize in the late Cretaceous, but the majority of surface domes in the Gulf, transporting rocks from the deep Infra-Cambrian Complex to surface level, are apparently of late Eocene-early Oligocene and Miocene ages respectively; indeed, these upshots represent important tectono-magmatic global pulses. From such observations, it seems likely that all major Eocene-Oligocene and Miocene salt formations in Iran are most readily explained either as 1) diapiric extrusions from the underlying thick Infra-Cambrian salt layer or 2) as precipitated layers from high-concentration brines expelled from the deep interior; whatever mechanism in question, the upward expulsion has apparently been powered by Earth's dynamo-tectonic pulses in association with the buoyant and dissolving power of supercritical hydrous fluids of upper mantle provenance. The ability of supercritical water to break down solid rocks into mud, on its upward flow through the crystalline crust (owing to its very low density), is likely to explain the dominance of monotonous mudrocks in many Iranian salt basins. Relevant to the extrusion model, Schlöder and Urai (2006) have studied mylonitic shear zones in Eocene-Oligocene rock salts describing processes of deformation and recrystallization in extruded central Iranian Eocene-Oligocene basins. Furthermore, authors like Jackson et al. (1990) and Talbot and Aftabi (2004) have stressed that all salt basins in Central Iran involve the same two salt sequences: a relatively pure Upper Eocene-Lower Oligocene accumulation and a more variegated and impure Miocene sequence.

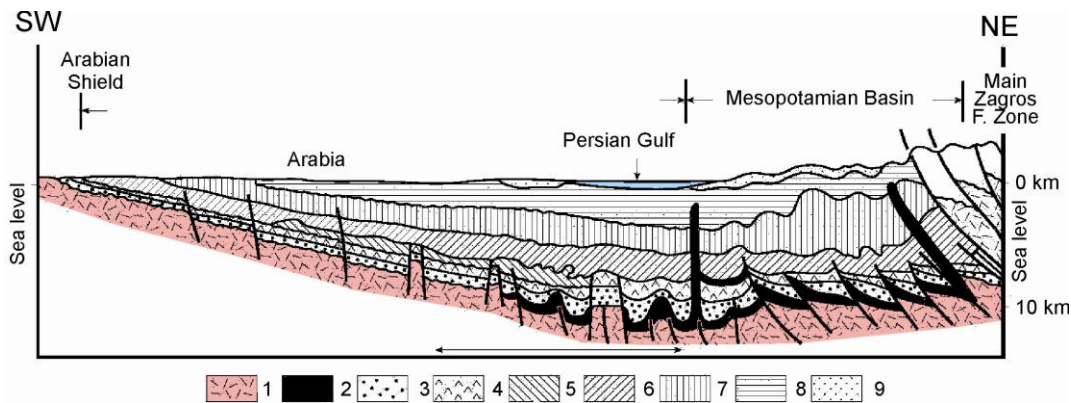


Fig. 2. The diagram displays a geological cross-section of the Gulf geosyncline, from eastern Arabia to western Iran. The buoyant Hormuz Salt Series, which is capping the Precambrian crystalline basement, has apparently injected the overlying Phanerozoic sedimentary cover; in many cases the Hormuz salt core is exposed in surface diapiric structures and is probably the main source for all major Meso-Cenozoic salt formations in the Persian Gulf-Iran region. Numbers are: 1, Precambrian basement; 2, Infra-Cambrian salt; and nos. 3-9 are Lower-Middle Palaeozoic, Permian, Triassic, Jurassic, Cretaceous, Tertiary and Quaternary sediments respectively. Diagram is based on compilation by Beydoun (1998).

A major geodynamic event, resulting from Earth's degassing and related reorganization of its internal mass, would naturally alter the planet's rotation characteristics and thereby triggering latitude-dependent lithospheric wrench deformation. During such events of global unrest, the time-equivalent equatorial belt would be particularly disposed to tectonic deformation, a situation that was particularly intensive during the Alpine climax. At that time (late Cretaceous-Eocene) deep oceans had, for the first time in Earth history, been established, and it can be expected that the accumulating volatile-rich upper mantle – the asthenosphere – had, by then, reached a relatively advanced stage. For these reasons, it is concluded that by the end of the Cretaceous the Earth was tectonically more unstable than ever before in its history – a situation that paved the way for the Alpine cataclysm (Storetvedt, 2003). Thus, inertia-driven *in situ* lithospheric wrenching, triggered by changes in planetary rotation and regulated by the Coriolis Effect, led to a global tectonic revolution. In this process, the *southern* palaeo-hemisphere was subjected to *counter-clockwise* torsion while the *northern* palaeo-lithospheric cap underwent *clockwise* torsion – producing an overall westward-directed transpressive deformation along the palaeo-equatorial belt (cf. **Fig. 3**). This implies that the most intense Alpine tectonic deformation reactivated the old Precambrian cooling-contraction dislocation – along which

the epicontinental Tethys seaway had had a protracted development. The fact that the high-pressure/low-temperature blue-schist metamorphism is concentrated to the late Cretaceous-lower Tertiary time span (see compilation by Ernst 1972), and particularly developed along the Alpine-Himalaya belt, underscores the fitness of the wrench tectonic system.

Being located within the general tracts of the Alpine palaeoequator, the Middle East was vulnerable to relatively strong inertia-triggered deformation. With most of the Middle East being located in the southern palaeo-hemisphere, at least the Red Sea-Persian Gulf region would have been affected by a certain counter clockwise tectonic ‘swing’. This is probably the dynamo-tectonic reason why the Red Sea Rift and the predominant structural lineament of the Gulf are oriented some 25° counter-clockwise relative to the overall bearing of the main East African Rift System (which had higher palaeo-latitudes, and therefore less affected by counter clockwise wrench forces during the Alpine climax. As will be discussed below, GPS velocities for sites across the Middle East (Reilinger et al., 2006) underscore that the counter clockwise Alpine tectonic wrenching is still taking place, including also Iran and Turkey.

During the life-time of the Tethys, the Earth has experienced a number of true polar wander events which all corresponds to well-established geological time boundaries (see Storetvedt, 2003). For the W Eurasian branch of the Tethys, the episodic changes of the relative equator led to significant environmental changes. Thus, the sub-polar setting of the Middle East in Infra-Cambrian time gradually changed to lower palaeolatitudes – becoming sub-tropical and then tropical during the late Palaeozoic-early Tertiary time span (see **Fig. 3**). Fully consistent with this picture is a recent palaeomagnetic study of lateritic weathering profiles of Permian age from northern Iran and western Karakoram, Pakistan, by Muttoni et al. (2009); they reported “stable low-inclination palaeomagnetic components carried essentially by hematite of chemical origin isolated in massive, fine-grained, and homogeneous ferricrete facies. These laterites originated at equatorial palaeolatitudes characterized by intense weathering processes under warm and humid climatic conditions”. Such observations fit extremely well into the fairly stationary, but dynamically active, global system adhered to above. Speculative propositions of drifting continental slivers (see below) are nothing but artifacts obscuring an orderly dynamo-tectonic system. When viewed in conjunction with **Fig. 1**, one notices the progressive changes of palaeolatitudes for the Middle East – from a high latitude sub-polar setting in Infra-Cambrian time to sub-tropical to tropical settings during late Palaeozoic – Lower Tertiary. Due to this gradual shift of the Earth’s spatial orientation, the Alpine-Himalaya belt was particularly prone to wrench tectonic processes in Alpine time. With reference to the evolution of the Tethys, we have so far dealt with an association of geodynamic, tectonic, environmental and palaeo-climatic issues – and given them ready and simple explanations without recourse to unconfirmed plate tectonic principles.

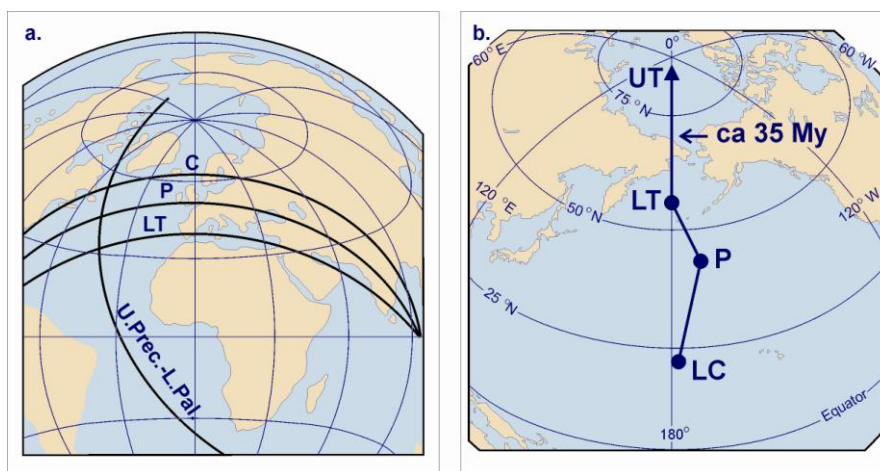


Fig.3. Diagram (a) illustrates the spatial shifts of the Earth’s body from late Precambrian to Alpine time – specified by episodic changes of the relative equator and based on combined palaeoclimate and palaeomagnetic evidence (cf. Storetvedt 1997, 2003, with earlier references). Diagram (b) shows the progressive spatial changes of the Earth for post-Middle Palaeozoic times in terms of palaeogeographic poles based on palaeomagnetic evidence. Notations are: LC, Lower Carboniferous; P, Permian; LT, Lower Tertiary; UT, Upper Tertiary.

Plate tectonics-enforced Tethys Ocean dismissed; factual diversity reinterpreted

Present state of affairs

The traditional view of the Tethys, as a relatively narrow epicontinental and endemic seaway with mega scale longitudinal extension, became markedly upset by the continental rearrangements inflicted by the plate tectonic revolution in the late 1960s. Thus, the postulated assembly of 'all continental crust' – Pangaea, subdivided into a northern Laurasia and a southern Gondwana – resulted in a pre-Mesozoic Tethys in the form of an extensive oceanic embayment widening eastward; the longstanding view of an endemic seaway was regarded old-fashioned and set aside – without a virtue of necessity. Thus, it is presently widely conceded that a once oceanic palaeo-Tethys had completely fallen victim to Permian-Triassic (Cimmerian) subduction along the suggested trench of the Eurasian palaeo-shores (including present northern Iran); the driver of this speculative subduction was rifting and northward spreading of a continental sliver broken off from the northern margin of the hypothesized Gondwana. An important element in the Palaeo-Tethys argument was undoubtedly the sporadic presence of late Permian ophiolitic mélanges along the northern Tethyan margins – consisting of a mixture of serpentized upper mantle mafic-ultramafic rocks along with diverse marine sediments, nowadays widely thought to be remains of obducted oceanic crust during the final closure of the Palaeo-Tethys Ocean. However, in the alternative global system alluded to above, the late Palaeozoic ophiolitic occurrences along the Tethyan northern shores would be palaeo-equator associated formations; in the new interpretation these mafic to ultramafic rocks are of upper mantle provenance – partly of solid state - in association with pyroclastics, limestones and cherts. The upper mantle material has been injected within transtensive segments of the overall transpressive palaeo-equator aligned fold belt. Hence, to account for ophiolite occurrences, no hypothetical drifting and colliding continental slivers are needed.

The popular plate tectonics-infected story submits that while the Palaeo-Tethys closed, a Neo-Tethys Ocean opened-up in its wake. During this new spreading phase, for which there are several versions (for a recent summary, see Muttoni et al., 2009), an extensive but relatively narrow continental sliver of late Precambrian and Palaeozoic crust broke off from the southern oceanic Tethys (part of the hypothesized Gondwana), migrating northward and finally colliding with, and adding to, Eurasia in the Triassic. However, due to the complexity of Tethyan curvilinear ophiolitic belts, the original 'Cimmerian Superterrane' is thought to have broken up in a mosaic of colliding micro-blocks (see for example Desmons, 1982) that make up significant parts of present day Turkey, Iran, Afghanistan, Tibet and parts of SE Asia. **Fig. 4** outlines a simplified version of the hypothesized Neo-Tethys drift model.

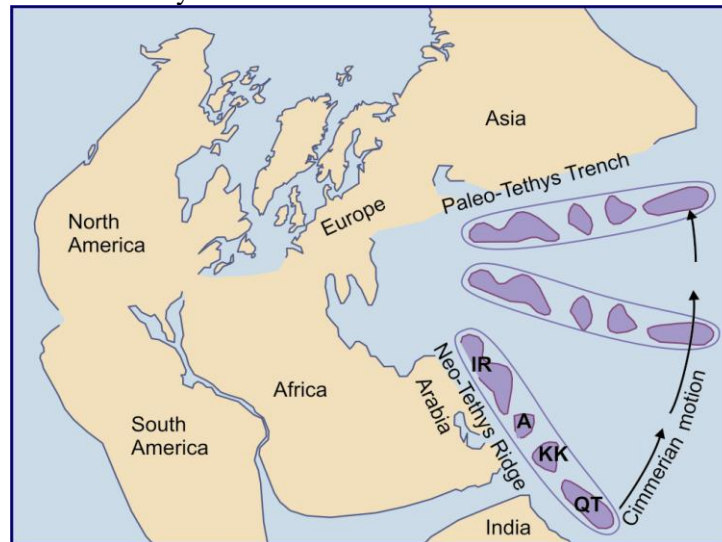


Fig. 4. Illustration shows a speculative plate tectonics plot of the Permian-Triassic continental configuration, favoured by authors like Van der Voo (1993) and Scotese (2001). Within the alleged eastward-widening oceanic Tethys, undergoing spreading and subduction, it is hypothesized that a continental sliver broke off from the southern (Gondwana) margin – gradually moving northwards, breaking up in subdivisions before eventually colliding with Eurasia in the Triassic. Notations are: IR, NW and Central Iran; A, Afghanistan; KK, Karokoram, Pakistan; QT, Quintang, Tibet. Simplified after Muttoni et al. (2009).

Based on plate tectonic-based palaeo-geographic models, studies of timing, rifting, separation and collisions of continental blocks, have led to a diversity of proposals (for reviews, see Gaetani et al. 2003; Stampfli et al., 2002). Numerous research projects and hundreds of papers have been devoted to study of palaeomagnetic, sedimentological and tectonic features of the Tethyan margins – in order to elucidate how the northern and southern margin platforms responded to the alleged opening and closing stages of the claimed deep oceanic Tethys. From the original proposal of a single basin Tethys, three Tethys basins have so far been proposed – denoted Palaeo-Tethys, Meso-Tethys and Ceno-Tethys by Metcalf (1996 and 1998). However, despite a longstanding research effort, there is obviously no satisfactory scientific conclusion – only a flora of propositions, within which unconfirmed plate tectonic principles are taken for granted. In reviewing the current situation, Dickins (1994) found little or no geological evidence to the plate tectonics constrained proposals. He argued that no critical examination of basic premises had been undertaken in recent decades, the basic pre-Mesozoic continental reconfiguration having been accepted with modification mainly of details.

It seems that the current flow of Tethyan research efforts is/has been strongly controlled by a famous psychological theory: *The Confirmation Bias*. In other words, by scientific ‘knit-picking’ (Kuhn, 1962) and an endless stream of ad hoc theoretical repairs, a ready solution is not in sight. The Middle Palaeozoic, Variscan and Alpine fold belts running E-W across Eurasia, with southward progressing ages, are currently regarded products of continental collisions (allegedly giving rise to both folding and uplift of mountain ranges) have led to a multiplicity of Tethys proposals. In the various drift scenarios both larger and smaller continental masses have migrated northward over greater distances – colliding with Europe and Asia in various stages, accreting to the Eurasian land mass from China to Western Europe. In the advance of the Alpine cataclysm it is proposed that India broke off from Australia and Antarctica in the early Cretaceous. The possibility that all important observations can be fitted into a much simpler tectonic framework, perhaps making all the sophisticated plate tectonics-inflicted ad hoc provisions unnecessary, has been overlooked.

India – a pivotal element in global tectonics

The current view is that India in the late Mesozoic was an island continent that drifted northward thousands of kilometers before it purportedly collided with Asia at around the Cretaceous-Tertiary boundary (around 65 my ago). It is frequently assumed that palaeomagnetism has provided the necessary ‘proof’ for this grand scale drift, including a certain counter clockwise rotation during its northward travel. **Fig. 5** gives a schematic illustration of the popular drift model. However, the dual-polarity structure of the palaeomagnetic field, as for example demonstrated by the Deccan Traps of NW India, presents an ambiguous basis for tectonic interpretation. Instead of assuming a mega scale northward translation of the sub-continent, an alternative *in situ* tectonic rotation of the Peninsula – ca. 130° in the clockwise sense – establishes conformity with the Eurasian palaeomagnetic reference frame (Storetvedt, 1990, 1997 and 2003). Similarly, the palaeomagnetic discrepancy between Europe and Africa can be readily accounted for by moderate relative rotations (in situ) of the two land masses – without invoking a fan-shaped oceanic Tethys. By shifting to an incompatible mobilistic system, regulated by changes in Earth rotation (discussed above), the real meaning of the mass of factual observations changes too.

According to the alternative palaeomagnetic interpretation, the original azimuthal orientation of India was markedly different from that of today; southern India was placed in the region of present-day eastern Pakistan. Towards the end of the Cretaceous, India was in an unstable position with respect to tectonics: 1) The sub-continent was located within the time-equivalent palaeo-equatorial region with maximum wrenching/inertial implication (governed by the Coriolis Effect), 2) its northern boundary was adjacent to the inferred fault-bounded Tethys basin, and 3) India was located at the northern extremity of the major N-S trending shear zone of the Central Indian Ocean. So with the coming of the Alpine climax in the late Cretaceous, and powered by a certain planetary acceleration, the India block was disposed to tectonic instability. The situation was not unlike that for Iberia at that time; being bounded by the Gibraltar-Azores Fracture Zone to the south and the North Pyrenean Shear Zone to the north, Iberia became tectonically squeezed between these two prominent fault zones and underwent large-scale late Cretaceous rotations (cf. Storetvedt et al. 1990, 1999). Thus, the tectonic history of India and Iberia – both being situated within the

Alpine palaeo-equatorial zone – are apparently intimately connected in terms of large-scale tectonic stresses. In fact, the Tethyan seaway, from north of India (Tibetan region) to the Mediterranean region, lay within the palaeo-equatorial zone (see **Fig. 3**) and therefore it was disposed to internal wrench deformation. The palaeomagnetic literature presents abundant examples of micro-block rotations within the Alpine-Himalaya region – as demonstrated for the micro-continental blocks of Central Iran (Soffel et al., 1996).

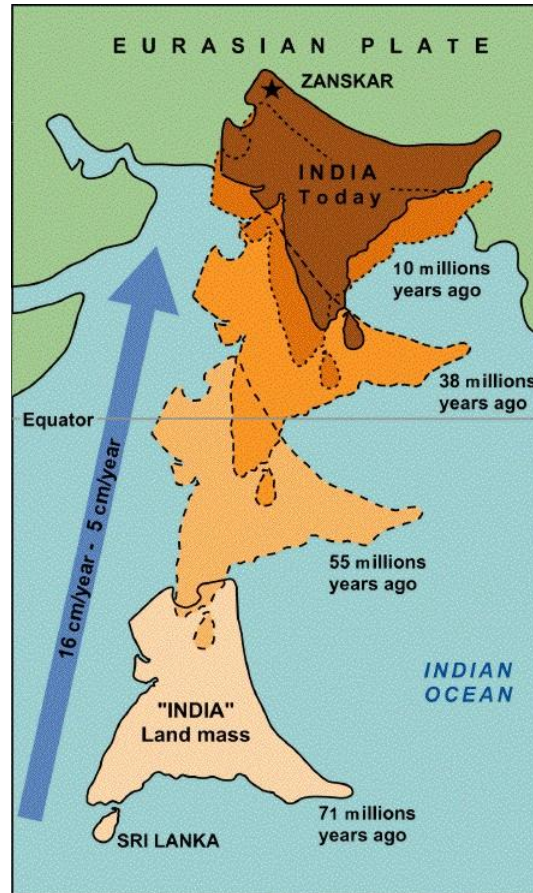


Fig. 5. Illustration shows the hypothesized, exceedingly popular Upper Cretaceous-early Tertiary northward translation of the Indian sub-continent before it allegedly collided with Asia at around the Cretaceous-Tertiary boundary. This model has, however, a long list of factual complications. Simplified after www.usgs.org

According to the alternative palaeomagnetic interpretation, the original orientation of India was azimuthally markedly different from that of today; southern India was placed in the region of present-day eastern Pakistan. But towards the end of the Cretaceous India was in an unstable position with respect to tectonics: 1) The sub-continent was located within the time-equivalent palaeo-equatorial region with maximum wrenching/inertial effect (governed by the Coriolis Force), 2) its northern boundary was adjacent to the inferred fault-bounded Tethys basin, and 3) India was located at the northern extremity of the major N-S trending shear zone of the Central Indian Ocean. So with the coming of the Alpine climax in the late Cretaceous, and powered by a certain planetary acceleration, the India block was disposed to tectonic instability. The situation was not unlike that for Iberia at that time; being bounded by the Gibraltar-Azores Fracture Zone to the south and the North Pyrenean Shear Zone to the north, Iberia became tectonically squeezed between these two prominent fault zones and underwent large-scale late Cretaceous rotations (cf. Storetvedt et al., 1990 and 1999). Thus, the tectonic history of India and Iberia – both being situated within the Alpine palaeo-equatorial zone – are apparently intimately connected in terms of large-scale tectonic stresses. In fact, the Tethyan seaway, from north of India (Tibetan region) to the Mediterranean region, lay within the palaeo-equatorial zone (see **Fig. 3**) and therefore it was disposed to internal wrench deformation. The palaeomagnetic and tectonic literature presents abundant examples of micro-block rotations within the Alpine-Himalaya region – as demonstrated for the micro-continental blocks of Central Iran (Soffel et al.,

1996).

Elimination of the proposed mega-scale drifting of India may indeed explain the lack of endemism in Indian terrestrial fauna (Chatterjee and Hotton, 1986, and references therein). On this problem Chatterjee (1992) wrote: “The paleoposition of India and its travel paths during the Mesozoic remain a riddle in conventional plate tectonics. Most reconstructions show peninsular India separating itself from Gondwana, and as an island continent drifting northward for more than 100 m.y. toward its eventual collision with the mainland of Asia. However, the lack of endemism among Indian Cretaceous terrestrial biota is clearly inconsistent with the island continent hypothesis. On the contrary, these fossils show their closest affinity with those of Laurasia and Africa, indicating that India maintained overland connections with these landmasses”. In other words, the palaeontological evidence concurs with the alternative palaeomagnetic solution: an stress-powered in situ rotation of the Indian land mass at around the Cretaceous-Tertiary boundary.

During early rotation stages of the India block, transtensive conditions along the shores of the regional Tethys seaway (bounding the India block to the north) expectedly gave way to serpentinized upper mantle peridotites; these altered, buoyant solid state ultramafic rocks were consequently subjected to density- and hydrostatic-driven diapiric flow along deep faults – preferentially routed into surface basins, sometimes in combination with magma of variable composition. These rock associations would then have formed the ophiolite complexes which occur scattered along the Alpine Himalaya/Tibetan belt. According to the alternative theory, the Deccan lava succession dates from the early stage of India’s detachment from the Tethyan basin to the north (Storetvedt, 1990, 1997 and 2003).

Other geophysical and tectonic aspects

The postulated in situ rotation of India would naturally have caused considerable tectonic reactivation and shearing along its border zones and at its base – increasing the fracture spacing of affected rocks and thereby paving the way for increased fluid infiltration from below. Furthermore, emplacement of ophiolite complexes would take place, and advanced crustal oceanization along its original border zones would have ensued. The resulting seismic effect would be lowered velocities for broader regions of the mobile block – extending from shallow depths down to a more significant low velocity zone below, say at 200 km depth, interrupting the higher velocities of tectonically less affected regions. According to this reasoning, broader regions of the rotated India lithosphere ought to display lowered seismic velocities (due to tectonic fracturing), while a central core with relatively fast velocities would taper out towards the ‘bottom’ of the mobile unit. Such expectations appear to coincide with factual observations.

In a P-wave tomography study of the region, Kennett and Widiyantoro (1999) obtained velocity images at different depth levels of the upper mantle that apparently fit well with the suggested predictions. The relative velocity distribution obtained by these authors shows that a sizeable elongated central nucleus of fast velocities is present at a depth of 100 km, but at 250 km there is little expression of a faster velocity lithosphere; the higher seismic wave speeds of the inner cratonic core having been narrowed down, in northern India, to a few centers of smaller dimension. Furthermore, it is noted that, beneath northern India, the higher velocities at around 250 km tend to form two orthogonal branches, which in the alternative (pre-rotation) configuration become oriented approximately N-S and E-W respectively. The orientation of this deep orthogonal structure corresponds to that of the global pre-Alpine near-orthogonal fracture pattern – presumably implanted into Earth’s brittle outer layer in the late Archaean (cf. Storetvedt 2003, and fig. 3 in Storetvedt and Longhinos, 2012).

The low-velocity ‘collar’ circumscribing the Indian craton may then be seen as a lithospheric crush zone caused by the inferred tectonic rotation. This motion would in turn have led to enhanced fluid-driven eclogitization, in association with accelerated delamination of the lower crust, isostatic subsidence, and basin formation. It can be presumed, therefore, that the oceanic embayments surrounding the Indian craton – the present Bay of Bengal and Arabian Sea, were originally parts of the Greater India tectonic unit. By inference, it follows that the two oceanic regions began to form shortly after the tectonic rotation had ceased – presumably in the early Palaeocene, a prediction that is borne out by a range of geophysical and geological facts (cf. Storetvedt, 2003, p. 267-279). Thus, the curvilinear Owen Fracture Zone (OFZ) seems to represent

the most prominent western tectonic boundary of the clockwise rotation of Greater India – inferentially producing a left-lateral shear belt. But also the Owen Basin, the thin-crustal but quasi-continental basin along the eastern coast of Arabia (see Whitmarsh, 1979), shows clear signs of having participated in this deformation event.

Following the major clockwise rotation and significant crustal oceanization of its surrounding domains, the Indian cratonic mass re-docked with Asia in about its present relative position. The rotation has apparently left a number of tectono-physiographic features consistent with India's inferred clockwise motion. For example, in the NW Arabian Sea the northern segment of the combined Owen-Murray Ridge/Fracture Zone exhibits a marked easterly swing – forming a curved and seismically very active fracture zone. To the north of India, the continental tectono-topographic features form a collar around the sub-continent (**Fig. 6**): from eastern Pakistan the highly seismic shear belt turn clockwise and continue along the broad band of major E-W oriented Himalayan-Tibetan strike-slip faults before the bunch of tectonic lineaments eventually (in eastern Tibet) turn sharply to SE-SSE – defining a tectonic pattern that is broadly consistent with the inferred clockwise rotation. The deep lithosphere-cutting fractures that formed during India's rotary motion is thought to have been of paramount importance for the rising of buoyant mantle fluids and the associated uplift of the Tibetan Plateau – along with its flanking mountain ranges – in the late Miocene (Storetvedt, 2003). As demonstrated by numerous GPS velocity studies in the Himalaya-Tibetan region (for compilation see Taylor and Yin, 2009) – for which the general pattern is portrayed in **Fig. 6** – show that with respect to Eurasia the rotational tectonics, incited during the Alpine climax, is apparently still in operation. Further, considering the major rotation figure for India, dating from Maastrichtian-Palaeocene times, one would anticipate finding significant Moho offsets across prominent regional fault zones – just as have been observed across other prominent crustal discontinuities, such as the North Pyrenean Fracture Zone (Daigniers, 1982). In fact, a recent seismic study of the Tibetan Plateau, Yue et al. (2012) found a 20 km Moho offset beneath the northern margin of the Kunlun Mountains, and a 10 km offset across the Jinsha River fracture zone; i.e. crustal sections with different thicknesses were juxtaposed.

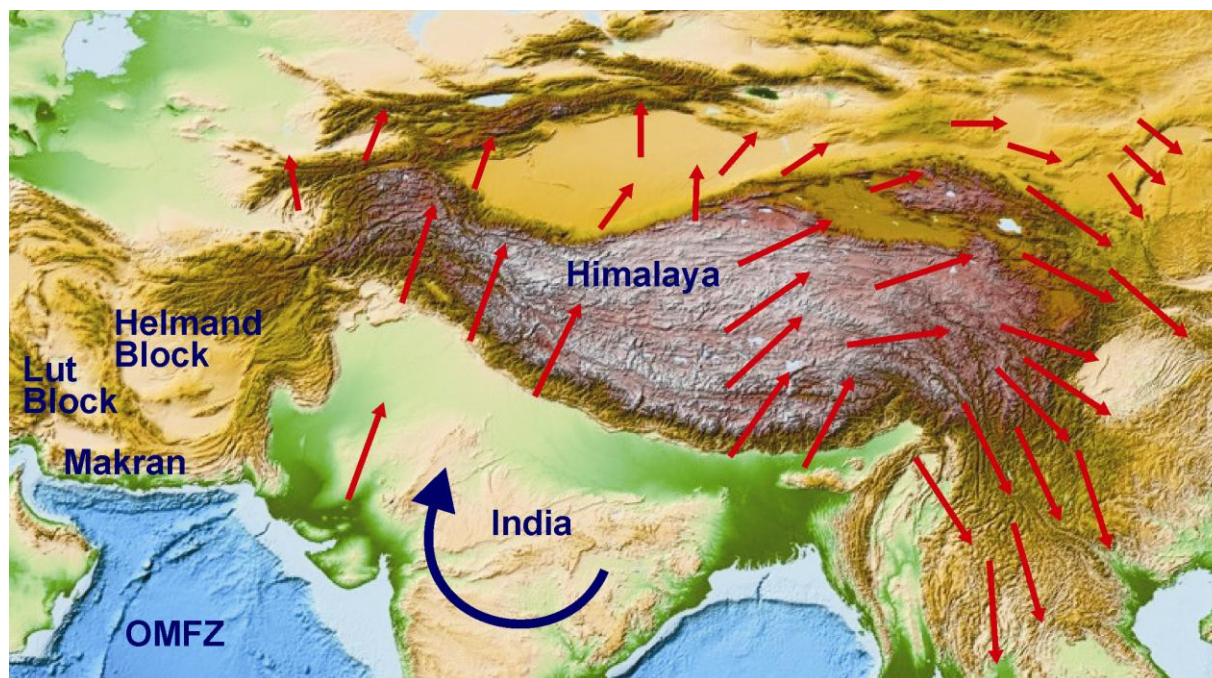


Fig. 6. Illustration shows a color-shaded relief map of the Himalaya-North India region, from noaa_world_topo_bathymetric_lg.jpg, overlain by a sketchy display of the GPS site velocity pattern – based on compilations by Zhang et al. (2004) and Taylor and Yin (2009). Note how the GPS velocity pattern, along with the curved tectonic zones of western Pakistan and north-eastern India/western Myanmar, fit in with the estimated major clockwise rotation of Greater India; this continental rotation, dating primarily from around the Cretaceous-Tertiary boundary, is likely to have had significant tectonic effect on the Helmand and Central-East Iranian micro-continental blocks – dragging them into counter clockwise rotations. See text for further discussion.

It is generally accepted that the Himalaya sector of the Tethys constitutes a nearly complete succession of Upper Proterozoic to Tertiary sediments – representing a protracted geosynclinal development similar to the Arabia Gulf region (**Fig. 2**). The 100 km-wide sedimentary basin is strongly folded, imbricated and subdivided by several fault-bounded tectonic units (e.g. Steck et al., 1993; Dezes, 1999). Following Dewey and Bird (1970) and Dewey and Burke (1973), the regional ophiolites were interpreted in terms of obducted former Tethyan oceanic crust. The latter authors envisaged the Indus Suture as a relic subduction zone along which a wide oceanic Tethyan crust had disappeared and left behind obducted ophiolitic complexes. In that case, however, the suggested oceanic trench and associated ophiolite belt ought to be located on the south flank of the Himalayan range. The fact that the position of the Indus Suture is situated north of the mountain range is problematic and cognitively threatening for the subduction model (Crawford, 1974).

The Indus Suture, which contains thrusts with occurrences of ophiolitic material and huge exotic blocks intercalated with Upper Cretaceous marine sediments, was interpreted by Gansser (1964 and 1974) and Le Fort (1975) as squeezed intra-basin masses: injection of deep seated material after opening up of short-lived fracture zones extending to mantle depths (Gansser, 1966). This explanation would be consistent with the tectonic rotation model for India; at the early stages of rotation, transtensive conditions would have opened up channels for upward tectonic squeezing of ductile upper mantle ultrabasics, which along with occasional magma would end up in surface basins. Furthermore, north of the Indus Suture three Mesozoic and Palaeozoic ophiolitic belts have been described, the ages of which increase northward (Chan and Pan, 1984; Tingdong et al., 1986). Any acceptable geophysical theory must be capable of explaining such a recurrent phenomenon. Obviously, a series of oceanic openings along the northern shores of the hypothesized Gondwana and closures (from Palaeozoic to Alpine times) progressively adding crustal slivers to Asia (the expected explanatory route for plate tectonics) would appear highly artificial and unlikely. The wrench tectonic theory offers a more ready explanation; the time-progressive southward shift of ophiolite occurrences relates to the progressive shift of corresponding palaeo-equators along which localized transtensive shearing with related ophiolite injections is likely to have taken place.

According to the wrench tectonic thesis, in Alpine time the Tethys seaway was turned into an overall transpressive belt: the northern palaeo-hemisphere underwent a moderate clockwise rotation while the southern palaeo-hemisphere moved a similar moderate amount but in the counter clockwise sense (see below). Though the actual palaeo-equator passed across Central India in a NW-SE direction, the actual tectonic boundary between the inertia-driven palaeo-hemispheres was apparently shifted northward to the Tethys fault-controlled basin. In addition to the global inertial wrenching, India's rotation provided an extra impetuous force to the Himalaya-Tibetan tectonics. In the larger Tethyan context, for which the overall thicker-crustal northern (Eurasian) mega-block had greater inertia than the overall thinner-crustal southern counterpart, the elongated seaway was broken up into deformed arcuate branches with southward convexity. Along the length of the Eurasian Tethys, the radii of these arcs are seen to increase eastward, and the largest of them – the Indonesian Arc – has apparently been pushed a considerable distance to the south. In other words, the original trend of the suggested 'E-W' running 'Benioff'-type dislocation is likely to have been strongly distorted in Alpine time. Owing to the greater inertial energy of the northern palaeo-hemisphere, it can be envisaged then why the Himalayan and Indonesian arcs have southward convexity and compressed (thrust) frontal segments. Thus, GPS-based velocity vectors in an India-fixed frame, defined by Jade et al. (2004), arrive at a significant arc-normal convergence between India and southern Tibet.

Oman margin and Makran front.

The northern branch of the seismically active Owen-Murray Fracture Zone (OMFZ) has a marked easterly bend before joining the more complex and seismically very active zone of eastern Pakistan – both tectonic branches having a convexity consistent with the suggested clockwise rotation of Greater India. During the suggested early Palaeocene tectonic reorganization in the northern Indian Ocean, the original lithospheric mass of the present Arabian Sea – as a constituent part of Greater India – was tectonically crushed thereby paving the way for effective fluid-accelerated sub-crustal eclogitization and related crustal oceanization (Storetvedt 2003). Regarding the OMFZ as the north-western tectonic border zone of India's mega-rotation, its sense of motion would apparently be left-lateral (see **Fig. 7**). In this context, one might anticipate that the

250 to 400-km-wide Owen Basin off SE Oman would have formed as an early Tertiary shear basin and possibly intimately associated with the emplacement of the ophiolite mélangé of Masirah Island (coastal SE Oman). From geophysical studies, Whitmarsh (1979) concluded that both the Owen Fracture Zone and the Owen Basin had intermediate crustal thicknesses (Moho depths of 15-20 km) somehow connected to the formation of the adjacent continental margin. If the Arabian Sea thinned from an original continental setting – as the wrench tectonic theory arrives at, the region ought to have a Palaeocene subsidence history. Deep sea drilling data on the OMFZ seem to accord with this suggestion (see Storetvedt, 2003, p. 269-272).

As has been outlined elsewhere (Storetvedt, 2003 and 2010b), linear marine-magnetic anomalies are incompatible with successive geomagnetic polarity inversions (the currently popular model). But strong evidence has accumulated that they basically are the product of wrench deformation and associated mineralogical alteration in the thin and mechanically weak oceanic crust. Hence, the marine-magnetic anomalies are apparently caused by contrasts in magnetic susceptibility in combination with induction by the ambient geomagnetic field. This implies that these anomalies actually are an expression of the underlying crustal shear grain. In mechanically relatively strong quasi-continental regions, such as in the Owen Basin, such anomalies would expectedly be weakly developed (i.e. have low amplitudes), a prediction which concur with actual observations (Whitmarsh, 1979). Within the predicted shear zone off NE Oman, an oblique tectonic grain as specified by the magnetic trend depicted in **Fig. 7**, is likely to have formed. The question is then whether the Masirah Island ophiolite complex also formed at some stage of the shearing process brought forward by India's rotation.

The Masirah ophiolite consists mainly of abundant serpentinized peridotites, cumulate gabbros, sheeted dykes and pillow lavas with limestone intercalations (Abbotts 1978; Moseley and Abbotts, 1979). The rock complex is sharply truncated by a NNE-striking, 5 km wide vertical mélangé – a mega-breccia, with blocks up to 2 km long, including all the above lithologies, with near-vertical NNE shear planes cutting through its matrix. Moseley and Abbotts (1979) argue that “the junction of mélangé and undisturbed ophiolite is sub-vertical, frequently forming a zone of extensive shearing with a NNE foliation parallel to the junction” – i.e. corresponding to the general trend of the Owen Fracture Zone. In their discussion of the ophiolite emplacement mechanisms, Moseley and Abbotts preferred that of a diapiric upthrust onto the continental margin, along near-vertical NNE-trending deep faults. In the presence of water, upper mantle peridotites would be liable to become serpentinized and rising buoyantly as deformed solid state diapiric material – notably along transtensive segments of high-angle fault zones. In the wrench tectonic situation considered here, localized transtensional conditions would easily have occurred along the shear grain, giving rise to multiple dyke intrusion. In fact, a post-emplacement sheeted dyke complex has a predominantly ENE trend, i.e. the Masirah dyke complex is oriented parallel to the weak linear magnetic anomalies of the Owen Basin (see **Fig. 7**) which cut across the regional NNE oriented fracture system.

While the Masirah Ophiolite of eastern Oman seems associated with India's mega-rotation – probably dating from the topmost Cretaceous or earliest Palaeocene, the Semail Ophiolite of northern Oman (see **Fig. 7** for location), one of the largest ophiolite bodies in the world, seems to have been emplaced somewhat earlier, probably during the onset of the Alpine tectonic revolution, being a product of the counter clockwise wrenching of the southern palaeo-hemisphere. The Semail complex is described as a major tectonic nappe squeezed between sedimentary sequences – a process dated as late Cretaceous (Glennie et al., 1974). Stratigraphic studies indicate that the Semail complex is a rootless slab lacking physical contact with the underlying mantle (e.g. Gealey, 1977; Searle et al., 1980), and undisturbed Maastrichtian sediments overlying the ophiolite bear witness that post-emplacement disturbances have been minimal. This is in marked contrast with the facing Zagros thrust front further north, which has been tectonically active to this day. However, it seems that the Masirah and Semail ophiolites have evolved in different tectonic regimes; the orientation of the two complexes is nearly orthogonal – having general strike directions of NNE and WNW respectively – and therefore we are most likely facing time-shifting reactivation of the old network of near-orthogonal parallel fractures (cf. Storetvedt, 2003). The fact that Oman is located within the Alpine palaeo-equatorial zone (see **Fig. 3**), for which wrench deformation would have been at its maximum, a temporal shift in regional stress regime – from one set of fundamental fractures to the near-perpendicular set,

can be considered very likely.

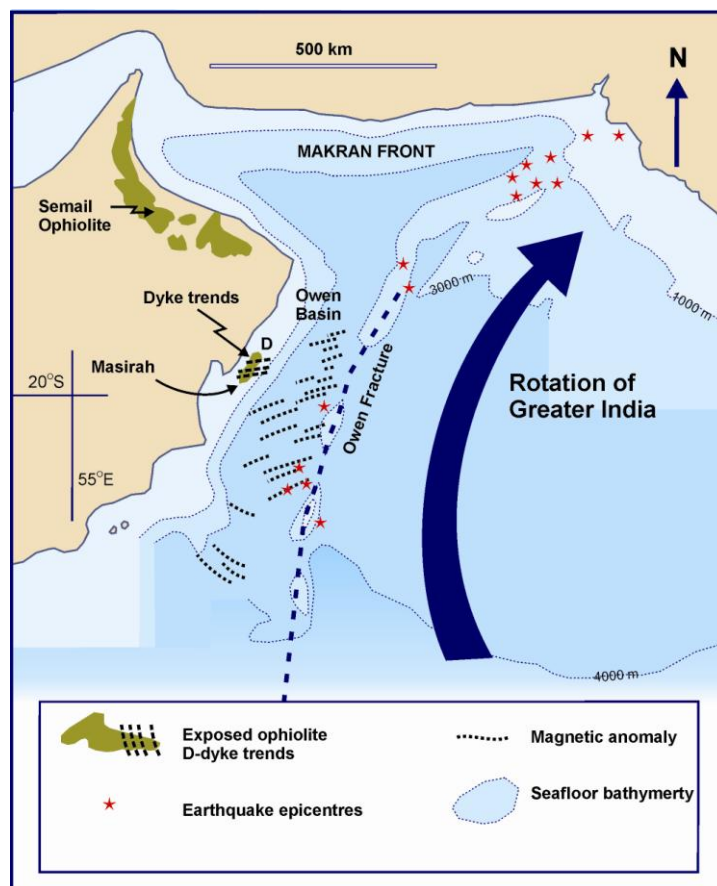


Fig. 7. Map of the north-western Arabian Sea displaying the curvilinear and seismically active Owen-Murray Fracture Zone (OMFZ). Emanating from Greater India's major clockwise rotation in the latest Cretaceous-early Palaeocene, the OMFZ is seen as a major left-lateral shear zone. The resulting tectonic grain of the landward (Owen) basin, manifested by weak linear magnetic field anomalies, concurs with the inferred left-lateral shear motion along the Owen Fracture. The coastal Masirah ophiolite complex, with its intersecting dyke complex, apparently formed during the same shearing process. In contrast, the much larger Semail ophiolite complex of Oman's north coast was emplaced within the perpendicular set of basic fractures which acquired transtensive conditions within the Alpine shear regime – paving the way for injection of mantle material. See text for further discussion. Diagram is based on Moseley and Abbotts (1979).

The arcuate Makran deformation belt runs along coastal south Pakistan and terminates in the Hormoz Strait area of SE Iran where the accretionary wedge has a fault-bounded transition to the Zagros fold-and-thrust belt (e.g. Molinaro et al., 2005; Regard et al., 2010). The Makran complex, which extends inland for some 100 km, may be seen as a westward continuation of the coeval Himalaya convergence front (Burgh et al., 2013). According to the latter authors, Inner Makran (in SE Iran) includes ophiolites emplaced in late Cretaceous to Palaeocene times – representing an upthrust of upper mantle material coeval with the Semail ophiolite complex. In the Inner Makran, shallow-water Upper Cretaceous limestones covers Cretaceous mélanges in which igneous and Cretaceous marine sediments are involved (Dolati, 2010). Thus, the Makran wedge was initiated during the late Cretaceous accumulating seawards with time; the Outer Makran represents a Miocene to Recent frontal wedge consisting of compressional folding, thrust faulting and imbrication of the sedimentary section (**Fig. 8**); the Makran complex then becomes closely similar to the Zagros complex. The contorted sedimentary pack, building a wide continental margin, seems to rest on a practically horizontal crystalline basement. According to Grando and McClay (2007), the rare portion of the wedge is uplifted and extended by normal faulting and ductile flow; spectacular shale diapirs and mud

volcanoes are present all along the external part of the wedge favouring pressure from fluids and gases. This brings us to the likelihood that tectonic compression has led to fracturing of the underlying crystalline crust with opening up of fluid pathways from the mantle. Thus, by the action of rising supercritical hydrous fluids, a strongly buoyant and corrosive substance, the association of an inner uplifted wedge, shale diapirs and mud volcanoes may be readily explained.

Despite the frequent reference to a Makran subduction zone, seismic evidence does not favour the existence of a deep landward-dipping oceanic slab (cf. White and Klitgord, 1976; White, 1982); hence, the Makran complex, which has sparse earthquake activity, is problematic in a subduction scenario. But despite the lack of seismic signals from the underlying continental upper mantle some authors seem to believe that active subduction beneath the Makran might still be taking place (Maggi et al., 2000). However, a bottom-simulating reflector indicates the presence of a thick gas-hydrate-bearing horizon at relatively shallow depths – apparently sealing off the upward flow of methane- and hydrogen sulfide-rich fluids, discovered as seeps along active regional faults (von Rad et al., 2000). An important finding is that the late Tertiary tectonic wedge is cut by the strike-slip Sonne Fault – obliquely crossing the late Tertiary frontal complex; its northward extension accords with the trend of the Persian Gulf and the main Zagros Thrust Belt, and its seaward continuation cuts across the Murray Ridge/Fracture (Kukowski et al., 2000). Again we are most likely facing tectonic reactivation of a fundamental fracture associated with relatively strong wrench deformation within the Alpine palaeo-equatorial zone.

The Iran sector

Iran apparently represents the most complex and diversified tectonic build-up of the Middle East. Numerous studies (e.g. Le Pichon 1968; McKenzie, 1970; Dewey et al., 1973 and 1986; Sengör 1984, to mention a few) have taken for granted that seafloor spreading in the South Atlantic has led to north-eastward migration of Africa (part of the hypothesized Gondwana) eventually resulting in tectonic elimination of the intervening Neo-Tethys basin. In the final closure of Neo-Tethys, Arabia's is thought to have collided with Iran and Asia Minor – giving impetus to the physiographic and structural complexity of the associated mountain belts. However, the flow of model proposals, including propositions of micro-plate behaviour, island-arc convergence, continent-continent collision etc., advanced for the sake of accommodating old and new facts within a plate tectonic context, has long ago ended in a kind of *reductio ad absurdum*. **Fig. 9** shows a physiographic (**a**) and simplified geological map (**b**) of Iran. The many circular or oval-shaped salt basins in many parts of the country, continental blocks surrounded by segments of ophiolitic complexes, and arcuate mountain ranges, are difficult to reconcile within even the most extravagant plate tectonic speculation. Even after four decades of meticulous plate tectonics inspired work, trustworthy solution appears more remote than ever. Plate tectonicists ought to remember that extrapolations into ever more intricate ad hoc elaboration make the true causality of nature impossible to work out.

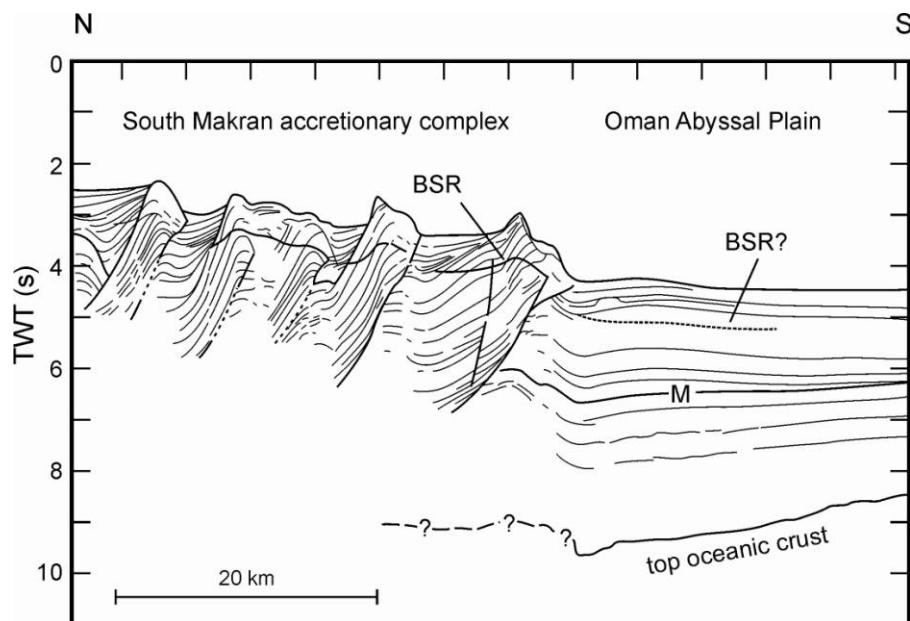


Fig. 8. Line drawing from a multi-channel N-S seismic profile across the Makran compressive front, S. Pakistan – see Fig. 7 for location. BSR denotes a sea-bottom-simulating reflector regarded as the base of a regional gas-hydrate zone. The top crystalline crust seems to be fairly flat, and absence of a deep crust-cutting discontinuity/slab negates subduction. Simplified after von Rad et al. (2000).

The western region of the NW-SE trending Zagros tectonic belt – extending from the Gulf of Oman in the south to the Turkish border in the north – forms a folded shelf area, and its bounding zone to the north-east constitutes a strongly imbricate province including ophiolite-radiolarite complexes (Berberian, 1995). Folding in the shelf region, which probably primarily dates from the Upper Miocene-Lower Pliocene (Stöcklin, 1968; Kassler, 1973), is currently related to the hypothetical Neo-Tethys closure with convergence between Arabia and Eurasia. The Zagros Mountains have intense earthquake activity, but the great majority of focal depths throughout the country are shallow-intermediate crustal events (Engdahl, 1998 and 2006); sub-crustal earthquakes have been suggested by some researchers (e. g. Moores and Twiss, 1995) though seismic activity in the upper mantle of the Zagros region has been ruled out by others – asserting that published focal depths in the upper mantle actually arise from mis-location of events occurring in the upper crust (e. g. Maggi et al., 2000; Engdahl et al., 2006). Thus, seismic definition of a Zagros subduction zone seems to be non-existent.

The post-late Precambrian sedimentary pack of the Zagros, spanning an estimated total thickness of 10-14 km, has accumulated during various tectonic events, but recorded unconformities and facies changes have so far not been acceptably explained. For example, the compressional history of the Zagros shows two main tectono-clastic wedges – of late Cretaceous-early Tertiary and Miocene-Pliocene ages respectively, separated by periods of non-deposition or accumulation of shallow-marine carbonates (cf. Homke et al., 2004, 2009; Saura et al., 2011; Verges et al., 2011). These tectonic events correspond to well-known upheavals in Earth history, but as with all other facets of the planet's pulse-like behavior plate tectonics has not been able to give trustworthy accounts for the underlying global dynamic machinery. Few researchers have openly addressed the pressing problems. However, Kashfi (1992) has considered several facts at variance with the ruling thesis.

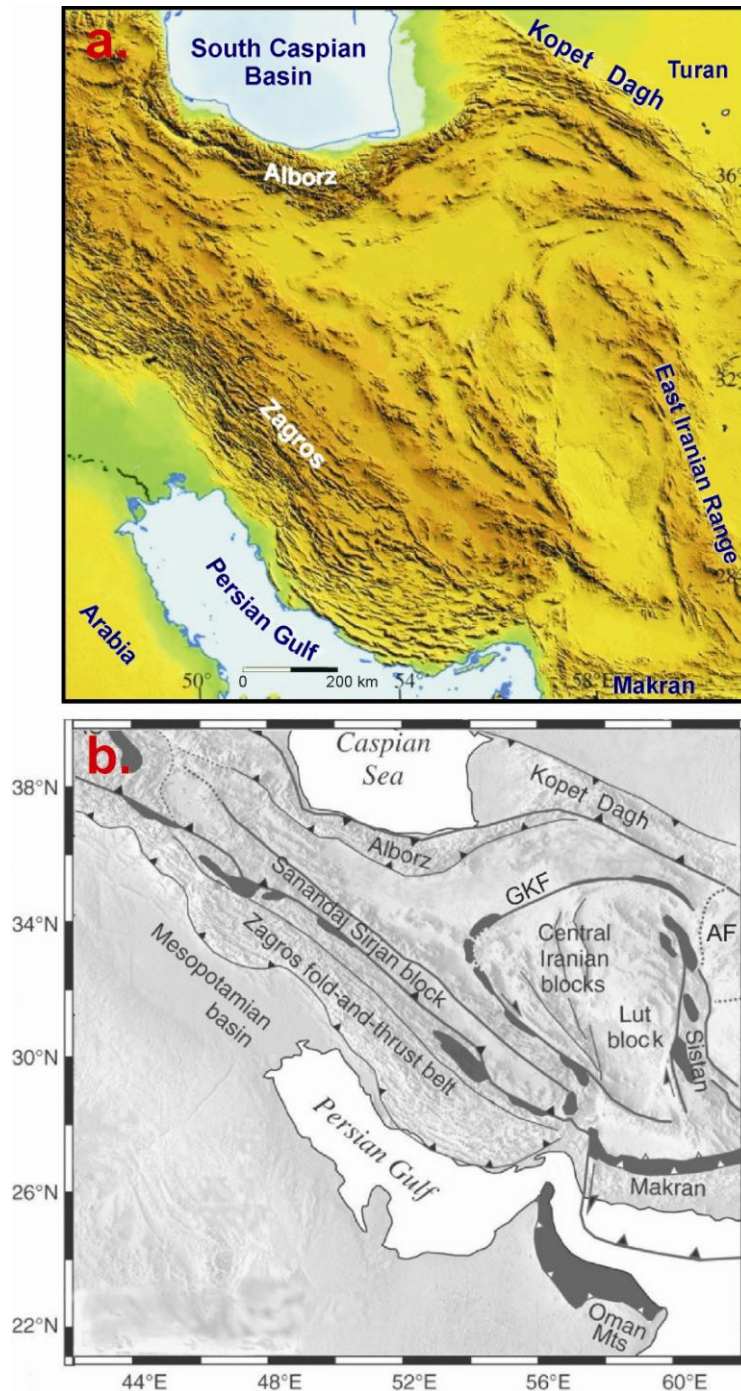


Fig. 9. Diagram (a) shows the physiographic features of the South Caspian/Iran/Gulf region (topography: digital elevation model SRTM30 from NASA Shuttle Radar Topography Mission – 30 arc-second grids mosaic). Note how the broad and slightly curved Zagros mountain belt in the south and much narrower and more strongly curved Alborz-Kopet Dagh range in the north are bounding a mosaic of circular to oval-shaped depressions – representing an assembly of Central Iranian micro-continental blocks surrounded by mountain ranges. Fig (b) gives a simplified tectonic map. Abbreviations in diagram (a) are: AF, Afghanistan; GKF, Great Kavir Fault.

Among the range of incompatible observations, Kashfi submitted that a) the distribution and scattered ophiolite/radiolarite occurrences in Iran are inconsistent with alleged suture zones, 2) Meso-Cenozoic volcanic rocks are unknown in areas adjacent to the purported Zagros subduction zone, 3) several extinct late Tertiary-Quaternary volcanoes are non-aligned and randomly scattered (remote from affirmed sutures),

4) the many basement characteristics of the Zagros Fold/Thrust Belt indicate that it is underlain by igneous-metamorphic complexes of continental origin, 5) outcrops of continental basement rocks crop out in many regions of Iran, and 6) the great majority of earthquakes occurs within the crust and pay no attention to presumed plate tectonic boundaries. For example, a concentration of current earthquake activity takes place along the folded shelf region, not behind surface expressions of an affirmed subduction zone northeast of the Zagros. Kashfi presented evidence in favour of the Zagros belt having formed by simple compression – without involvement of a hypothetical Neo-Tethys closure. In the same direction, Brunn (1976) argued that Iran has always been an integral part of Eurasia. Adding to the long list of puzzling observations, versus plate tectonic expectations, Amidi et al. (1984), discussing the petrology and geochemistry of Eocene volcanic rocks of Central Iran, found no agreement with hypothesized subduction-related volcanism.

The outer Imbricate fold-and thrust belt is, to the north, bounded by the right-lateral Main Zagros Fault which delimits the Sanandaj-Sirjan Zone – a 150 to 200 km wide thrust complex involving metamorphic, igneous and sedimentary rocks of Palaeozoic-late Mesozoic ages – from the frontal complex (e.g. Alavi, 1994 and 2007). The frontal fold- and thrust belts includes the Inner and Outer Ophiolite zones which currently are thought to have formed during the early-stage Neo-Tethys subduction in the late Cretaceous (e.g. Shafaii Moghadam et al., 2010). However, late Mesozoic ophiolites are widespread in Central-East Iran, without any natural connection to assumed subduction zones – despite frequent assertions to the opposite – occurring along arcuate mega-scale fault zones and circumscribing the central continental block association – Lut, Tabas and Yazd blocks (Stöcklin, 1968). The northern boundary of the Lut block, for example, the nearly 600 km long Great Kavir-Doruneh Fault, shows very limited exposure of ophiolite masses. Along the western boundary of the Lut block the ultramafic-mafic associations of Nain, Baft and other localities do not form a coherent mass (Desmons, 1982), and also the Sistan ophiolite complexes – branching northward from the Makran region – occur in discontinuous segments and does not join the Sabzevar ophiolite belt along the northern border of the Central Iranian blocks. Indeed, the presence of circular continental blocks encircled by irregular and discontinuous ophiolitic complexes poses unsolved problems for plate tectonics-enforced interpretations. On the other hand, if we consider the Iranian region being affected by moderate Alpine wrench tectonics – to the effect that it is being squeezed between the northern and southern palaeo-lithospheric caps in relative rotation (the northern palaeo-hemisphere performing clockwise torsion and the southern palaeo-hemisphere moving in the counter clockwise sense) – observations such as marginal thrust belts, salt basins, internal continental blocks in relative rotation and discontinuous ophiolitic sequences are just as might be expected (see below).

The curvilinear Alborz Mountain Range in northern Iran is thought to have originated in response of the closure of the hypothetical Palaeo-Tethys – with a continental sliver of Gondwana provenance welding together with the southern margin of Eurasia around late Triassic time (Brunet et al., 2007). However, the major phase of regional deformation is Miocene and younger, and related to the assumed Arabia/Eurasia convergence (Zanchi et al., 2006) – presumably powered by hypothesized seafloor spreading in the Red Sea. Fold and fault axes trend NW-SE in western Alborz and NE-SW in the eastern part of the mountain chain, and structural and seismological evidence shows that the deformation partitioned along range-parallel thrusts and strike-slip faults of left-lateral character (Jackson et al. 2002). Departing from the general picture, Allen et al. (2003) reported crustal shortening associated with right-lateral ESE-WNW trending strike-slip faults, and Ritz et al. (2006) submitted that an “internal domain of central Alborz is not affected by a transpressional regime but by an active transtension with a WNW-ESE extensional axis” – a motion which they argue is of late Pleistocene age. On every prominent regional aspect, problems abound. Thus, recently Motavalli-Anbaran et al. (2011) gave the following short list of unsolved first-order regional problems: “Important questions concern the crustal structure of the South Caspian Basin underneath its extremely thick sedimentary cover, the reason for the disappearing of the Caucasus relief in the Caspian Sea, and the origin of the Alborz Mountains and its crustal as well as lithospheric structure”. Judging from the prevailing left-lateral strike-slip motions, with associated landward-facing thrust belts along the southern as well as the northern tectonic boundaries, one is inclined to believe that Iran has been (and probably still is) subject to an overall west-directed transpressive pressure – in addition to undergoing internal deformation. Post-early Miocene volcanism in the southeastern border zone of the Central-East Micro-Continental Block (Boccaletti

et al., 1976; Hassanzadeh, 1994) supports a younger phase of internal mobility in Iran.

The structurally complex Central-East Iran consists of four main micro-continental blocks separated by major faults; the outer boundary of this block assembly is characterized by disconnected complexes of Upper Cretaceous to Lower Eocene ophiolitic masses. In terms of lithostratigraphy, the lower rock sequences of these blocks represent late Precambrian and Palaeozoic metamorphic, volcanic and sedimentary rocks – covered by well-developed and thick Mesozoic sedimentary sequences. Soffel et al. (1996) studied the characteristic fossil directions of magnetization of Mesozoic sediments and volcanics from three regions within the Central-East micro-continental complex and from one region (Natanz) located west of the micro-continental assembly. The results show a fairly clear picture: results from the Natanz region are consistent with those of the adjacent Eurasia (Turan region), while the fossil magnetization vectors from the central blocks suggest that the interior of Iran has been subjected to significant post-Triassic rotations, adding up to more than 90° in the counter clockwise sense. Consistent with the palaeomagnetic observations, right-lateral shear between the Central-East Iran and Afghan blocks is accommodated on N-S striking faults bounding the aseismic Lut Block (Walker and Jackson, 2004), and Wellman (1966) – studying orientations of the wrench faults in this region – again arrived at a counter clockwise motion for the fairly aseismic Lut Block. It seems that tectonic wrench forces favour an overall counter-clockwise rotation for the Central-East Iranian domain, and this motion is probably also responsible for the marked north-facing bend of the Eastern Alborz-Kopet Dag mountain range (cf. **Fig. 9a&b**).

Accepting the rotation alternative of Central Iranian continental block assembly, smaller scale transtensional regimes with associated basin formation, would inevitably develop along the outer margins of these blocks. In eastern Iran, the rather large ophiolitic mélange zones have been assigned ages between late Cretaceous and Eocene (e.g. Vialon et al., 1972; Stöcklin, 1974), and the Dehshir ophiolite bodies of (Central Iran), including a variety of tectonized mafic to ultramafic rocks, are reported to be overlain by a late Cretaceous limestone sequence (Shafaii Moghadam et al., 2010). These observations are consistent with the wrench tectonic thesis in that the major tectonic deformation must be referred to the Alpine climax – i.e. the Upper Cretaceous to Lower Tertiary time span. Furthermore, under the tectonic conditions favoured here, ductile upper mantle peridotites would naturally be subjected to pressure increase thereby generating upward tectonic squeezing of solid state peridotitic material (at temperatures of, say, 500°C) through deep fractures, to be emplaced in surface basins along with associated volcanics. However, due to the inferred shearing-associated ‘injection’ mechanism, these margin complexes, as well as their surrounding rocks, would be liable to attain intermediate to high grade regional metamorphism. Amphibolite facies metamorphism has indeed been reported from the Sabzevar ophiolite of NE Iran (Tehrani, 1975), and large bodies of marbles (intimately associated with Iranian ophiolite complexes) have been interpreted as products of contact metamorphism (Ricou, 1970 and 1971; Haynes and McQuillan, 1974). This development pattern concurs with that of Brookfield (1977) who argues that ophiolites are found in narrow tectonic belts between rigid platforms – emplaced during complex high-angle wrench faulting.

A tomography profile across the Zagros Zone

Looking for signs of the predicted down going crustal slab beneath the north-east dipping Main Zagros Thrust and the Sanandaj-Sirjan metamorphic zone, Shomali et al. (2011) have carried out a teleseismic tomography study of a cross-section from the Gulf to well into the Central Iranian micro-continental region (CIMC). The authors report that “The image shows a sharp lithospheric boundary at the Main Zagros Thrust between 100 km and 250 km depth with P-wave velocity about 3 per cent faster within the Arabian Shield to the south. A step-like increase in lithospheric thickness across the Zagros collision zone is assumed to separate two different mantle structures namely the Arabia (to the south) and the Eurasian (to the north) domains. The most striking feature resolved is a north-dipping slab-like positive velocity anomaly”. **Fig. 10** shows the results of the obtained P-phase teleseismic tomography inversion.

The fairly complex upper mantle velocity model of Shomali et al., presented by **Fig. 10c**, was tentatively linked to the subduction model (taken for granted) – arguing that the observed deep aseismic and higher velocity structures could be disconnected aseismic slab fractions, adhering to earlier propositions that mantle sections of many Benioff zones might be without earthquake activity. But to avoid further ad hoc

speculation, perhaps time has come to openly spell out that many tectonic fronts/arcs are without deep seismicity simply because the dual mechanisms of seafloor spreading and subduction are nothing but fiction? Anyway, within the framework of wrench tectonics the Moho deepening as well as the complex lithospheric structure beneath the Main Zagros Fold and Thrust Belt, depicted in **Fig. 10a & c**, suggest a completely different interpretation.

Let us consider first the low-velocity upper mantle at the northern section of the investigated profile, beneath the CIMC, which differ markedly from the high-velocity upper mantle for the southern section (Arabian Shield). Besides, the CIMC is almost devoid of a shield-like lithosphere, a feature which Shomali et al. believe is caused by a warmer than normal upper mantle, but without bolstering their proposition with factual evidence. However, it is difficult to envisage why the thermal state of the Arabian Shield upper mantle should be significantly different from that of the CIMC. A more relevant explanation of the low-velocity upper mantle for CIMC may be associated with palaeomagnetic evidence for a major post-Jurassic rotation of this continental complex (discussed above). The mechanical distortion of the CIMC during its rotation would naturally have brought about significant reactivation of the ubiquitous fracture network (of the CIMC crust and brittle upper mantle), as well as perhaps breaking up new and more irregular rock discontinuities; this deformation would naturally have greatly increased the fracture spacing thereby opening up for increased fluid/gas infiltration from the mantle beneath. The inferred increase in fracture volume, in addition to a higher content of volatiles, is probably a more realistic explanation of the CIMC low-velocity upper mantle – creating its observed negative velocity contrast versus that of the more un-deformed Arabian Shield. In the central section, beneath the Main Zagros Thrust Zone, the lithosphere has a very complex velocity structure (**Fig. 10c**) in addition to a significant deepening of the inferred Moho (**Fig. 10a**). This part of the profile is likely to represent the regionally most fractured lithospheric segment apparently consisting of a broad wedge of north-dipping structures which may have led to a certain degree of anisotropy. However, the near-vertical P-phase discontinuity of several per cent beneath the thrust zone – down to depths of at least 500 km – constitutes a mosaic of high- and low-velocity regions that are difficult to reconcile with lithospheric anisotropy.

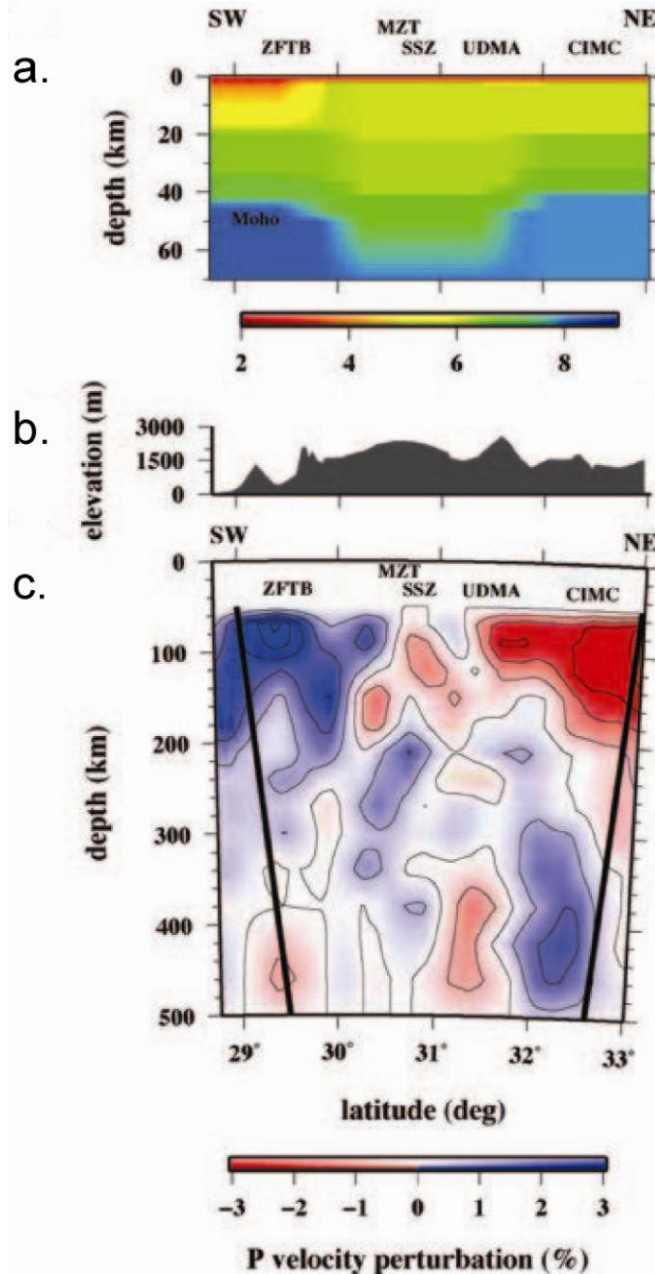


Fig. 10. Diagram (a) shows a cross-section of the Zagros crustal model of Shomali et al. (2011), while diagram (b) describes variations in elevation along the profile. Diagram (c) demonstrates the upper mantle velocity structure obtained from P-phase teleseismic tomography. Regions with higher and lower relative velocity are shown by blue and red colours respectively, and the oblique lines (in c) delimits the most well-resolved area of the inversion. After Shomali et al. (2011).

The most striking feature is a large steeply north-dipping high-velocity mass that seemingly follows the presumed north-dipping path – diving beneath the low-velocity upper mantle layer of Central Iran; in the complete absence of deep seismicity this is unlikely to be a fragment of a subducting slab. As an alternative interpretation, high-velocity features could be delaminated lithosphere of dense eclogitic masses which due to gravity instability have detached from the peridotitic upper mantle – on their way to settle at some deeper level. Mantle eclogite may have a variety of origins, often produced by high-pressure crystallization, but studies have shown that transition to eclogite is strongly augmented by the presence of hydrous fluids; thus, in order for the metamorphic reactions to go forward, water-rich fluids seems much more important than either temperature or pressure (Austrheim, 1998), and Leech (2001) concluded that delamination of eclogitic

masses is controlled by the amount of water available for the deformation associated with the actual metamorphism-regulated density changes. In a fractured lithosphere, like that of the Zagros Thrust Zone, gasses and hydrous fluids are likely to be present in abundance and therefore paving the way for effective eclogite transformation and related gravitative instability – peeling off lithosphere sections. Because of their relatively high density, eclogite will sink to some greater depths (depending on composition); but as the sunken eclogitic masses presumably heats up they may become buoyant and rise, probably creating a kind of ‘yo-yo tectonics’ (Anderson, 2005). This may perhaps explain the complex mosaic of low- and high-velocity masses depicted in diagram (10c). Anyway, the anomalous upper mantle velocity segment beneath the Main Zagros Thrust Belt, consisting of a near-vertical mantle ‘slice’ with steeply dipping internal velocity structures, is markedly at variance with the plate tectonic hypothesis. The model of a degassing Earth, where hydrous fluids have penetrated the strongly tectonized lithosphere leading to processes such as eclogitization and gravity instability of fractions of ‘original’ peridotitic upper mantle, serpentinization of the lower crust and un-metamorphosed parts of the peridotitic layer, and not least the strongly corrosive effect of supercritical water (hydrous fluids) which in addition, due to its very low density, has a strong buoyant force, seems to provide much more robust explanations.

The suggested over-thickened crust indicated for the central part of the Zagros profile is most likely anomalous (serpentinized) upper mantle material; instead, a closer inspection of the crustal structure would most likely show up with a certain thinning – a situation eventually arrived at for the Sierra Nevada Range of western North America (see Wernicke et al., 1996, and references therein). Wernicke et al. concluded that the southern Sierra Nevada provides an example of a continental mountain chain supported mainly by lateral density variations in the upper mantle – i.e. the range is held up by a Pratt-type mantle root rather than an Airy-type crustal root. To conclude this discussion of the Zagros profile, Shomali et al. were puzzled by the fact that the highest mountains are shifted to the north with respect to their inferred crustal root (see Fig. 10b). However, the highest mountain elevations correspond to the mafic-ultramafic UDMA arc which expectedly would represent the deepest regional fracture zone – dipping down (steeply) between the low-velocity Central Iran and the major high-velocity mantle ‘chunk’. It seems likely, therefore, that this presumably deep lithospheric fracture zone would act as an effective channel for supercritical fluids which because of their strongly buoyant nature would give rise to the highest mountains of the region. Mouthereau et al. (2006) wondered why the regional uplift of the Zagros did not happen before post-Miocene time – long after the main Zagros tectonic deformation had taken place. In a degassing Earth model such delayed uplift has its natural cause (see Storetvedt, 2003) and is only enigmatic in the context of classical isostasy and plate tectonic models. Thus, late- to post-Miocene uplift is a characteristic feature of all mountain ranges on Earth, regardless of their age of underlying tectonics (cf. Ollier and Pain, 2000), and should, along with the rest of Earth history, be viewed within the frame of a brand new global theory.

The pre-Alpine dynamic Earth

Time for paradigm change

Above, we have given a variety of facts and arguments in disfavour of the plate tectonics-constrained Tethys; by PT-enforced closing of the Atlantic, the late Palaeozoic Tethys has become an eastward-widening oceanic embayment – bound by the hypothesized Gondwana continental assembly in the south and Laurasia in the north. Based on this popular palaeo-geography, it is envisaged that a diversity of continental slivers and more irregular continental masses have split off from Gondwana, allegedly drifting north to finally amalgamate with Eurasia. The evidence for longer periods of Tethyan faunal endemism has been set aside. In the various drift propositions – for which all take the unconfirmed notions of seafloor spreading and subduction for granted – have during the last 4-5 decades turned the Tethys issue into a chaotic mix of facts and ad hoc theoretical intricacies. Predictions in terms phenomenological interconnections are hard to find. For example, in the Iranian region it is conceded that a two-stage Tethyan opening and closing (Palaeo- and Neo-Tethys) has completely fallen victim to subduction – in the early Triassic and early Tertiary respectively. In this way, the early Cimmerian and main Alpine tectonic phases are currently explained. However, geophysical evidence has failed to unravel presumed subduction zones, seismicity from predicted subducted slabs is glaringly absent, major fold-thrust belts consist primarily of shelf sediments, and

ophiolitic masses (fragmented basic to ultra-basic masses mixed up with marine sediments), which according to the prevailing opinion are remnants of former oceanic crust, do not occur where they are expected to be found. A significant PT puzzle is the disconnected ophiolite complexes circumscribing the central Iranian continental block(s).

Regrettably, the PT ideology has vaccinated the Earth Sciences against taking the consequence of contradictory facts; to a large extent opportunistic ignorance and institutionalized intolerance have apparently replaced true geosciences inquiry.

We have already seen how the traditional Tethys concept – a relatively narrow epicontinental seaway that extended E-W across southern Eurasia – gives a much simpler and more realistic platform for explaining a series of important facts. For example, the longstanding endemic fauna of this seaway requires a persistent closed-in palaeo-geography; these are important observations which the PT-inflicted oceanic embayment model has had to ignore or explain away (cf. Hsu and Bernoulli, 1978). The protracted and relatively quiet depositional history of the Tethys was, in the Lower-Middle Mesozoic, interrupted by faulting which gave rise to a horst-and-graben topography with greatly variable water depths (Trümpy, 1971). However, the most important stages of the Tethyan tectonic unrest – with folding, shearing and thrusting – are Alpine age phenomena, with peak activity in late Cretaceous-Lower Tertiary, Upper Eocene-Lower Oligocene, and Neogene times respectively. This sequence of tectonic events – transforming the Tethyan tract from a protracted and relatively quiet depositional basin to a strongly folded crustal belt, topped up by late Miocene-Recent uplift of the Alpine-Himalaya range, undoubtedly requires a theoretical revolution. In a wider perspective, the dynamo-tectonic machinery which ended the Tethyan seaway represents the younger end of Earth's episodic history; its pulse-like dynamic behaviour has seemingly been the impetus for implantation of discontinuities (time boundaries) in the geological record (Storetvedt, 2003). Naturally, the evolutionary facets of the Tethys are intimately bound to the planet's operating dynamo-tectonic system. In this essay we have re-installed the pre-plate tectonics epi-continental Tethys, and by adopting the theory of Wrench Tectonics we arrive at a new understanding of the tectonic development of the Middle East – presumably stripped for the knotty ad hoc situation prevailing today.

The Mesozoic run-up

It seems a reasonable starting point that the geological history began with a gaseous proto-planet which by elemental segregation led to a thick primordial crust with a thermo-dynamically highly unstable interior (Storetvedt, 2011). In consequence, during the course of geological time continual planetary degassing and related reorganization of interior mass has apparently modified the crust and upper mantle continuously. It follows that the present constitution of the Earth – including the peridotitic upper mantle, the irregular gas and fluids-infiltrated asthenosphere, the Moho discontinuity, granitization of the continental crust, and formation of the thin and compositionally complex oceanic crust – is the provisional end product of this eternal process. The gradual build-up of high hydrostatic pressures at levels of the upper mantle has led to diverse metamorphic reactions – primarily through eclogitization and serpentinization – processes which are thought to have played a most decisive role in the transformation of crust and upper mantle (Storetvedt, 2003 and references therein).

At a critical level in the build-up of hydrostatic pressures in the topmost mantle – gradually forming an irregular volatile-rich asthenosphere along with pockets of magma, conversion to dense eclogite would have developed; at more advanced stages of these metamorphic reactions, strongly transformed rock masses would then have been subjected to gravity-driven delamination and inward motion that eventually would have stopped at a level of neutral buoyancy (Anderson 2005). In this way, advancing eclogitization has given rise to progressive thinning of an early thick pan-global continental-type crust (from the bottom upwards); progressive crustal loss to the mantle and related isostatic subsidence of the ever thinner deep sea crust did eventually, during the Cretaceous, produce widespread oceanic depressions – for the first time in Earth history. The gas/fluid-driven metamorphic rock transformations would naturally have been most effective in sections of strongly tectonized lithosphere. Above we used these principles to interpret the upper mantle seismic P-velocity perturbations beneath the Main Zagros Thrust Zone.

During the protracted planetary degassing, the Earth's surface would have been subject to an accelerated accumulation of juvenile water, notably during the Mesozoic. However, the associated growth of deep sea basins did not only accommodate the increasing volume of surface water, but had also the capacity to house the formerly widespread epicontinental seas – thereby gradually draining the land masses. In addition, continual degassing and related reorganization of internal matter is bound to have altered Earth's moment of inertia periodically, instigating dynamic changes expressed by relatively distinct variations in planetary spin rate and intermittent events of true polar wander (changing the planet's spatial orientation and thereby resetting the equatorial bulge). These dynamical changes set off a range of inertia-driven tectono-magmatic processes, including exhalation of volatiles from the asthenosphere – varying from sedate to forceful surface expulsions (cratering) – which gave rise to significant climatic and biological changes. From late Jurassic onwards, thinning and basification of former continental crust advanced more rapidly than before so that, by the early Tertiary, the deep oceanic depressions were approaching their present global distribution.

The build-up of excessive upper mantle volatile pressures triggered a range of related intermittent processes; those parts of the crust that underwent accelerated oceanization processes – and were underlain therefore by divisions of the asthenosphere that acquired the most effective build-up of high volatile pressures – were naturally subjected to longer-term uplift, while the remaining surface area – the continental blocks to be – were much less affected by buoyant forces from the asthenosphere. Thus, in phase with uplift of developing oceanic crust, the lower-lying parts of the continents were subjected to sea level transgression. In response to increase and release of volatile pressures within the oceanic asthenosphere, the evolving oceanic crust moved up and down causing associated periodic sea level changes (transgressions and regressions) across low-lying lands. The sequence of regressive sea level events would then relate to progressively deeper oceanic basins. The generalized global sea-level curve for post-Precambrian times is depicted in **Fig. 11a**, while a more detailed representation of sea level fluctuation for the past 25 million years (Neogene) is depicted in **Fig. 11b**.

The characteristic spasmodic style of Earth history – the well-known upheavals of magmatic, tectonic, biological and environmental processes, defining geological time boundaries – is readily explained by the inertia-based Wrench Tectonics theory. But associating global tectonics with Earth rotation is not an entirely new idea; already a century ago, the Austrian geologist Damian Kreichgauer (1902) submitted that tectonic belts were closely associated with Earth rotation. He argued that due to inertial effects fold belts had developed in two different palaeo-geographic locations: either along time-equivalent equators, or as rifted zones in near-orthogonal – palaeo-meridional – settings. Based on rock evidence for palaeoclimate, Kreichgauer was able to draw polar wander paths that show remarkable similarities to modern polar wander curves based on palaeomagnetic data (cf. **Fig. 3b**). Thus, the southward progression across Europe of the combined palaeo-equators and principal tectonic belts – for Middle Palaeozoic to Alpine times – can readily be accounted for. For example, the E-W trending intra-continental Permian-Triassic (early Cimmerian) tectonic zone of Central-South Europe with further extension across the South Caspian region (for rock evidence, see Eftekharneshad and Behrooz, 1991) fits the wrench tectonic system extremely well; no Cimmerian-age closing of the hypothesized Palaeo-Tethys is required to explain the late Palaeozoic-Triassic tectonics of North Iran.

During the Lower and Middle Palaeozoic the continents were extensively flooded, during which the relatively shallow Eurasian Tethys and Para-Tethys seas seemingly had their most extensive distribution (see Boucot and Johnson, 1973). Beginning in the Lower Mesozoic, after the late Permian-early Triassic volatile 'exhaustion' and related biological catastrophe – associated with a deep regression, a new accumulation of asthenospheric gasses and fluids began. The Mesozoic increase of hydrostatic pressure in the topmost oceanic mantle provided an escalating lifting power on the evolving deep sea crust, causing a long-term transgression only interrupted by regressive events at around the Triassic-Jurassic and Jurassic-Cretaceous boundaries. The advancing Mesozoic transgression which culminated in the Cenomanian – some 100 m.y. ago (see **Fig. 11a**), signaled the coming of the Alpine tectonic revolution. This Cenomanian sea-level high-stand was followed by a major sea-level lowering. The regression-related oceanic deepening, with inward

motion of delaminated crust, gave rise to a certain planetary acceleration which, in combination with the hydraulic power affecting the asthenosphere, led to series of tectono-magmatic, climatic and biological consequences. For example, the major Deccan flood basalt province and the large Chixculub structure in Mexico – along with numerous other craters and magmatic events across the globe (see Storetvedt, 2003; Storetvedt and Longhinos, 2012), are products of the late Cretaceous dynamic cataclysm. Above all, at that time (late Cretaceous to early Tertiary) the Earth was thrown into a series of strong tectonic pulses – collectively referred to as the Alpine climax.

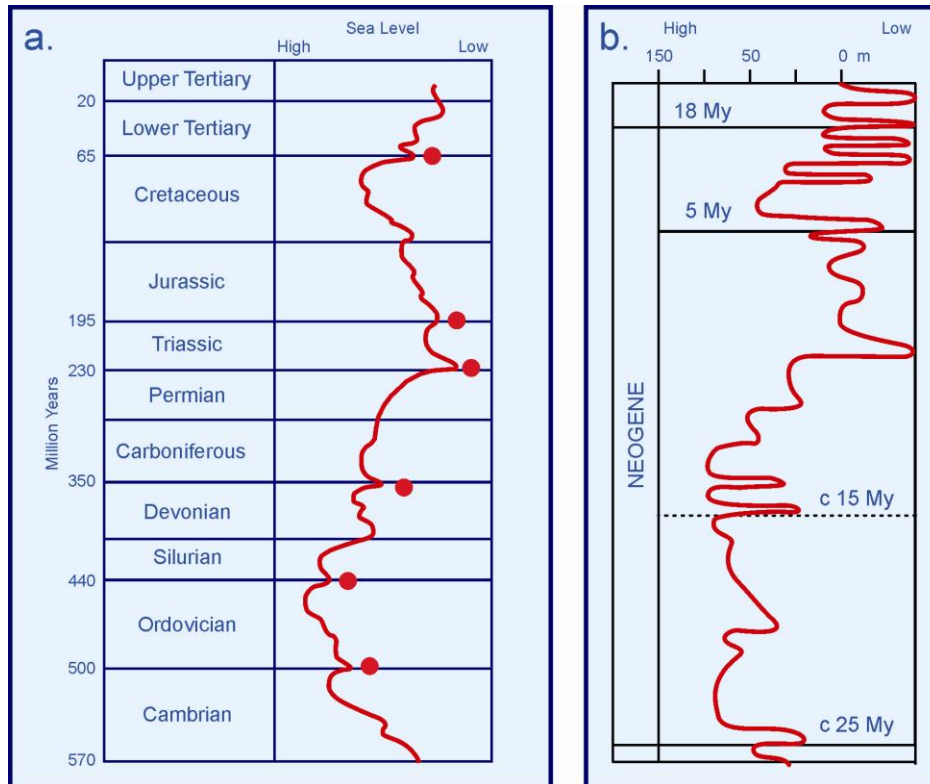


Fig. 11. Diagram (a) shows a generalized post-Precambrian sea level curve in which full circles mark the six principal happenings of marine mass extinction following relatively sharp sea-level low-stands (regressions). Note that the biotic catastrophes correspond to times of relatively sharp drops of sea level. According to the Wrench Tectonics theory, global sea level lows reflect events of oceanic crustal subsidence, being the product of intermittent crustal loss to the mantle; in this oceanization process, associated planetary acceleration set off events of lithospheric wrenching (torsion), enhancing pressure increase in the asthenosphere which in turn led to pulses of toxic gas exhalations at the surface resulting in biotic crises. Diagram (b) gives the Exxon proposal for global sea level fluctuation for the late Tertiary (Neogene). Diagram (a) is based on Hallam (1992) and diagram (b) is simplified after Haq et al. (1987).

Alpine wrench tectonics of the Middle East

The mobile system

By the end of the Cretaceous, widespread deep oceanic regions had, for the first time in Earth history, been installed. The once thick pan-global crust had gradually developed into a mosaic of remaining, variably sized continental blocks surrounded by thin and mechanically much more fragile oceanic crust. In addition, the degassing-related crustal oceanization had also, by now, led to the build-up of the fluid/gas-infiltrated asthenosphere. In other words, by the end of the Cretaceous the lithosphere had become tectonically much more unstable than ever before in Earth's history. In earlier geological times, tectonic activity had largely been concentrated within specific crustal zones; these regions either constituted overall transpressively or transtensively deformed palaeoequator-aligned geosynclines (depending on whether the Earth had undergone periodic acceleration or enhanced deceleration), or they formed sheared rift zones oriented at steep angles to their corresponding palaeoequator. But by the late Cretaceous the crustal/lithospheric

response to changes in Earth rotation took another course; owing to a certain planetary acceleration, a significant part of the global tectonic processes was ‘transferred’ from the continents to the weaker and more easily deformable oceanic tracts. In this global tectonic transition, the broad and thinly-crustal oceanic regions were turned into a new type of mega-scale tectonic belts not seen on Earth before. This inertia-activated structural upheaval, which affected the globe from the latest Cretaceous to well into the Lower Tertiary, naturally had a profound tectonic consequence for the Tethyan Middle East – including significant tectono-magmatic activity in Iran. During this cataclysm, delamination of the crust continued, first of all in oceanic regions, giving rise to a number of polar wander episodes, the most significant one taking place at around the Eocene-Oligocene boundary – some 35 m.y. ago (cf. **Fig. 3b**).

The late Cretaceous acceleration of the Earth’s spin led to latitude-dependent wrenching of the global lithospheric – producing a certain westward drag along the palaeo-equatorial zone which passed along the Mediterranean and the Middle East (**Fig. 3a**). The kinematic system constituted a clockwise wrenching of the northern palaeo-lithosphere and a corresponding counter clockwise torsion of the southern palaeo-lithosphere; naturally, both continental and oceanic lithospheres took part in this global wrenching process. For example, the relative latitude-dependent rotation explains the well-established palaeomagnetic declination discrepancy between Europe and Africa (note that these continents were located on opposite sides of the actual palaeo-equator). **Fig. 12** illustrates the Eurasia/Africa relative rotation; the inertia effects gave rise to tectonic forcing along the palaeo-equatorial belt – producing the structural foundation for the late Neogene uplift of the Alpine-Himalaya range. During their relative motion, Africa and Eurasia must, overall, have experienced similar marginal velocities (Storetvedt, 1997), but depending on variations in their instantaneous speed of rotation both dextral and sinistral displacements would have taken place on individual faults along the developing elongate tectonic region. Another natural consequence of this wrench system would be complex rotational behaviour of micro-continental blocks within the overall transpressive Alpine-Himalaya fold belt (e.g. Iberia, Italy, India and Central Iran Micro-continent). Furthermore, due to the latitude-dependent wrench forces (such as specified by the Coriolis Effect) the continental masses subjected to mechanical torsion would have experienced internal deformation – to the extent that the wrenching effect would increase towards the palaeo-equatorial belt. This implies that regions such as the Middle East would have been particularly vulnerable to Alpine tectonic complexity.

Alpine tectonic climax

Within the new tectonic framework shearing would have taken place on a variety of scales, and the high pressure-low temperature conditions implied by blueschist and magmatic bodies distributed along the Alpine-Himalaya tract are readily compatible with the wrench tectonic arrangement (cf. Storetvedt, 2003). Local transtensional regimes, with associated basin formation, would inevitably develop in places. Hence, ductile (solid state) upper mantle material would easily, due to hydrostatic-tectonic pressure increase, be subjected to upward squeezing through deep fractures – often associated with magma. The classic stratigraphy of these so-called ophiolites consists of an ultramafic-mafic complex, sedimentary group, and a metamorphic unit. Subsequent shearing along the fold belt has often squeezed these ultra-mafic rock bodies into their present disconnected pattern – ripped off from their deep roots. Lippard et al. (1986) suggested that the great majority of ophiolites in Iran are late Cretaceous (pre-Palaeocene) in age. However, during emplacement of these complexes, there would have been open supply routes for fluids from the mantle – carrying a load of metallic compounds eventually deposited as ore bodies in many regions along the Alpine-Himalaya belt; Iran, Pakistan and Afghanistan are regarded particularly rich in metallic mineral deposits (cf. Kamitani et al., 2012). Furthermore, considering a tectonic shearing regime in Alpine deformation zones, it is not surprising that the high-pressure tectonic belts with glaucophane-bearing blueschist are basically confined to late Cretaceous-Tertiary metamorphic terranes.

By the onset of the Alpine tectonic revolution, the epi-continental Tethys had existed for at least a few hundred million years. However, with the Tethyan axis being positioned some 10° of latitude north of the late Cretaceous-early Tertiary equatorial region the time-equivalent transpressive deformation became shifted a little to the north. However, due to the inertial deformation along the seaway, the Tethyan great circle trend became sub-divided into a number of smaller scale arcs, but very little ‘crustal’ shortening seems

to have occurred along the tectonized belt. By the late Cretaceous the crust of the Indian Ocean (as well as that of other world oceans) had been markedly attenuated and mechanically weakened, so with the counter clockwise wrenching of the southern palaeo-hemisphere the Indian Ocean lithosphere was subjected to major penetrative shearing – basically reactivating, bending and enlarging segments of the fundamental orthogonal fracture systems. The resulting arcuate structural pattern, mostly NNE-SSW striking, is well displayed by satellite altimetry data. Arising from this lithospheric torsion is the prominent Central Indian Shear Zone, located between the Laccadive-Chagos and Ninety-East ridges, and with India located at its northern extremity. In addition to having its northern boundary to the fault-controlled, weakened crust of the Tethys, India was – with the coming of the Alpine climax – located within a high shearing stress palaeo-equatorial junction. In this unstable situation, the India sub-continent was liable to tectonic re-rotation(s). Regional analysis of palaeomagnetic directions has arrived at a rotation figure of some 130° in the clockwise sense (Storetvedt, 1990) – a conclusion which concurs with a variety of geological and geophysical evidence (see Storetvedt, 2003, and discussion above).

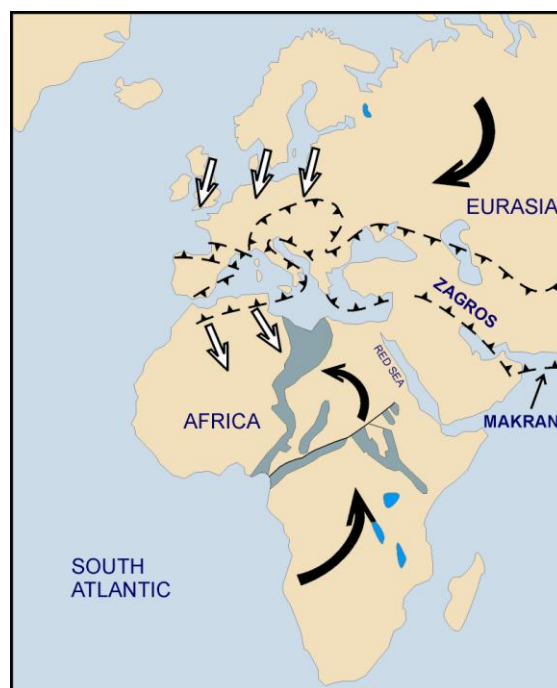


Fig. 12. Illustration depicts the inferred inertia-triggered relative rotation of Africa and Eurasia (bold arrows) in late Cretaceous to Lower Tertiary time (Alpine climax) with generalized tectonic effect on the intervening Tethyan belt. As the inertial motions are latitude dependent – with increasing effect towards the palaeo-equator – the internally variable Alpine rotation of Africa is therefore displayed by two arrows with different curvature. GPS velocity studies suggest that these motions are still in operation (see **Fig. 13**). The intervening crustal belt – basically following along the axis of the former Tethys seaway – constitutes an overall transpressive zone representing the Alpine-Himalaya mobile belt. In this kinematic system, Africa and Eurasia represent segments of a westward wrenching of the entire palaeo-lithosphere for which the palaeo-equator – the common boundary of the two lithospheric ‘caps’ – became the Alpine belt proper. As seen from **Fig. 13**, the counter clockwise rotation of the ‘Africa’ embraced also the Middle East: the Zagros fault got right lateral strike slip, while the Caspian Sea region, affected also by the clockwise motion of Eurasia, got a more diversified tectonic structure. The westward torsion of the two palaeo-hemispheres also led to significant tectonic reactivation and deformation of the thin-crustal oceanic regions – forming the tectono-mineralogical basis of linear marine magnetic anomalies (Storetvedt, 2010b). The global wrenching processes included the break-up of a mega-shear zone across the Indian Ocean, and a significant in situ clockwise rotation of India. The latitude-dependent rotation of Africa led to internal continental deformation. In this process, the old fracture network was reactivated paving the way for the formation of continental basins in orthogonal settings. The well-established pre-Alpine palaeomagnetic declination discrepancy between Africa and Eurasia, caused by their relative rotation, is shown by open arrows.

The major rotation of Greater India naturally would have had significant tectonic consequences notably along its north-western margins; for example, in eastern Pakistan the Tethys basin was squeezed into a sharp northward twist with arcuate tectonic boundaries. Due to the complex regional stress situation – constricted by Eurasia's clockwise torsion, the counter clockwise wrenching of the Indian Ocean lithosphere, and topped up by India's mega-rotation – the Tethyan Basin of the eastern Middle East (Iran, Pakistan and Afghanistan) was turned into a relatively chaotic mix of oval-shaped continental blocks – appearing as relatively aseismic depressions – enclosed by larger and smaller ophiolitic masses, injected through steep boundary faults. Owing to the late Neogene mountainous uplift along their circumscribing tectonic zones, the continental blocks now appear as depressions. However, in consequence of the Alpine tectonic squeezing processes, continental masses like the Pamir, Helmand and Central Iran blocks would have been susceptible to rather unpredictable rotations. For example, Central Iran has apparently been forced into a major counter clockwise rotary motion – a conclusion demonstrated by palaeomagnetic direction studies (Soffel et al., 1996) – and by widespread Upper Cretaceous to Eocene volcanic activity in Iran.

The tectonic pattern of the western Middle East, from the Caspian region to Turkey, displays a much greater regularity in both width and basin-aligned geological structure. But the overall transpressive regime has seemingly been punctured by numerous localized transtensive regions within which upper mantle material has been injected into surface basins – forming ophiolite complexes. However, it seems very likely that during subsequent tectonic shearing these surface complexes have become disconnected from their deep mantle roots – similar to that reported for the northern Oman ophiolite (Gealey 1977; Searle et al. 1980). The Semail ophiolite complex of NE Oman, which has a near-perpendicular setting versus the regional shear field, has apparently been subjected to transtensive condition much more so than the Masirah complex which is located along the tectonic shear grain; this difference in tectonic regime is probably the reason for the much larger size of the Semail ophiolite body. During the Alpine climax, the Tethyan Middle East – located within the time-equivalent equatorial zone – was subjected to westward-directed torsion with faulting, thrusting and imbrications along the Tethyan margins. During later global wrenching events, notably during late Eocene-early Oligocene and Middle-Upper Miocene – additional folded and imbricated shallow-water sediments have been attached to the outer tectonic boundaries.

The Neogene Middle East

After the late Cretaceous transgressive peak, the global relative sea-level was followed by a regressive tendency during most of Lower Tertiary. But from around the Eocene-Oligocene boundary (some 35 m.y. ago) the regressive phase was put in reverse: a transgressive phase began and culminated with the relatively high sea-level stand characterizing the Lower Miocene. As can be seen from the eustatic sea-level graphs of **Fig. 11**, the general Upper Tertiary sea-level rise was punctured by a number of distinct regressive events – which in turn, based on arguments presented above, would have led to changes in Earth rotation and related global tectonic pulses. If we take the paleontological clock data at their face value, the overall slowing of Earth rotation during the Tertiary was one of oscillating deceleration (cf. Storetvedt, 2003), probably directly associated with a number of distinct dynamo-tectonic pulses. In any case, a sharply-delineated event of polar wander took place at around the Eocene-Oligocene boundary (ca. 35 m.y. ago), during which the relative equator shifted from the Mediterranean region to its present geographical position (cf. **Fig. 3b**) – causing reshaping of the Earth's body. During this event sub-tropical Europe experienced significant cooling towards a climatic situation similar to that of today. This major angular shift of the equatorial bulge clearly had a strong effect on the hydrostatic pressures within the asthenosphere upon which the rotating globe served as a kind of hydraulic pumping device. In many ways the polar wander event some 35 m.y. ago can be seen as the terminal spasm of the Alpine climax and responsible for the widespread tectono-magmatic activity at that time.

In continental settings, the Eocene-Oligocene dynamic event apparently triggered the eruption of the Ethiopian flood basalt sequence (37 ± 1 m.y.) and the Iran region experienced considerable magmatic activity. Pressurized upper mantle volatiles found their way to the surface – forming, for example, the Popigai crater (35 m.y.) in Russia. In North America, a certain (Northern Hemisphere) clockwise inertial swing of the continent brought about transtensive conditions in locations along its Arctic and Atlantic

margins. The resulting opening up of fluid pathways led to gas blow-out craters such as: Houghton, Mistantın, Wanapitei Lake, Montaignais, and Chesapeake Bay (see fig. 17 of Storetvedt and Longhinos 2012). Adding to the diversity of geological processes occurring at this time, the Eocene/Oligocene volcanic ashes of the Massignano stratigraphic section, Italy, contain a distinct Ir peak – in association with shocked quartz – dated at 35 m.y. (Montanari et al., 1993). The major relative shift of the equatorial bulge around 35 m.y. ago obviously affected also the hydrostatic pressure system of the Middle East asthenosphere. Thus, pressurized supercritical hydrous fluids, high concentration brines of variable chemistry, lighter hydrocarbons carrying a load of diverse metalliferous compounds, and magma of diverse chemistry, would predictably have forced their way to the surface. Rocks like the Eocene alkaline volcanics (Amidi et al., 1984) and the thick salt basins of Central Iran (e.g. Rahimpour-Bonab and Alijani 2003; Rahimpour-Bonab et al., 2007; Vaziri and Majidifard, 2010) are likely to have formed as late Eocene-Oligocene dynamic injections from the upper mantle. Following Vaziri and Majidifard (2010), the Garmsar salt structures are of Eocene-Oligocene age – forming mighty diapirs consisting of an association of halite, gypsum, red marls and volcanic rocks.

For most of Oligocene time the global sea level was regressive, and according to Khalili et al. (2007) Central Iran was affected by strong tectonic movements at that time – an observation that concurs with the dynamo-tectonic system advanced here. However, beginning in the late Oligocene, the shore line once more encroached on lower-lying lands, culminating in the widespread Lower-Middle Miocene transgression (**Fig. 11b**). However, the Miocene sea level high stand was interrupted by a few distinct regressive pulses, notably by two successive low-stands some 15 m.y. ago and followed by a marked regression around 8 m.y. ago. These sea-level events are likely to be associated with crustal loss to the mantle – giving rise to acceleration in Earth rotation and/or events of polar wander – which would set off tectonic pulses in the form of new phases of lithospheric wrenching. On this basis, one can account for the outer Miocene sedimentary imbrications of the Middle East – adding to the earlier (late Cretaceous to Lower Tertiary) tectonic wedges along the Tethyan margins. Furthermore, the dynamic Earth would activate its hydraulic pumping ability to form diapiric structures which in surface basins, developing in transtensive settings, may show up as a complex mix of geological material, such as:

- 1) The pulse-like dynamic surging of high concentration brines from the upper mantle would, in surface basins, precipitate to form accumulations of thick masses/layers of halite and other salts (such as gypsum and anhydrite) – for which their chemical composition could vary with time,
- 2) The upward surging would expectedly be driven by hydrous fluids in their supercritical state which, due to the ability of such substances to entrain and dissolve solid material, would have produced rock mud *en route*,
- 3) In the strongly buoyant diapiric flow, for which the hydraulic power locally could have varied from sedate to explosive, fragments of older rocks would have followed the stream/to the surface, and
- 4) Starting in the upper mantle, the upward surging/diapiric flow would easily have tapped asthenospheric pockets of magma – to end up as surface volcanism.

Furthermore, the mid-Miocene sea level events correlate with the origin of the Columbia River basalts (16 ± 1 m.y.) and with the well-preserved Ries and Steinheim craters of S. Germany (interpreted here as blow-out structures dated at 14.8 ± 0.7 m.y.). In the Makaronesian insular region, Lower-Middle Miocene and younger littoral horizons have been uplifted to heights of 400-500 metres above sea level (Mitchell-Thomé, 1976), and Neogene volcanic activity is widespread in the Atlantic (cf. Storetvedt 1997, and references therein). The climatic-geographic situation which had been brought about by the 35 m.y. polar wander event, – during which the relative equator shifted from the Mediterranean to around its present position across Central Africa – was put in reverse during the Miocene. In this dynamic process, temperatures in Europe reached a new maximum in ‘mid’-Miocene time (see Buchardt, 1978), and the eastern Mediterranean was again characterized by relatively flat-lying palaeomagnetic inclinations typical of subtropical latitudes (see Atzemoglou et al., 1994). In other words, the combined palaeoclimate and palaeomagnetic evidence favours a specific northward shift of the relative equator in ‘mid’-Miocene time – cutting across Central Arabia. The Upper Tertiary spatial turnings-over of the Earth’s body, implying that the equatorial bulge moved back and

forth over the Middle East region, were inferentially in phase which the regressive pulses shown by **Fig. 11b**. Owing to the asthenospheric pressure variations arising from changes in Earth rotation, the planetary body functioned like a hydraulic contrivance – gushing mantle volatiles en route for the surface.

The geological effects of the shifting relative equatorial bulge would be recognized as tectonic discordances and magmatic horizons – notably in palaeo-equatorial regions, features that are easily spotted, for example, in the Neogene sedimentary succession of the Sinai Peninsula. Extending this argument, it may be assumed that the final Miocene shift of the relative equator, to its present setting in Central Africa, took place in Messinian time – some 5 m.y. years ago. At that time, the Earth had been through a long dynamo-tectonic history with repeated fracture reactivation and lithospheric break-up – a process that had reached its peak during the Alpine climax. Following the asthenospheric volatile ‘exhaustion’ succeeding the Alpine tectonic revolution, resumed build-up of upper mantle volatile pressures took place in the Lower-Middle Miocene – being the internal mechanism behind oceanic basement uplift and the related sea level high stand at that time. The relatively long Miocene transgression was, during the Upper Miocene, followed by phases of regression – inferentially associated with events of oceanic crustal attenuation and basin subsidence. Due to the combination of changes in Earth rotation and asthenospheric pressure increase caused by sub-crustal delamination, pressurized and strongly buoyant supercritical fluids were able to penetrate to higher levels of the crust than ever before in Earth history. Thenceforth, the road was eventually cleared for the coming of modern mountain ranges.

Along fold belts (both old and new), notably in regions of deep lithosphere fracture zones, topographic elevations began to show up, and with the sustained action of surface erosive and sculptural agents the modern mountain ranges began to take shape. In this way, topographic mountain ranges – a newcomer in Earth history (see Ollier and Pain, 2000) – can be explained. Earth history has apparently developed in one direction only – building up a sequential order of inter-connected processes (Storetvedt, 2003) and with the lofty mountain ranges representing one of the provisional end products. Hence, the late Tertiary uplift of the Zagros and Alburz ranges is no mysterious happening at all – just a recent effect in a natural chain of developing geological events. The structure of the Central-East Iranian and Helmand micro-continental blocks, now appearing as a number of individual basins separated by mountain ranges, can readily be explained. During the Alpine climax, the interior of the relatively broad fold belt of the Pakistan-Afghanistan-Iran region was turned into a mosaic of individual continental blocks – for which all of them may have been subjected to variable counter clockwise rotation. This rotational lithospheric break-up undoubtedly created deep fault zones, surrounding the individual continental blocks. So with the volatile-driven latest Miocene and Pliocene upheaval of the circumscribing tectonic sections, the present-day physiographic pattern – consisting of aseismic basins separated by tectonically active mountain ranges – came into existence.

The principle of increasing inertial deformation towards palaeo-equatorial regions is well demonstrated for the Middle East; this region is an integral part of the Alpine palaeo-lithosphere and is therefore, like Africa, subjected to counter clockwise rotation/internal deformation. As demonstrated in **Fig. 13**, the GPS velocity vectors increases from Nubia to Arabia/Iran – before they make a marked westward swing along the strongly tectonized (and therefore more deformable) Alpine fold belt. Thus, the tectonic rotation/deformation figure displayed by GPS data in the palaeo-equatorial region is markedly larger than that estimated from palaeomagnetic data (20°) for Africa as a whole. An interesting conclusion following from the GPS pattern is that the Cyprus and Aegean arcs become transpressive tectonic fronts. It seems quite possible that these arcs are remnants of the old Precambrian great-circle contraction fracture – tectonically deformed into smaller arcs principally during post-Messinian time (see also discussion by Storetvedt and Longhinos 2012). From **Fig. 13** it is also noted that the structures that offset the central Red Sea rift and the oblique fracture zones cutting across the oceanic ridges of the Gulf of Aden and NE Arabian Sea have the same general orientation as the GPS velocity field. Also, the reactivated basement structures of SE Arabia are broadly consistent with the GPS scheme. In support of the arguments presented above, – that the regional salt basins are fed either from the Neo-Proterozoic Hormoz salt layer, or from high concentration brines dynamically expelled from the upper mantle, Edgell (1996) submitted that major basement fault trends

control salt tectonics in the S. Arabia-

Persian Gulf basin.

Both sides of the Red Sea are bounded by the exposed Precambrian Shield. Seismic studies suggest that, apart for the possible exception of the narrow axial fissure zone, its underlying crust is quasi-continental or 'transitional' in character (e.g. Makris et al., 1991, Rihm et al., 1991). Based on the fairly large number of observations (primarily from boreholes, but also from island exposures) of Precambrian basement rocks in the Red Sea, north of 19°N, several authors have predicted the presence of attenuated continental crust contaminated to various degrees by basaltic injections during Neogene time (e.g. Cochran 1983 and Bonatti 1985). Origin of the Red Sea has been a matter for longstanding discussion, but within the ingrained plate tectonics thinking the question has largely been muddled by sea floor spreading dogmatism; a real solution, interlinking the mass of interesting observations and phenomena, has remained undecided. However, it seems widely accepted that Afar and the Red Sea represents a large-scale rift in intermediate stages of transition – transforming from a continental to an oceanic type crust. The rift system represents a split-up between Nubia (Africa) and Arabia since late Oligocene-Miocene time (e.g. Sultan et al., 1993; Ghebreab, 1998; Ligi et al., 2012), but the possibility that this crustal discontinuity could be a vertical collapse structure – a partly attenuated continental crust without noticeable separation of its border zones – has, in recent decades, not been a matter for serious discussion. However, a variety of observations are indeed consistent with the latter model.

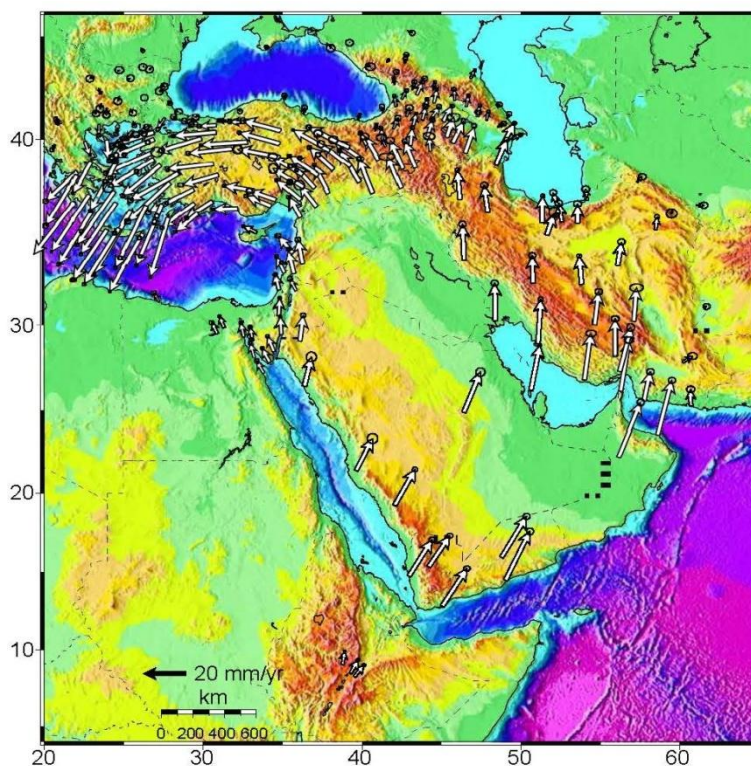


Fig.13. Map displaying decimated GPS-derived velocities of the Middle East relative to Eurasia with 1 σ error ellipses. Note that the counter clockwise motion of the velocity field – extending from Nubia (Africa), across Arabia, swinging markedly counter clockwise when passing Iran and Turkey, and ending in the tectonic fronts of the Cyprus and Aegean arcs. The NNE-NE oriented shear pattern of the Red Sea, Gulf of Aden and NW Arabian Sea is consistent with the GPS velocity system. After Reilinger et al. (2006).

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Red Sea, Gulf of Aden and Dead Sea Rift

The Red Sea region is underlain by Miocene and younger sediments, with salt sequences reaching a thickness of up to 7 km, and salt diapirism is also shown on seismic reflection profiles (e.g. Girdler and Styles, 1974; Searle and Ross, 1975; Izzeldin, 1987). The narrow axial valley – which is continuous from 15°N to 18°N, intermittent up to 24°N and absent north of 24°N – has many anoxic brine-filled deeps – the salinities of which are mainly NaCl at near saturation (e.g. Miller, 1964; Hartmann et al., 1998). Referring to our discussion above, it seems likely that the Red Sea is at an intermediate stage of crustal oceanization, with a mean Moho depth in the central rift zone of around 7-8 km – a process that has evolved along a old, deep fracture zone; in particular, the Red Sea development seems to have got a boost in the Upper Oligocene and Miocene – probably related to the regressive events displayed in **Fig. 11b**. Due to its proximity to the late Cretaceous-early Tertiary palaeo-equator, wrenching was expectedly relatively strong in the Red Sea region. In the resulting shearing regime, which according to GPS velocity data is still in operation, transtensive conditions would easily have developed – along which the high concentration brines would be surged up from asthenospheric levels. The rich metal deposits in hydrothermal pools along the central Red Sea rift could similarly be regarded as having been searched up from the mantle in geodynamic pulses.

More direct evidence in favour of a wrench tectonic origin of the Red Sea is provided by the geology of Zabargad Island (23, 5°N). Thus, both Precambrian basement rocks and late Cretaceous cover sediments occur in high-angle tectonic contact with upper mantle ultramafics; the sediments are intensely deformed, and the upper mantle peridotites display pervasive folding and foliation (e.g. Piccardo et al., 1988; Seyler and Bonatti, 1988; Agrinier et al., 1993). According to Agrinier et al., mantle derived hydrous fluids have percolated through the peridotites before their deformation during diapiric uplift. U-Pb age dating of zircons from a felsic gneiss at the immediate contact with the central Zabargad peridotite body has given ages of 23.2 ± 5.9 m.y. and 22.4 ± 1.3 m.y. (Bosch and Bruguier, 1998); the authors regarded the 22.4 m.y. age as the actual age of diapiric emplacement of the peridotite – intruded into attenuated continental crust during an early stage of Red Sea formation. Accepting these U-Pb ages, it seems reasonable to conclude that the Zabargad asthenospheric ductile/solid rock diapir was dynamically injected during one of the regressive events within the overall Lower Miocene sea level high stand.

Tectono-dynamic considerations support the proposition that the East African Rift System (EARS) broke off, at a steep angle, from the late Precambrian-early Palaeozoic palaeo-equator passing E-W just south of Africa (Storetvedt, 2003, and **Fig. 1**). During subsequent global tectonic pulses, this old fracture zone seems to have repeatedly been reactivated and extended northward (cf. Storetvedt, 1997) – following along the ‘N-S’ set of the fundamental orthogonal fracture system of early Precambrian age (see **Fig. 3** in Storetvedt and Longhinos 2012); a most significant phase in this tectonic reactivation history accelerated in Alpine time. Continental rifting and flood basalt event began at around 30 m.y. in Ethiopia and Yemen (Hofmann et al., 1997; Ukstins et al., 2002) – during the late Oligocene eustatic sea level low (see **Fig. 11b**), presumably marking the onset of crustal thinning in the Red Sea and Gulf of Aden. The basalt province of the Afar depression lies at the intersection between the Red Sea and Gulf of Aden rifts, but the quasi-continental crust of this region – with Moho depth estimates varying between 16 km and 32 km (Dugda et al., 2005;

Hammond et al., 2011) – suggests that sub-crustal delamination is much further advanced in the adjacent Red Sea and Gulf of Aden. However, at the onset of the regional tectono-magmatic activity some 30 m.y. ago, much of the Red Sea and Gulf of Aden was at or near sea surface (cf. Bosworth et al., 2005).

Initially, the orientation of the Red Sea and Gulf of Aden rifts had original ‘N-S’ and ‘E-W’ orientations respectively, but during Upper Cretaceous-Lower Tertiary time these regions – located within relatively unstable tectonic positions just to the south of the actual palaeo-equator – were subjected to a ca. 25° of counter clockwise wrenching. According to **Fig. 13** the inertial rotation and regional shearing – the latter cutting obliquely across the central Red Sea and Gulf of Aden rifts, and oriented in the direction of the GPS velocity vectors – are apparently still in operation. In its northern end, the Red Sea branches off to the NNE – following along the Gulf of Aqaba and the Dead Sea Rift over a length of more than 1000 km. Orientation and distribution of GPS velocity vectors suggest that this major fracture is a left-lateral shear zone; indeed, a major strike-slip history along the Dead Sea Rift – with displacement ranging upward to more than 100 km – has long been proposed. This mega-scale strike slip is however uncertain – having been obtained by matching the platformal sedimentary cover and some units of the Precambrian basement complex across the fracture zone (for a recent summary, see Garfunkel and Ben-Avraham, 1996). In our interpretation, the Dead Sea Rift becomes a splay fault on the northern extremity of the mega-scale East African Rift. In view of the documented Neogene subsidence history for the Red Sea and Gulf of Aden basins, presumably having made Arabia more easily susceptible to Alpine age wrench forces, it seems likely that the strike-slip motion along the Dead Sea Rift is primarily of Miocene age. According to the tectonic thesis adhered to here, the Dead Sea Rift would naturally have acquired transtensive conditions in places with development deep fault-bounded intra-cratonic basins – such as the 150 km long Dead Sea basin. If this reasoning is correct, we would expect to see a subsidence and sedimentation history in the Dead Sea Basin (DSB) very similar to that of the Red Sea.

Various seismic studies (Mechie et al. 2009; Mohsen et al., 2011) have estimated a sedimentary infill in the Dead Sea ranging upward to some 11 km. Garfunkel and Ben-Avraham (1996, and references therein) have summarized the depositional history which shows that the basin began with the 1-2.5 km thick clastic formation of early to late Miocene age. According to the latter authors, in the early history of the basin sedimentation kept pace with subsidence – i.e. the basin did not form a depression at that stage. Since then subsidence has been faster than sedimentation whereby a deep topographic trough has developed. Then, in Messinian time (6-4 m.y. ago) the basin fill was followed by a several kilometres thick sequence of salts – confined to the deepest depressions. Referring to fig 3 of Zak (1967), Garfunkel and Ben-Avraham describe the major Sedom salt diapir as a “12-km-long salt wall which rose along the fault on the western side of the deep trough”. The fact that the Messinian salt sequence was followed by clastic deposits, despite the fact that the basin continued its development into a deep depression, argues against the evaporitic origin model. Again we are faced with the more likely alternative of an injection mechanism: high concentration brines expelled from the mantle. Furthermore, the accumulation of the major accumulation of Dead Sea salts in Messinian time correlates with a dynamo-tectonic pulse at that time – manifested by a distinct regression.

Conclusions

In this paper we have taken a fresh look at the Upper Cretaceous-Tertiary tectonic evolution of the Middle East – applying a new tectonic theory: *Global Wrench Tectonics*. Disregarding the ad hoc-laden and non-working plate tectonic model, we have based our reconsideration on the traditional notion of an epicontinental Tethys seaway which during Alpine time became strongly tectonically disrupted and finally, in late Neogene time, replaced by the Alpine-Himalaya mountain range. The rationale behind our reevaluation is the geological and tectonic consequences of variations in planetary rotation characteristics – either by way of a) changes of Earth’s spin rate or through b) events of spatial re-orientation of the Earth’s body (the phenomenon of true polar wander).

Resulting from these changes of Earth rotation are 1) episodic inertia-regulated lithospheric deformation – for which the palaeolatitude-dependent Coriolis Effect is the restraining factor in the larger scale structural picture, and 2) changes of hydrostatic pressures within the asthenosphere – that have caused significant

transformation of fractured crust, besides setting off a range of surface geological and environmental processes. In other words, we have taken a brand-new look at the traditional notion of 'The Pulse of the Earth' – which in its new dynamic understanding is applied to the interlinking of some main tectonic facets of the Middle East.

In the wrench tectonic thesis, the palaeo-equatorial belts became particularly disposed to overall transpressive deformation. And as it turned out to be, the axis of Tethyan intra-continental basin coincided closely with the late Cretaceous-early Tertiary palaeo-equator which passed along the Mediterranean and Persian Gulf regions. Hence, at this time the Middle East Tethyan tract was subjected to significant transpressive deformation – producing marginal compressive fronts, within-basin tectonic rotations and development of transcurrent fault zones. Ophiolites, which occur in disconnected larger and smaller bodies along prominent tectonic boundaries, are interpreted as having formed through injections of upper mantle material into surface basins which have developed under localized transtensive conditions. In this process the Middle East became a most prominent sector of the Alpine tectonic revolution. Thus, continental masses – both external and internal to the Tethyan belt – were subjected both block rotation and internal deformation. For example, in the eastern region, India – which lay adjacent to the southern border of the Himalaya-Tibetan Tethys – underwent a significant *in situ* tectonic rotation, a conclusion that is bolstered by palaeomagnetic data, fault-plane solutions, GPS velocity vectors, and tectono-physiographic evidence. Similarly, a significant counter clockwise rotation of the Central Iranian micro-continental blocks is supported by a number of independent geophysical and geological evidence.

In the new dynamo-tectonic scenario major salt basins, often with thicknesses in the order of kilometres, are interpreted as precipitates from high concentration brines surged up from the upper mantle during geodynamic events. For example, the major Infra-Cambrian Hormoz salt layer, formed while the Iran-Pakistan region had palaeo-polar location, came into existence at a time when Earth's spatial orientation changed markedly – producing a major shift of the equatorial bulge and related hydrostatic pressure increase. In the same way, the major late Tertiary salt basins of Iran, Red Sea and the Dead Sea are interpreted as massive salt injections from the mantle triggered by Miocene geodynamic events. The expulsive phases of these high concentration brines are correlated with eustatic episodes of sea level low stands – which represent periods of global-extent crustal loss to the mantle – providing increasing volume capacity of oceanic basins. During Alpine time the Earth's lithosphere had become increasingly fractured, and the peak volatile pressures of the uppermost mantle had been exhausted. So when the hydrostatic pressures began to their rebuilding, the lithosphere had been strongly ruptured enabling mantle fluids to penetrate to higher levels of the lithospheric than ever before – notably along deeply fractured tectonic belts and other deep crustal dislocations. Thus, due first of all to the strong lifting power of super-critical hydrous fluids, the rise of mountain ranges accelerated, turning larger parts of the once epicontinental Middle East Tethys into a mountainous tract.

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GEOPOLITICAL CORNER

BAD VIBRATIONS: LESSONS FROM L'AQUILA

A closer look at last October's Italian court verdict that found six earth scientists guilty of involuntary manslaughter reveals some intriguing facts – and fictions.

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Perth, Australia

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On Sunday 5th April, 2009, five days before Good Friday, the inhabitants of L'Aquila ("The Eagle", population about 70,000) in central Italy's Apennine Mountains, felt two tremors. The first struck just before 11pm local time. It measured 3.9 on the magnitude scale, the second 3.5. Strong enough to loosen some objects, but unlikely to wake you up.

Nevertheless, there was a lot of anxiety. A low-level quake swarm had occurred the previous week - eight tremors of at least magnitude 3. A major quake, magnitude 6.3, hit central Italy about four hours later, at 3.32am local time. More than 300 residents were killed, 1,500 injured, 65,000 homeless, with damage estimated at about 15 billion dollars.

L'Aquila has a shaky history. An earthquake damaged its San Francesco Church in late 1315. Others struck in 1349 (January 22, 800 fatalities), 1452, 1461, 1501, 1646, 1703 (February 3, 3,000 fatalities), 1706 and 1786 (July 31, 6,000 fatalities).

There was a period of quiescence for almost two centuries, until a magnitude 5 quake struck on June 26, 1958. The 2009 quake was seventy-five times stronger than this one, and 3,000 times more powerful than the 5th April tremors.

Three years later, on Monday 22nd October, 2012, seven members of Italy's National Commission for the Forecast and Prevention of Major Risks (NCFPMR) were given six-year jail sentences after a two-year trial, banned from holding public office and forced to pay court costs and damages. The L'Aquila Seven were: Franco Barberi, head of Serious Risks Commission; Enzo Boschi, former president of the National Institute of Geophysics and Volcanology; Giulio Lorenzo Selvaggi, director of National Earthquake Centre; Gian Michele Calvi, director of European Centre for Earthquake Engineering; Claudio Eva, physicist; Mauro Dolce, director of the Civil Protection Agency's earthquake risk office; Bernardo De Bernardinis, former vice-president of Civil Protection Agency's technical department.

The prosecution argued they had spread "inaccurate, incomplete and contradictory" statements about the early tremors. They were also criticised for being "falsely reassuring". Boschi had said a major earthquake was "unlikely", but did not entirely exclude this possibility, while De Bernardinis stated publicly there was "no danger".

Scientific opinion was tabled arguing the early tremors were typical of seismic activity before major convulsions. Yet the defendants classified them as a "normal geological phenomenon". More damning was Judge Marco Billi's conclusion: their risk assessment "was incomplete, inept, unsuitable, and criminally mistaken".

"I thought I would have been acquitted. I still don't understand it", said a stunned Boschi. Co-defendant Claudio Eva, 74, described it as, "a very Italian and medieval decision." "An earthquake," he also noted, "is like an assassin that returns to the scene of a crime after centuries, but you can never tell when."

The case will not be decided until heard by an appellate court. The L'Aquila Seven remain free until completion of the appeals process, which apparently could take years.

Their defence lawyers argued that earthquakes could not be predicted and even if they could, nothing could be done to prevent them. "If an event cannot be foreseen and, more to the point, cannot be avoided, it is hard to understand how there can be any suggestion of a failure to predict the risk," defence lawyer Franco Coppi said before the verdict was delivered.

Shock about the judgment echoed around the world, just as it had done when the trial began. Was this Italian justice, Galileo-style? Many felt – and still feel - science itself is on trial (again).

In 2010, more than 4000 scientists signed an open letter to Italian President Giorgio Napolitano. They called the allegations "unfounded," as there was no way NCFPMR could predict an earthquake. Others found the indictments "unfair and naïve".

Malcolm Sperrin, a British scientist, reportedly said: "If the scientific community is to be penalised for making predictions that turn out to be incorrect, or for not accurately predicting an event that subsequently occurs, then scientific endeavour will be restricted to certainties only, and the benefits that are associated with findings, from medicine to physics, will be stalled."

The L'Aquila Seven, however, were not charged with failing to predict the earthquake, *but with conducting a superficial risk assessment and presenting incomplete and falsely reassuring findings to the public* (my italics).

Brian Kennett, Australian National University Professor of Seismology, Earth Physics, felt "the Italian group may have been too reassuring". Whatever the outcome, the judgement "will have a major inhibitory effect on any group worldwide making pronouncements about future risk."

Wayne Peck, senior seismologist, Seismology Research Centre at Environmental Systems and Services concurred: "To err in one direction leaves one open to being charged with being "too reassuring" but to err in the other leaves them open to being accused of being alarmist. Either way, minor nuances in the language used can be interpreted differently by different audiences, leaving the experts in a no-win situation."

Professor David Spiegelhalter, Winton Professor of the Public Understanding of Risk at the University of Cambridge, called it a "bizarre verdict will chill anyone who gives scientific advice. I hope they are freed on appeal." "The lesson for me is that scientific advisers must try and retain control over how their work is communicated, and are properly trained to engage with the public."

Prof. Bill McGuire, Professor of Geophysical and Climate Hazards at the University College London, said the verdict was extremely alarming: "If this sets a precedent then national governments will find it impossible to persuade any scientist to sit on a natural hazard risk evaluation panel. In the longer term, then, this decision will cost lives, not save them."

One prominent Australian columnist suggested "a few Italian judges" perhaps could "sort out our climate alarmists who predicted permanent droughts, empty dams, more hurricanes and dangerous sea-level rises."

In L'Aquila, however, the trial more about the failure of a government-appointed committee to adequately evaluate and communicate the potential risks.

When charges were laid in June 2010 by public prosecutor Fabio Picuti, some described it as an attempt to scapegoat the country's most respected geophysicists.

"I know they can't predict earthquakes," said Picuti. "The basis of the charges is not that they didn't predict the earthquake. As functionaries of the state, they had certain duties imposed by law: to evaluate and characterize the risks that were present in L'Aquila."

"Either they didn't know certain things, and that is a problem; or they didn't know how to communicate what they did know, which is also a problem."

What of the judgement's context? Applying Sherlock Holmes's axiom - "the little things are infinitely the most important" – reveals some interesting facts, and fictions.

With his obsession with coincidences, causal chains and chicanery, two intriguing events – one involving Giampaolo Giuliani, *aka* [Radon Man](#), the other, a toad colony (see **Lesson 9** below) – would not have escaped Conan Doyle's master sleuth. Both apparently exhibited pre-seismic anticipatory behaviour near Ovid's home-town, Sulmona (population 25,000), a mountain pass away from L'Aquila, just before the quake.

Giuliani worked for 40 years as a laboratory technician at Italy's National Institute of Nuclear Physics, including 20 years at the nearby Gran Sasso National Laboratory until his retirement in 2010.

He believes radon gas emissions fluctuate significantly in the day or so before an earthquake. Despite huge scepticism in the scientific establishment about the method's reliability as short-term predictor, he installed four home-made radon detectors throughout the region.

Radon Man's provincial experiment had dramatic consequences: it triggered a sequence of events that ultimately led to the trial.

He claimed to have detected unusually high radon levels in the area. Believing them to signal an impending earthquake, he gave Sulmona's mayor his (unofficial) prediction: one would strike on the afternoon of 29th March. The mayor duly ordered vans carrying loudspeakers to drive through the town and warn residents.

No earthquake hit Sulmona on 29th March. The following day, national civil-protection officials cited Radon Man for *procurato allarme*, or instigating public alarm under [Codice penale italiano](#) Art. 658 - *Procurato allarme presso l'Autorità*. He was forbidden from making further public (and online) pronouncements.

After the April 2009 quake, he became "something of a savant and a martyr" in the Italian tabloids, an amateur who had trumped the scientific establishment. *The Guardian* described him as "The Man Who Predicted An Earthquake". Marcello Melandri, Boschi's lawyer, however, had a different take. Giuliani had been terrifying local residents with nonsense.

Guido Bertolaso, head of Italy's Department of Civil Protection (DCP), "was very worried" about the Sulmona panic spreading to L'Aquila. On 31st March, six days before the deadly earthquake, De Bernardinis, DCP's deputy chief, and the six scientists - all members of its Major Risks Committee - scheduled an official meeting and media conference in the town.

A recorded telephone conversation made public halfway through the trial suggested it was convened with the explicit aim of reassuring the public about short-term earthquake risk. Were the scientists used—or did they knowingly allow themselves to be used—in a DCP attempt to calm the population?

The media conference, unfortunately, downplayed the possibility of an earthquake. De Bernardinis claimed recent tremors actually reduced earthquake risks: "[T]he scientific community continues to confirm to me that in fact it is a favourable situation," he said, "that is to say a continuous discharge of energy."

When asked directly if the public should sit back and enjoy a glass of wine rather than worry about earthquakes, De Bernardinis replied: "Absolutely, absolutely a Montepulciano doc [Montepulciano d'Abruzzo *Denominazione di origine controllata*]. This seems important."

As part of the prosecution's case, Picuti argued fateful decisions made by local residents on the night of the earthquake were influenced by these statements.

"You could almost hear a sigh of relief go through the town," said Simona Giannangeli, a lawyer representing some families of eight University of L'Aquila students who died when a dormitory collapsed. "It was repeated almost like a mantra: the more tremors, the less danger." "That phrase," in the opinion of one L'Aquila resident, "was deadly for a lot of people here."

One distraught resident (who lost family members) told Picuti the messages coming from commission's meeting "may have in some way deprived us of the fear of earthquakes. The science, on this occasion, was dramatically superficial, and *it betrayed the culture of prudence and good sense that our parents taught us on the basis of experience and of the wisdom of the previous generations*" (author's italics). In other words, they would have been better off ignoring scientific opinion (in this case) and trusting their intuition.

According to Stephen Hall's [account](#), many people "viewed the meeting as essentially a public-relations event, [ironically] held to discredit the idea of reliable earthquake prediction [and, by implication, Radon Man] thereby reassuring local residents."

Christian Del Pinto, a DCP seismologist for the neighbouring region of Molise, attended part of the meeting. He later told prosecutors that the proceedings were a "grotesque pantomime". Even Boschi now says that "the point of the meeting was to calm the population. We [scientists] didn't understand that until later on."

Yet clearly communicating earthquake risk to the public should not be difficult. The US Geological Survey is [emphatic](#): "Neither the USGS nor Caltech nor any other scientists have ever predicted a major earthquake. They do not know how, and they do not expect to know how any time in the foreseeable future. The USGS focuses its efforts on the long-term mitigation of earthquake hazards by helping to improve the safety of structures, rather than by trying to accomplish short-term predictions."

While most seismologists resist making definitive statements about the location and timing of earthquakes, many are prepared to make probability statements. [Mark Quigley](#), Senior Lecturer in Active Tectonics and Geomorphology at NZ's Canterbury University, is one of them.

He recently noted that only six of Italy's 26 major earthquakes in the past 60 years were preceded by minor fore-shocks. In fact, a medium-sized shock in a swarm forecast a major event within several days only about 2 per cent of the time. So had the L'Aquila Seven "issued a specific warning that a major earthquake was coming prior to the event, they would have had a 98 per cent chance of being wrong".

But if, as Quigley suggests, it takes "a ton of courage for scientists to speak openly about low-probability scenarios, particularly if these comments are used to accuse them of scare-mongering," it is unclear how this kind of probabilistic risk assessment will ever "protect" communities.

That said, *Nature* reported that scientists at the one-hour meeting made the following [statements](#): "A major earthquake in the area is unlikely but cannot be ruled out," and "in recent times some recent earthquakes have been preceded by minor shocks days or weeks beforehand, but on the other hand many seismic swarms

did not result in a major event," and also "because L'Aquila is in a high-risk zone it is impossible to say with certainty that there will be no large earthquake."

Had the L'Aquila Seven publicly emphasised earthquake unpredictability; had they not communicated, intentionally or inadvertently, such a "reassuring" image of expert authority to anxious citizens, the outcome might have been different – for both the defendants and at least some of the victims.

Ironically, the Latin inscription on L'Aquila's black eagle crest - *Immota manent* – translates as "remain (or be) unmoved". Will the appeals court be moved sufficiently by the L'Aquila Seven's plight – how, for example, could they be expected to pay damages of millions of dollars – and revoke their prison sentences?

Lesson 1: An alarmist statement is a prediction.

Lesson 2: A reassuring statement is a prediction.

Lesson 3: An invitation to relax and have a glass of wine during an earthquake swarm is a reassuring statement. (De Bernardinis's suggestion to have a glass of Montepulciano was, according to one lawyer, "a joke! To have made a joke about a glass of wine and then face a conviction is absurd. It's something out of the Middle Ages.")

Lesson 4: An invitation to panic (and to de-carbonise your life, civilisation and planet during a climate change scare) is an alarmist statement.

Lesson 5: Chalk is not cheese; speculation is not science.

Lesson 6: When walking under a cascade of uncertainties, carry an umbrella.

Lesson 7: For forecasters of "low-probability events" and complex natural phenomena (earthquakes, climate change, etc), "dirty-weather" catastrophists with a Noah complex, etc, a prediction: "Reality always has the last laugh".

Lesson 8: For "risk prevention" experts (and government agencies), a mantra: "I (we) don't know".

As for the alleged pre-seismic [anticipatory behaviour](#) of a reproductively active Common Toad colony 74km from L'Aquila five days before the April 2009 quake; it is – as Holmes would have concluded – "a long shot, Watson, a very long shot!" (If toad anxiety suggests an impending quake, then presumably anxiety in *homo sapiens* is "predictive" too?)

Lesson 9: For punters in active seismic zones, a tip from the track: "Never bet on anything that talks, trembles, or croaks."

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Marco Billi presides over the L'Aquila Seven hearing in L'Aquila, central Italy. (Photograph: Claudio Lattanzio/EPA).



Giampaolo Giuliani and ruins of L'Aquila after the April 2009 earthquake. (Photograph: John Dollar and Getty Images.)

About the author: Michael Kile has an MSc degree from the Imperial College of Science and Technology, University of London and a Diploma from the College; a BSc (Hons) degree (geology/geophysics) from the University of Tasmania, and a BA from the University of Western Australia. He is a regular online contributor and author of *No Room at Nature's Mighty Feast: Reflections on the Growth of Humankind*; ISBN 0-646-23550-8, (1995); <http://popindex.princeton.edu/browse/v62/n3/a.html#62:30002>, and *The Aztec solution to climate change*. His latest project is, *The Devil's Dictionary of Climate Change*.

PUBLICATIONS

The Tsunami Threat: Research and Technology

Edited by: Nils-Axel Mörner, Stockholm, Sweden

The book (ISBN 978-953-307-552-5) is printed by Intech (www.intechopen.com). The book can be ordered via orders@intechweb.org. Every single chapter can be downloaded free of charge.

As the title says, this book deals with “the tsunami threat”. With a remarkable coincidence, this book was launched just two months before the disastrous tsunami event at Fukushima in Japan on March 11, 2011. The subtitle of the book is “research and technology”. The book is on 714 pages. The content is organized in three main sections; (1) Hazard and vulnerability including 10 chapters, (2) Observational records including 11 chapters, and (3) Technologies including 11 chapters. Surely, the book is “a well of tsunami knowledge”.

Back Cover

Submarine earthquakes, submarine slides and impacts may set large water volumes in motion characterized by very long wavelengths and a very high speed of lateral displacement, when reaching shallower water the wave breaks in over land – often with disastrous effects. This natural phenomenon is known as a *tsunami* event. By the December 26, 2004, event in the Indian Ocean, this word suddenly became known the public. The effects were indeed disastrous and some 227,898 people were killed. Tsunami events are a natural part of the Earth’s geophysical system. There have been numerous events in the past and they will continue to be a threat to humanity; even more so today, when the coastal zone is occupied by so much more human activity and so much more people. Therefore, tsunamis pose a very serious threat to humanity. The only way for us to face this threat is by increased knowledge so that we can meet future events by efficient warning systems and aid organizations. This book offers extensive and new information on tsunamis; their origin, history, effects, monitoring, hazards assessment and proposed handling with respect to precaution. Only through knowledge do we know how to behave in a wise manner. This book should be a well of tsunami knowledge for a long time, we hope.

Preface

Just after 9.30 in the morning of Sunday, November 1, 1755 (All Saints Day), Lisbon was struck by a very large earthquake. Buildings collapsed, roaring sounds filled the air, particles were thrown up in the air obscuring the Sun, fire started and an immense tsunami wave broke in over land. A terrible disaster had occurred, often known as “*the Disaster at Lisbon*”. Large parts of the city were in ruins and possibly up to 100,000 persons were killed. “*Take care of the living and bury the dead*” was the laconic advice to the dumbfounded King José I from his minister Sebastião José Carvalho e Melo, later to become known as Marquis de Pombal, one of the true heroes of the tragic event. The prime area of disaster was the coastal sections of Portugal, Spain and Morocco. The tsunami wave was also recorded in Brazil and the West Indies. The disaster had wide intellectual impacts, too. The philosopher Leibniz had claimed (1714) that “*this is the best of worlds*”. In *Candide* (1759), Voltaire used the “Destruction of Lisbon” as the final evidence against Leibniz’ idea, and let the world become far from ideal, rather close to hell. Some saw the disaster as an act of God and claimed that Lisbon therefore was not to be rebuilt, an idea strongly contested by Voltaire. Lisbon was, of course, rebuilt.

The Lisbon 1755 event was probably the first well-recorded tsunami in the history of tsunami research. Over 250 years have passed since the event. Still, it seems, we have learned very little. A new event may well reoccur “at any time” in the same area. Today, we are very much more vulnerable for extended disastrous effects, however; the number of people has multiplied several times, buildings have crept very close to the sea, and the beaches are crowded with people. An effective warning system should have been installed, and

a disaster plan should have been constructed. It should have been a central issue for the sake of precaution. Still, this is not yet the case.

On December 26, 2004 (the Boxing Day), the Indian Ocean was struck by a disastrous tsunami event that killed, at least, 227,898 people. It was initiated by the Sumatra-Andaman Island Earthquake of a magnitude of M 9.3 on the Richter scale. This earthquake set up a series of tsunami waves that spread away from the epicentre at a rate of about 700 km/hour. When the waves reached coastal areas they started to break in over the coasts. The first sign of the approaching tsunami was an initial withdrawal of water. This phase lasted for some minutes then came the disastrous breaking wave followed by its back-swash phase. The world was shocked and amazed. This time we seem to have learned a lesson (just read this book).

Today, there is an Indian Ocean tsunami warning system and agencies are established to guide in case of a new event and to support in the field.

The above two examples of exceptionally large tsunami events both refer to submarine earthquakes. Volcanism, submarine slides and impacts may also generate tsunamis. The Krakatoa multiple volcanic eruptions occurred on August 26–27, 1883. The 4th eruption at 10.02 on August 27 set up a very intensive and destructive tsunami with a death toll in the order of 40,000 persons. The maximum wave height was 35 m and it was still 2.4 m high when it, after 2.5 hours, reached Jakarta.

The Storegga submarine slide at about 7000 BP set up a tsunami, which is well recorded along the Norwegian coasts (e.g. Bondevik et al., 1997) and in Scotland (e.g. Dawson et al., 1988). Even terrestrial slides that go into a lake or the sea set up local tsunamis.

The huge impact that is held to have hit the Earth at the Cretaceous/Tertiary (C/T) boundary is likely to have set up a very large tsunami that had disastrous effects on the fauna and flora at the end of the Cretaceous (e.g. Bourgeois et al., 1988). Recently, tsunamis have also been claimed to occur on Mars as a function of impacts (Mahaney et al., 2010).

Even boulders that fall from a vertical cliff into the sea (or a lake) may set up a minor local tsunami wave. When Charles Darwin and his group on the 20th of January, 1832, were watching the glaciers on the opposite side of Beagle Channel, a big iceberg fell into the sea. It set up a large and rapidly moving wave, which threw their boat up on land and nearly killed them (Darwin, 1839). Today, we know that this was a local tsunami.

This book, we may say, is another sign of the new awareness of the tsunami phenomenon, which is a natural process in Earth's dynamics (Mörner, 2010). Tsunamis have always been a part of Earth's dynamics and will always continue to be so. What we as humans can do, is to undertake precautional efforts like installation of warning systems and establishment of effective disaster planning. All this calls for a basic knowledge about the phenomenon as such, and this is just the reason why this book is published today.

The title of the book was chosen to provide a direct message that we are dealing with a “*threat*” to humanity in the form the phenomenon called *tsunami*, which in the past has caused much damage and much suffering. The Indian Ocean tsunami in 2004 with a death toll of 229,866 persons was number 13 or 12 on the terrible list of death toll per natural disaster event (Mörner, 2010, Table 2).

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NEWS

Earthquake sessions at the European Geosciences Union (EGU) General Assembly 7 to 12 April, 2013, Vienna, Austria

In the themes of Natural Hazards (NH.4) and Seismology (SM.3) of EGU General Assembly, two sessions dedicated to seismic risks and prediction are planned. To support these sessions, the convener needs more papers. Please contact Dr. Valentino Straser urgently for more details, vstraser@ievpc.org.

Deadline for abstract submission: 9 January, 2013.

Conference website: www.egu2012.eu/,

International Earthquake and Volcano Prediction Center
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Earthquake Prediction Center Ends Successful Test Program Early

Monday, December 17, 2012
8:00 AM EST

Press Release 03-12-17-12

The recently organized International Earthquake and Volcano Prediction Center (IEVPC) announces today that it has stopped its internal earthquake test program early because of a near perfect record in its test program and the vital need to begin saving lives immediately.

The IEVPC has just achieved an almost flawless level of perfection in earthquake prediction as demonstrated in the first three tests of its Catastrophic Geophysical Event (CGE) Monitoring and Warning System (CMWS). As a result, the IEVPC has decided to stop further evaluations and immediately begin notification of governments around the world of its now verified ability to predict the largest and most destructive earthquakes with a high degree of certainty.

According to Chairman/CEO Mr. John L. Casey, "We can no longer hold back in letting the earthquake prone nations of the world know that a proven system for highly reliable prediction of large earthquakes now exists. These are the type of geophysical dangers that routinely kill thousands of people around the world every year, while at the same time destroying homes and businesses and in effect ruining the livelihood of many thousands more. The need to cut short our internal test program, originally planned for almost twenty earthquakes, is obvious. We now have a process for earthquake prediction that is so reliable that it must immediately be put into place wherever lives are at risk. The decision we have made to stop evaluation of

our proprietary earthquake process is similar to major drug testing programs. It is not unusual for new drugs to have testing stopped abruptly if the initial results are so compelling and people are dying every day without the drug. Likewise, we have decided we must not wait any longer but must aggressively get out the word about our capabilities.

What we need now is for nations of the world to recognize that it is a myth that earthquakes cannot be predicted and to begin to establish communication networks and standardized monitoring systems in known high risk zones. Other international groups are also coming out with effective tools for earthquake prediction because of recent technological advances and like us, the integration of many prediction techniques and precursor signals into a single predictive process. Once in place, we believe we can maximize the time people have to prepare for these destructive events by providing months, weeks, and days of advance notice. While we will doubtless continue to improve our process for quake detection, there is no longer a need to continue the test program. At the same time, there is an overwhelming humanitarian need to end it.

In September of last year I was approached by some of the world's best seismologists in earthquake prediction to create this new organization that would integrate their combined skills, techniques, and decades of experience. They came to me because of my success in climate change prediction and especially how it relates to variations in earthquake and volcanic activity. Under the leadership of Director of research Dr. Dong Choi, we have been busy assembling the best and brightest in earthquake prediction under one roof."

In the past two months, the IEVPC concluded three separate tests in different areas of the world resulting in near perfect prediction for timing, location and magnitude of large earthquakes. These included the following:

1. Kamchatka Peninsula, Russia. This test resulted in correct prediction of timing and location of a major earthquake event resulting in an amazing nine quakes ranging from M4.6 to M5.8 over a very short three day period. These temblors, in combination, replaced the IEVPC's previously predicted single quake of M7.5-M8.8. Mercifully for the people of Kamchatka and the Pacific Rim, as the final and substantial energy of the quake approached the surface it dispersed among several faults lines off the east coast of Kamchatka during October 14-18, 2012. This quake in its final form of multiple powerful quakes produced no known loss of life. Had a single quake come with the total available energy, thousands of lives might have been lost with a Pacific-wide tsunami produced. Several IEVPC Associate Scientists were involved with this prediction including Dr. Z. Shou, Dr. M. Hayakawa, Dr. A. Bapat and Mr. V. Straser under the leadership of IEVPC Director of Research Dr. Dong Choi.
2. Celebes Sea of Northern Indonesia. As a result of IEVPC precursor analysis conducted by lead investigator and Director of Research, Dr. Choi, an M6.0 oceanic quake was correctly predicted and took place on October 17, 2012 at the location and within the time frame estimated. Because of the deep ocean nature of this isolated quake's epicenter, no damage or loss of life was recorded.
3. Myanmar. On November 11, 2012 a M6.8 quake struck central Myanmar near the location predicted with the magnitude and in the time frame as internal IEVPC estimates had forecast. Twelve lives were lost based on initial figures released by the government.

Leading the initial precursor signal analysis and early detection of the Myanmar quake was renowned Indian seismologist Dr. Arun Bapat. Dr. Choi was also involved in this quake's analysis and used other signals to confirm Dr. Bapat's preliminary conclusions. The final opinion arrived at was for a potentially catastrophic geophysical event (CGE) which would strike central Myanmar within two weeks after November 6, 2012 and would have a magnitude between M6.5 and M7.0. As it turns out, Dr. Bapat was perfect in his

assessment. Dr. Bapat is one of the most distinguished leaders in this field and his history making prediction of the Myanmar quake is only one example of the talent that resides in the IEVPC.

According to Dr. Bapat, “While it was impossible to know whether the Myanmar quake would happen since the IEVPC process had not been evaluated for an inland quake before, the fact that it did along with the Celebes Sea and Kamchatka quakes has given us enough justification to end the test program early and begin to notify the earthquake threatened nations of the world. Mr. Casey and Dr. Choi have done a great service to all by asking those like myself with many years in the field of earthquake prediction to come together to end the myth that these destructive earthquakes cannot be predicted. I believe we are now at that point in human history.”

Dr. Choi added, “We have had a remarkable level of success in our very first three tests. Further, they included diverse geophysical situations. The Kamchatka event was a traditional off shore Pacific Rim oceanic trench fault type quake zone. The Celebes Sea quake was a central oceanic deep ocean event with no companion fault. The Myanmar event was an inland quake with an associated known fault line. It is important to note that our process worked correctly in three distinctly different situations and was another reason for ending the test program quickly. If our process had worked only for one type of quake and not others we might have had to stop and reevaluate our process. That is no longer required. It’s time to put our program for earthquake prediction in the field and start saving lives.”

Mr. Casey echoes Dr. Choi’s comments with, “This level of success in our predictions for Kamchatka, the Celebes Sea and Myanmar carries even more significance when one realizes all our work has been done on a shoestring budget. The potential for saving lives in the many thousands every year is now real. Beginning this week we will start a systematic program for raising the capital needed to expand our operations out of our start-up phase and notify every nation that has to deal with CGE’s that we are here and able to help protect their people. The IEVPC has demonstrated that a new era in reliable earthquake forecasting has arrived.”

The International Earthquake and Volcano Prediction Center is headquartered in Orlando, Florida, USA. The primary research facility is in Canberra, Australia with branch offices of cooperating scientists and researchers planned for the USA, India, China, and Japan. The IEVPC is a non-profit science research organization dedicated to the mission of protection of people through early prediction of Catastrophic Geophysical Events (CGE) such as earthquakes, associated tsunamis, and volcanic eruptions. The IEVPC web site is at www.ievpc.org.

FINANCIAL SUPPORT

Following suggestions from many readers, NCGT Newsletter has become an open journal. Now anyone can access all issues without log in. This will increase the number of readers dramatically. This means we have to rely on good-will, voluntary donations from readers as well as commercial advertisements to defray the journal's running costs. We welcome your generous financial contributions. Hard copy subscription fee for 2013; US\$140/year (or equivalent euros) plus postage (air mail). Advertisement fee structure: **Premium positions**. Page 3 (after the Editorial), full page – U\$400/issue, U\$1460/year. **Back cover**, full page – U\$200/issue, U\$720/year (or equivalent euros). Half page – 80% of the full-page price; **Other positions**. 10% discount from the back-cover price. For more information, please contact editor@ncgt.org.

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ABOUT THE NCGT NEWSLETTER

This newsletter was initiated on the basis of discussion at the symposium “Alternative Theories to Plate Tectonics” held at the 30th International Geological Congress in Beijing in August 1996. The name is taken from an earlier symposium held in association with 28th International Geological Congress in Washington, D. C. in 1989.

Aims include:

1. Forming an organizational focus for creative ideas not fitting readily within the scope of Plate Tectonics.
2. Forming the basis for the reproduction and publication of such work, especially where there has been censorship or discrimination.
3. Forum for discussion of such ideas and work which has been inhibited in existing channels. This should cover a very wide scope from such aspects as the effect of the rotation of the earth and planetary and galactic effects, major theories of development of the Earth, lineaments, interpretation of earthquake data, major times of tectonic and biological change, and so on.
4. Organization of symposia, meetings and conferences.
5. Tabulation and support in case of censorship, discrimination or victimization.