POSSIBILITY OF COUPLING THE MAGNETOSPHERE – IONOSPHERE DURING THE TIME OF EARTHQUAKES

Taha Rabeh[1], Gabriele Cataldi[2] and Valentino Straser[3]

1- NRIAG, Cairo (Egypt)

2- LTPA Observer Project, Radio Emissions Project, Albano Laziale/Lariano, Rome (Italy)

3- International Earthquake and Volcano Prediction Center, Orlando, Florida (USA)

Taha Rabeh: taharabeh@yahoo.com

Gabriele Cataldi: ltpaobserverproject@gmail.com

Valentino Straser: vstraser@ievpc.org

Abstract

In this work we attempt to quantify and investigate the causes of earthquakes using the magnetic signal and hence to predict. We proceed several trails to quantify forces using Sq-variation currents in the Earth's lithosphere and the electromagnetic induction prevailed in the ionosphere at the time of earthquakes. The deep sources of magnetic field prevailed in the Lithosphere has been investigated using the magnetic jerks. Also, the relationship between the applied stress and the corresponding variation in the remanent magnetization has been investigated for rock samples collected along active tectonic zones, while the electromagnetic variations prevailed in the ionosphere were studied using Kp index with respect to the earthquake occurrences.

The results show that correlation between the variations in the magnetic field and the tectonic activities has been approved along the diurnal and long term variations.

The cross-correlation coefficients (PCC) factors between the correlated data sets are ranging between 0.813 and 0.94 indicating strong linear relationship. We concluded that we can trace a noticeable magnetic signal during the 24 before earthquake events. We determine the occurrence times of geomagnetic impulses (jerks) at the time of earthquakes. We show a direct relation between the stress and the remanent magnetization confirming the additional magnetic values (ΔH) that is added to the main magnetic field. Also analysis of the Kp and the variations of geomagnetic bacground (perturbations) shows the possibility of the coupling interaction process between the magnetosphere-ionosphere during the time of earthquake. In fact, by analyzing the modulation of solar activity taking as reference the change in density of the solar wind, was verified that M6+ global seismic activity is influenced by the variations of the density of the solar wind.

Key words: Sq variations, earthquakes, magnetic jerks, Seismic Geomagnetic Precursor (SGP), Interplanetary Seismic Precursor (ISP).

1. Introduction

Several mechanisms have been evoked to explain the listhosphere-atmosphere-ionosphere coupling. It has been proposed that pre-seismic electric fields on the ground can be generated activated by plastic deformations during the slow cooperative build-up of stress **(Freund, 2000, Freund and Sornette, 2007)** but these currents prior to ionospheric anomalies have not yet been observed (**Kamogawa, 2006**). Geomagnetic external disturbances, like geomagnetic storms and cloud-to-ground lightning have also been proposed as a mean to trigger seismicity (e.g.

Sobolev and Zakrzhevskaya, 2003). Duma (1999) focus on the involvement of the regular diurnal variations of the Earth's magnetic field, known as Sq-variations in this process and **Duma & Ruzhin (2003)** attempted to quantify the forces which resulted from the interaction between the induced Sq-variation currents in the Earth's lithosphere and the regional Earth's magnetic to assess its possible influence on the tectonic stress field and, as a consequence, on seismic activity.

As both seismic and magnetic data are available we check the existence of a temporal and spatial relationship between ionospheric magnetic disturbances and seismicity and we can evaluate the Sq affects along with the diurnal magnetic variations corresponding to the seismic activities. This mechanism proposed by **Duma (1999) and Duma and Ruzhin (2003)** as a trigger of earthquake activity. We show that both short term and long term magnetic changes correlate with the seismic activity for Gulf of Suez and Gulf of Aqaba regions, Egypt. We also analyze a set of large earthquakes with magnitudes 5 ≥ and magnetic data from observatories around the world to illustrate the tracing time of the magnetic signal due to earthquake. The data used in the analyses are obtained from standard geomagnetic observatories.

The deep sources of magnetic through the physical process of the isostatic Lithosphere to maintain the Earth's stability and that is happening by centrifugal rotation force of the earth due to major earthquakes has been investigated using the magnetic jerks. A jerk is defined as a sudden change in secular variation taking place and is visible as a step function in the secular acceleration. The geomagnetic jerks phenomena were investigated by **Courtillot et al., (1978); Le Mouel et al., (1982); Vestine, (1952); and Alexanderscu et al., (1995). Golovkov et al. (1989, 1995); Le Mouel and Courtillot, (1981) and Nevanlinna, (1995)** indicated the existence of an impulsive change before 1900, 1947 and 1958. **Fabio Florindo and Laura Alfonsi**

(1995) showed possible relationship between strong earthquakes and geomagnetic jerks. The magnetic jerks derived from Amtasia and Misallat geomagnetic observatories were calculated and correlated the earthquakes of magnitudes 5 ≥. We show good correlation between the pulses of the magnetic field derived from the Earth's Core or magnetic Jerks and the tectonic events (earthquakes).

To study the tectonic role in increasing the magnetic field at the time of earthquakes, an intensive laboratory analyses were subject to number of oriented rock samples collected from active tectonic zones along Red Sea and Gulf of Aqaba areas.

To investigate the external solar effect and its relationship to the earthquakes a set Kp indices from geomagnetic observatories and earthquakes data from the website of USGS, National Egyptian Seismological Network (ENSN) were analyzed.

2. Relationship between Sq and earthquake activity

2.1. Long term and diurnal comparison

The diurnal magnetic variations Sq also called “magnetic quiet-day solar daily variations” **(Chapman and Bartels, 1940)** are generated in the Earth’s ionosphere, mainly by solar radiation and tidal forces. It can be computed by removing the absolute values of the horizontal magnetic field from the mean values of the horizontal magnetic component H along the day time. This procedure was applied to the continuous magnetic data available measured at Misallat Geomagnetic Observatory in Egypt and Amtasia Geomagnetic Observatory in Israel. Their geographic latitudes are 29.515 N and 31.550 N, respectively.

Considering the seismicity of the study area, the seismic catalogue includes a group of about 41459 seismic events in Egypt with magnitudes ranging from 1> and <8 for which magnitudes have been computed by National Research Institute of Astronomy and Geophysics (NRIAG) along more than 100 years. From this dataset we produced a three hour running mean using local time for the three observatories in Local Time.

We can test the existence of a long term correlation if we compare the average monthly earthquake rate of magnitude ≤ 5 Richter within the study area with the H-component of Sq between 1960 and 2000 at Misallat (Fig. 1a) and between 1986 and 2000 at Amtasia (Fig. 1b). Also, the correlation exists along the Sq diurnal variations of the magnetic observatories (Figs 2a&2b). The cross-correlation coefficient factors (PCC) between the magnetic and seismic data sets have been calculated using SPSS software, (2007). The results show that these coefficients are ranging between 0.813 and 0.94 indicating a strong direct linear relationship (Table, 1).

Figures 2a&2b show strong evidence of correlation. In general, the comparison between average magnetic and average seismic data shows that earthquake occurrence and Sq depend both on Local Time in the same way, as suggested before (**e.g. Conrad, 1909, 1932; Shimshoni, 1971; Duma, 1997; Duma and Vilardo, 1998**), pointing to the existence of a general relation between time dependent earthquake activity and regional Sq variation. Maximum values for the number of earthquake events are slightly latter than the corresponding maximum of Sq, between 10 and 15 Local Time, whereas, the minimum values are found between 0 and 5.

2.2. The magnetic signal as a seismic trigger

We made several trails to investigate the magnetic signal due to earthquake during continuous period for the days before and after some recent the seismic events. The results we got show a clear magnetic signal indicated by increasing the main values of the magnetic field variations during the day before the earthquake and sometimes extends during the earthquake period depending on aftershocks and their magnitudes. We show several selected results for magnetic signal arranged in order of their magnitudes. One example is the 25 December 2004 M_w = 9.1 earthquake that took place west coast of northern Sumatra, Indonesia, which epicenter was located at 3º 316' N and 95º 854' E (*cf.* Figure 3a). It caused an increase in ΔH of approximately 45 nT at Guangzhou geomagnetic observatory of 2948 km apart. Another example is the 11 march 2011 earthquake occurred at Japan, with M_w = 9.0. Its epicenter was located at 38.322° N and 142.369°E We traced ΔH of about 40 nT at Kakioka geomagnetic observatory of about 281 km away (*cf.* Figure 3b). Figure 4a shows ΔH of about 30 nT at Memambetsu geomagnetic observatory of 739 km apart resulted from the 15 November 2006 M_w = 8.3 earthquake of Kuril islands while ΔH of about 15 nT at Teoloyucan geomagnetic observatory of a distance 6089 km resulted from 3 November 2002 M_w =7.9 earthquake at Alaska(*cf.* Figure 4b). Similar the 12 January, 2010 earthquake occurred at Haiti of M_w = 7.0 causes increasing in ΔH of about 25 nT at San Juan geomagnetic observatory and the 6 April, 2009 of Italy cases an increase of near 8.0 nT at Chambon La Foret geomagnetic observatory of 1074 km apart (*cf.* Figures 5a and 5b).

Table 2 shows some major earthquakes and the corresponding variations in ΔH as well as the traced distance. Based on the statistical analyses after **Rabeh et al.,**

2009; we can notice that the ΔH magnitude is inversely relation with the distance and in direct relation with earthquake magnitude.

2.3. Magnetic jerks and strong earthquakes

The annual mean values of any magnetic element (northern (X), eastern (Y) and vertical component (Z)) as recorded at a particular geomagnetic observatory generally undergo a steady decrease or increase in time. This change is called the «geomagnetic secular variation» and is linked to the cause of the main field itself (**Parkinson, 1983**). The jerks are a sudden change in secular variation and are visible as a step function in the secular acceleration. These magnetic signals generated in the Earth's core and diffused through the electrically conducting mantle; provide a valid constrain to the mantle electrical conductivity estimates (**Runcorn, 1955; McDonald, 1957; Courtillot and Le Mouel, 1984**). Several authors also tried to correlate these impulsive variations to other geophysical phenomena; among others, **Le Mouel and Courtillot (1981**) correlated these secular acceleration impulses with minima in the Earth's rotation rate suggesting some kind of core-mantle coupling.

In this paper the effects of the strong earthquakes on the dynamic of the outer fluid core are considered. To investigate this phenomenon we had analyzed several numbers of strong earthquakes of magnitudes 5≥ measured by National Egyptian Seismological Network (**ENSN**) at Gulf of Suez and Gulf of Aqaba areas with Jerks/pulses derived from Misallat geomagnetic observatory in Egypt and Amtasia geomagnetic observatory in Israel during the period 1900 up to 2000. The data were smoothed using a year running average.

The result in Figure 6 shows several peaks/jerks coinciding between the occurrence of strong earthquakes and the magnetic field singularities. We can notice the geomagnetic impulses (jerks) are correlated with the recorded earthquakes. We can notice also the magnitudes of the pulsations from Misallat geomagnetic observatory are larger than the pulsations derived from Amtasia geomagnetic observatory. We can conclude that the magnetic pulsations are inversely correlated with distance from the epicenter of the earthquakes.

2.4. Peizomagnetic effect

A laboratory experiment was installed to study the stress effect versus the remanent magnetic (RM) that exists in the rock samples collected along the fault planes along the Red Sea and Gulf of Suez and Gulf of Aqaba (*cf.* Figure 7a). These samples were collected from rock blocks not affected by weather alterations from depths range between 40 cm to 60 cm. The Peizomagnetometer apparatus consists of three main units: mechanical unit, electrical unit and measurement unit (magnetometer and stress meter). The stress was applied to the sample by advancing the piston of the hydraulic non-magnetic cylinder driven by an air hydraulic unit. The pressure on the samples reaches up to 800 bar in order to avoid the failure of the sample and controlled by using a control. A core rock samples of 2.5 cm in diameter and long 6 cm collected from different active tectonic sites in Egypt (see Table 3). We have measured the variation of remanent magnetization (RM) parallel and perpendicular to the applied stress axis. The variation of remanent magnetization parallel to the applied stress axis versus stress has been determined for 25 basalt samples, 10 dolerite samples, 13 diorite samples and 20 gabbro samples.

The results (*cf.* Figures 7a & 7b and Table 3) show the direct relations between the stress and the remanent magnetization. The magnitude of ΔH is depending so far on the type mineral constituents but we will not go so far in that field of expertise. Therefore we can stated that this method confirms that there is additional magnetic values (ΔH) is added to the main magnetic field due to the tectonic pressure along the fault planes at the time of earthquake.

2.5. The solar impact on seismicity

To study the solar impact on seismicity more closely we compare the magnetic index Kp with the seismic energy released over wide seismically active regions. Kp characterises the planetary magnetic field disturbances, mainly caused by solar particle radiation, the solar wind. Kp indices, given as 3-hr averages, have been continuously published by ISGI, France, since 1932.

We correlated the 3-hr averages Kp with the 3-hr averages of magnitudes of the major global earthquakes of magnitudes $5 \geq M_w$. The results (see Fig. 8a) show good correlation between the variations of the Kp index and the variations in the magnitudes of earthquakes. To confirm this correlation we have selected the most quite year 2009 for the detailed analyses. We removed one week before and after the earthquake events. We made a correlation between Kp without removing these periods and Kp data after removing the data for the mentioned periods. The results show the existence of highest amplitudes (see Fig. 8b) for the data without removing indicating the presence of relationship between the solar activities and earthquakes.

Another confirmation of the solar activity impact has on global seismic activity comes from a study conducted between 1 January 2012 and 31 December

2013. The study showed that all M6+ earthquakes occurred on Earth in 2012-2013 were always preceded by an increase in solar activity: increase of solar wind density (ACE/EPAM; ENLIL Heliosphere Ecliptic Plane). These increases of solar activity produced perturbations of the Earth's magnetic field (see Fig. 9) that preceded all the M6+ earthquakes occurred on a global scale (**Radio Emissions Project; G. Cataldi, D. Cataldi and V. Straser., 2013**).

3. Discussion and Conclusions

This study shows a close relationship between the variations of the magnetic field (Sq) with respect to earthquake activities. The Gulf of Suez and Gulf of Aqaba, Egypt was the selected active seismic area to investigate the jerks and the magnetic variations due to presence of the Egyptian seismic network and geomagnetic observatories lies in Egypt and Israel. We analyze the magnetic data with respect to the seismic data for long term, seasonal term and diurnal variations. In general the analyses show good correlations along the mentioned duration. We show here the magnetic signal very clear during the day before the earthquake along some selected sites along the globe

Investigation the relationship between the earthquakes of magnitudes ≥ 4.0 and the magnetic spikes/impulses (jerks) along two geomagnetic observatories in Egypt and Israel using secular variation of the H-components of the magnetic field show several peaks/jerks coinciding between the occurrence of these earthquakes and the jerks along H-components of the magnetic field. We found that the magnitude of these jerks is depending on the magnitude of earthquakes and the sensitivity of the used magnetic apparatus used in the recording process as well as the distance between earthquake’s epicenter and the geomagnetic observatory.

It is known that earth's crust is suffering enormous deformation due the stress resulted from plate tectonic movements at the time of earthquakes (**Harris, A.R., and Simpson, R.W. 1992**). We have proceeded this laboratory experiment to prove the existence of additional ΔH as a result of the stress caused by tectonic movement/earthquakes with ignoring the bulk mineral effect and just take into consideration the major rock constituents of the earth's crust. The results derived from the peizomagnetic analyses show direct relations between the stress and the remanent magnetization which confirms that there are additional magnetic values (ΔH) is added to the main magnetic field due to the pressure along the fault planes.

On looking to the external magnetic sources especially the solar impact on seismicity, we made a correlation between the 3-hr averages Kp with the 3-hr averages of magnitudes of the major global earthquakes of magnitudes $5 \geq M_w$ shows a good matching with the variations in the magnitudes of earthquakes. It has been confirmed by selection a quite year and removing maximum suspected active tectonic periods before and after the earthquake events. This result shows the existence of the relationship between the solar activities and the earth's seismicity.

The simultaneous detected signals from ionosphere related to the prevailed tectonics of the lithosphere and the solar activities can suggest a coupling between the ionosphere and magnetosphere could be exist during the earthquake's period due to electromagnetic waves injected into ionosphere from the lithosphere.

4. References

Alexandrescu, M., Gilbert, D., Hulot, G., Le MoueL, J.L. and Saracco, G., (1995): Detection of geomag- netic jerks using wavelet analysis, J. Geophys. Res. V. 100, pp. 12557-12572.

Chapman, S. and Bartels, J., (1940): Geomagnetism. Oxford Univ. Press (Clarendon), London and New York.

Conrad, V., (1909): Die zeitliche Verteilung der in den ¨osterreichischen Alpen- und Karstl¨andern gef¨uhlten Erdbeben in den Jahren 1897 bis 1907, Mitteilungen der Erdbeben-Kommission, KaiserlicheAkademie der Wissenschaften, Neue Folge, No. XXXVI, pp. 1–23.

Conrad, V., (1932): Die zeitliche Folge der Erdbeben und bebenausl¨osende Ursachen, Handbuch der Geophysik, Band IV, Berlin, Verlag Borntraeger, pp. 1007–1185.

Courtillot, V., Ducruix, J. and Le Mouel, J.L., (1978): Sur un acceleration recente de Ia variation seculaire du champ magnetique terrestre. C.R. Hebd. Seances Acad. Sci. Ser. D, V. 287, pp. 1095-1098.

Courtillot, V., and Le Mouel, J.L., (1984): Geomagnetic secular variation impulses. Nature, V. 311, pp. 709-716.

Duma, G., (1997): Zyklen der Starkbebenaktivit¨at und deren Relevanz fur Fragen der Erdbebensicherheit, Schweizerischer Ingenieur- und Architektenverein, Dokumentation D0145, SIA Z¨urich.

Duma, G. and Vilardo G. (1998): Seismicity cycles in the Mt. Vesuvius area and their relation to solar flux and the variations of the Earth's magnetic field, Phys. Chem. Earth, 23, 9–10, 927–931.

Duma, G., (1999): Regional geomagnetic variations and temporal changes of seismic activity: observations of a so far unknown phenomenon, attempts of

interpretation, 22nd General Assembly of IUGG, Birmingham, England, Session JSA15 (Abstract).

Duma, G. and Ruzhin Y., (2003): Diurnal changes of earthquake activity and geomagnetic Sq-variations. Natural Hazards and Earth System Sciences, V. 3, pp. 171–177.

Fabio Florindo and Laura Alfonsi, (1995): Strong earthquakes and geomagnetic jerks: a cause-effect relationship? ANNAL! DI GEOFISICA, VOL. XXXVIII, N. 3-4, September-October 1995.

Freund, F., (2000): Time-resolved study of charge generation and propagation in igneous rocks, J. Geophys. Res., 105, 11,001–11,019.

Freund F. and Sornette D., (2007): Electro-Magnetic Earthquake Bursts and Critical Rupture of Peroxy Bond Networks in Rocks. APS preprint.

Golovkov, V.P., Zverera, T.I. and Simonyau, A.O., (1989): Common features and differences between «jerks>> of 1947, 1958 and 1969, Geophys. Astrophys. Fluid. Dyn., V. 49, pp. 81-96.

Golovkov, V.P., Simonyau, A.O. and T.l. Zverera (1995): The geomagnetic jerk in 1914-15 comparing with jerks of 60'h and 70'h, IUGG, XXI General Assem- bly, Boulder, July 2-14, 1995, abstract, V. A, 140.

Harris, A.R., and Simpson, R.W., (1992): Changes in static stress on southern California faults after the 1992 Landers earthquake, Nature, V. 360, pp. 251-254.

Kamogawa M. (2006): Preseismic Lithosphere-Atmosphere-Ionosphere Coupling. Eos, Vol. 87, No. 40, 3 October 2006.

Le Mouel, J.L. and V. Courtillot (1981): Core motions, electromagnetic core-mantle coupling and variations in the Earth's rotation: new constraints from geomagnetic the Earth's rotation: new constraints from geomagnetic secular variation impulses, Phys. Earth Planet. Inter., V. 24, pp. 236-241.

Le Mouel, J.L., Ducruix, J. and Duyen, C., HA, (1982): The worldwide character of the 1969-1970 impulse of the secular acceleration rate, Phys. Earth Planet. Inter., V. 23, pp. 72-75.

Mcdonald, K.L. (1957): Penetration of a geomagnetic secular field through a mantle with variable conductiv- ity, J. Geophys. Res.., V. 62, P. 117.

Nevanlinna, H. (1995): Evidence of a geomagnetic jerk NEVANLINNA, H. (1995): Evidence of a geomagnetic jerk in 1870, IUGG, XXI General Assembly, Boulder July 2-14, 1995, abstract, V.. A, 140.

Parkinson, W.D. (1983): Introduction to Geomagnetism (Scottish Academic Press, Edinburgh and London), P. 434.

Rabeh, T., and J M., Miranda, and Milan Hvozdara, (2009)**:** strong earthquakes associated with high amplitude daily geomagnetic variations, Natural Hazard Journal, published on the website with DOI - 10.1007/s11069-009-9449-1.

Runcorn, S.K. (1955): The electrical conductivity of the Earth's mantle, Trans. Am. Geophys. Union, V. 39, P. 191.

Shimshoni, M. (1971): Evidence for Higher Seismic Activity During the Night, Geophys. J. R. Astr. Soc., V. 24, pp. 97–99.

Sobolev, G., and N. Zakrzhevskaya, (2003): Magnetic storm influence on seismicity in different regions, Geophysical Research Abstracts, 5, 00135.

SPSS Statistics Standard (2007): An IBM statistics software Version 16.0.0, copyright © 1993– 2007 , IBM, united states.

Vestine, E.H. (1952): On the variations of the geomagntic field, fluid motions, and the rate of the Earth's central core, Proc. Nat. Acad. Sci., V. 38, pp. 1030-1038.

Cataldi G., Cataldi D. and Straser V. (2013): Variations Of Terrestrial Geomagnetic Activity Correlated To M6+ Global Seismic Activity" Geophysical Research Abstracts, Vol. 15, EGU (European Geosciences Union) General Assembly 2013.

Straser V. (2012): Can IMF And The Electromagnetic Coupling Between The Sun And The Earth Cause Potentially Destructive Earthquakes?. New Concepts in Global Tectonics Newsletter, no. 65, December, 2012. Terenzo PR, Italy.

Figure Caption:

Figure -1: Correlation between:

a) Correlation between the mean average of annual earthquake frequency (nh) of 4 ≥ at Gulf of Aqaba and Gulf of Suez and the horizontal magnetic variations from Misallat geomagnetic observatory for long term.

b) Correlation between the mean average of earthquakes (5 ≥) at Gulf of Aqaba and Gulf of Suez and the horizontal magnetic variations from Amtasia geomagnetic observatory for year average value.

Figure -2

a) Correlation between the mean average of earthquakes (5 ≥) at Gulf of Suez and diurnal magnetic variations Sq from Misallat geomagnetic observatory along 1960 to 2000 period.

b) Correlation between the mean average of earthquakes (5 ≥) at at Gulf of Aqaba and Gulf of Suez and diurnal magnetic variations Sq from Misallat geomagnetic observatory along 1987 to 2000 period.

Figure -3: Magnetic field variations for H-component before earthquake event:

a) West Coast of Northern Sumatra, Indonesia 26 Dec., 2004 of magnitude 9.1.

b) Japan Earthquake 10 March, 2011 of magnitude 8.9.

Figure -4: Magnetic field variations for H-component before earthquake event:

a) Kuril Island earthquake 15 Nov., 2006 of magnitude 8.3.

b) Alaska, USA earthquake 3November, 2002 of magnitude 7.9.

Figure -5: Magnetic field variations for H-component before earthquake event:

a) Haiti 12 January, 2010 of magnitude 7.

b) Italy earthquake 6 Apr., 2009 of magnitude 6.3.

Figure -6: Correlation between the geomagnetic Jerks derived from Amtasia geomagnetic observatory and Misallat geomagnetic observatory as well as the seismic events during the period from 1970 to 2000, whereas H-MLT and H-AMT are the horizontal magnetic component derived from Misallat and Amtasia geomagnetic observatories.

Figure -7:

a) Location map shows the site of the collected rock samples used for peizomagnetic analyses.

b) Relation between the changes in the rock stresses and the variations in the remanent magnetization of the basalt and dolerite rocks.

c) Relation between the changes in the rock stresses and the variations in the remanent magnetization of the gabbros and diorite rocks.

Figure -8:

a) Correlation between the mean values of Kp indices and the 3 hour mean values of earthquake's magnitudes ≥ 5 on Richter scale for the period 1995 to 2008.

b) Correlation between the variations of Kp index data along the year 2009 and the Kp index data after removing values corresponding the earthquake's periods.

Figure -9: Example of geomagnetic disturbances associated with M6+ earthquakes: Wide and intense increase of geomagnetic background (Seismic Geomagnetic Precursor – SGP) that preceded, for about 6-3 hours, the Vanuatu M6,1 earthquake (28 February 2013).

Table Caption:

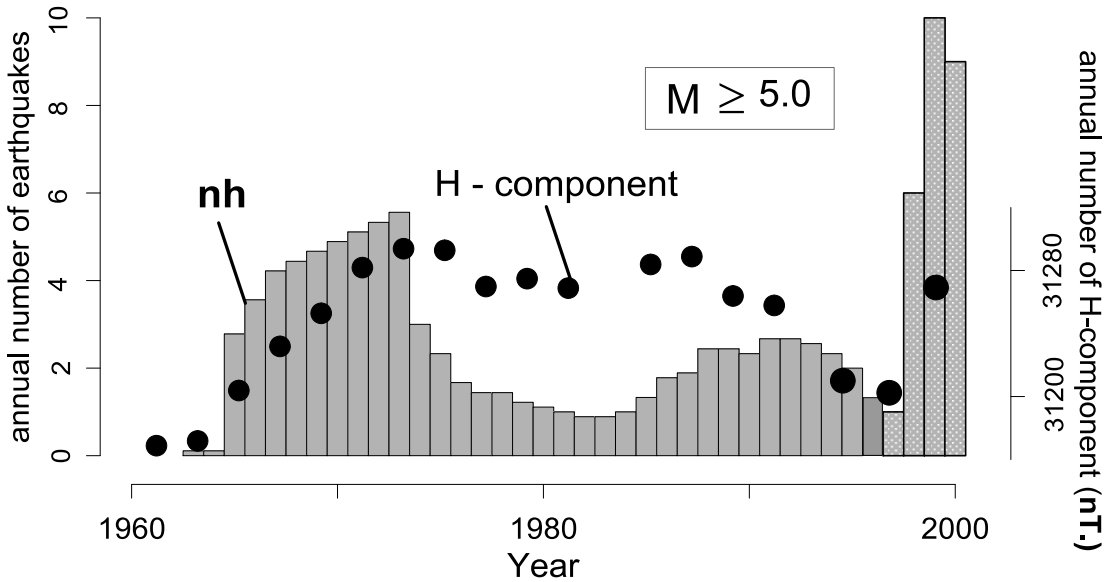
Table 1: Calculating the correlation coefficients

Table 2: Shows examples for major earthquakes and the corresponding variations in ΔH with respect to distance between earthquake's epicenter and the recorded magnetic observatory.

Table 3: Shows the relationship between the variations in the remanent magnetization of different rocks with respect to variations in the stress.

Figure: 1

(a)


annual number of earthquakes
0
2
4
6
8
10
M ≥ 5.0
nh
H - component
1960
1980
2000
Year
31200
31280
annual number of H-component (nT.)

(b)

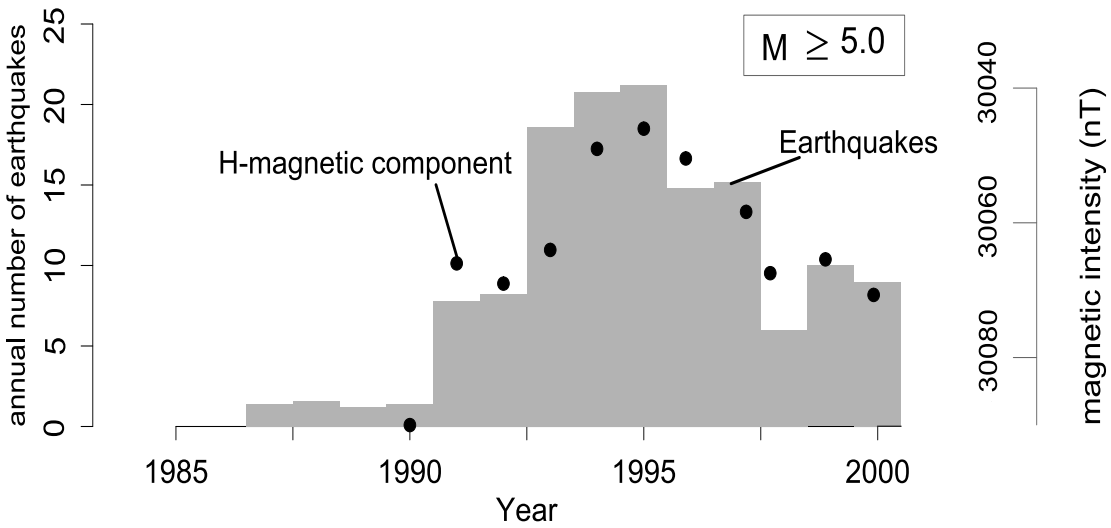
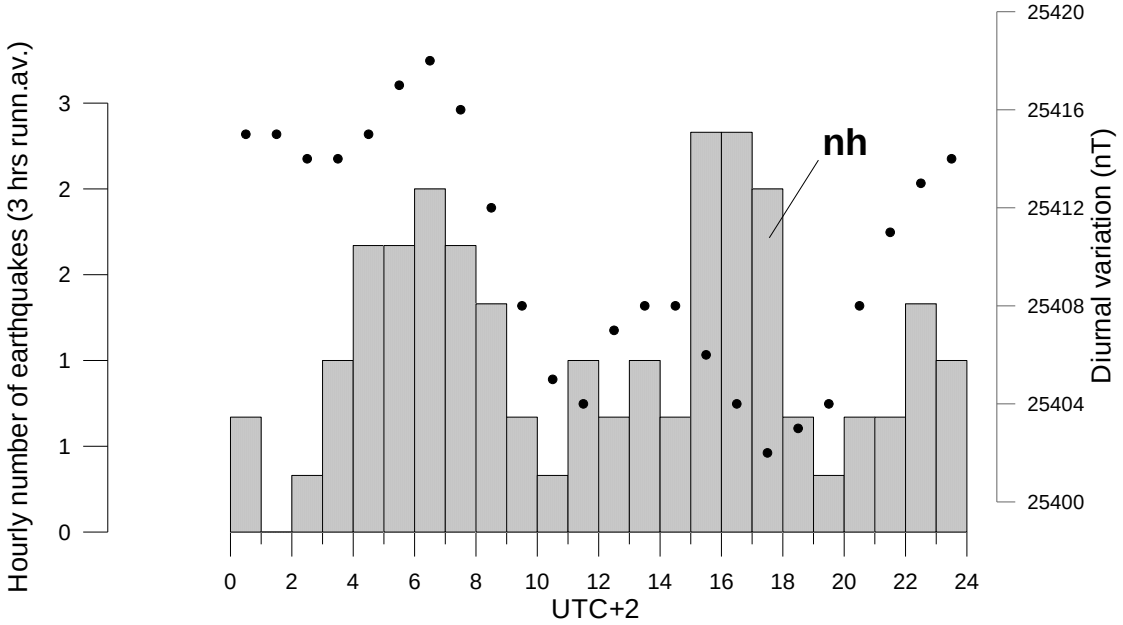

annual number of earthquakes
0
5
10
15
20
25
M ≥ 5.0
H-magnetic component
Earthquakes
1985
1990
1995
2000
Year
30080
30060
30040
magnetic intensity (nT)

Figure: 2

(a)


Hourly number of earthquakes (3 hrs runn.av.)
Diurnal variation (nT)
nh
UTC+2
0
1
1
2
2
3
25400
25404
25408
25412
25416
25420
0 2 4 6 8 10 12 14 16 18 20 22 24

(b)

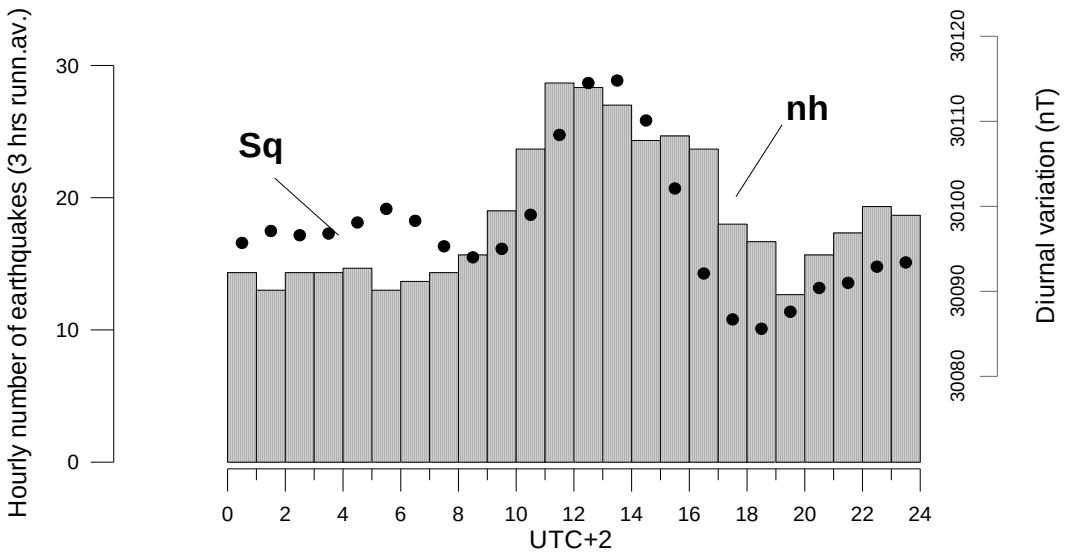
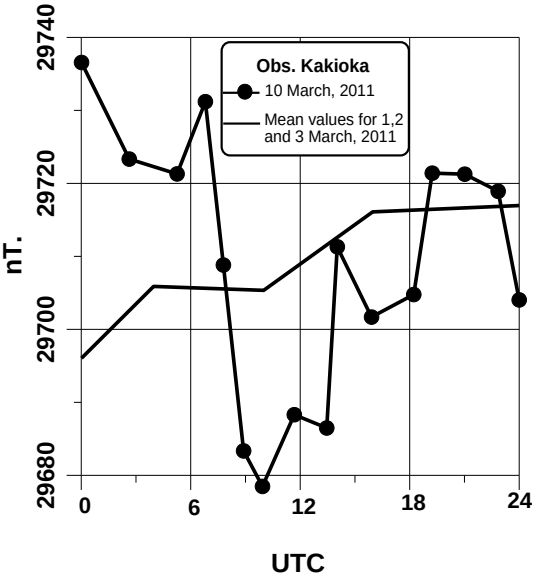
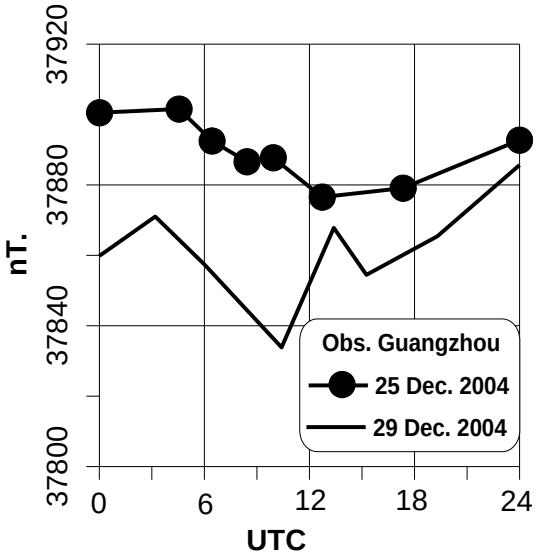

Hourly number of earthquakes (3 hrs runn.av.)
Diurnal variation (nT)
Sq
nh
UTC+2
0
10
20
30
30080
30090
30100
30110
30120
0 2 4 6 8 10 12 14 16 18 20 22 24

Figure: 3

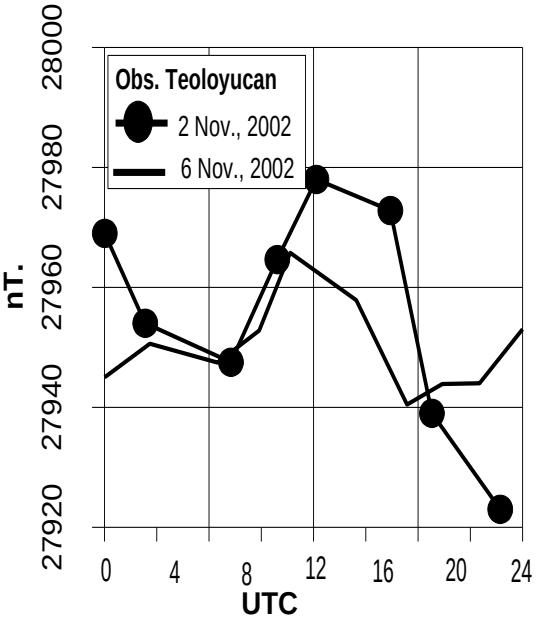


(b)

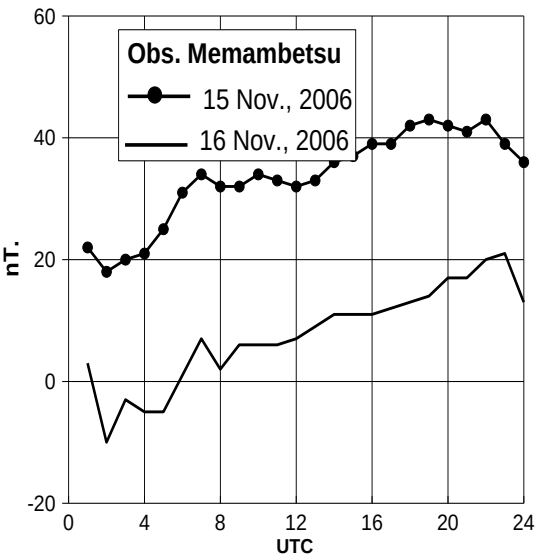


(a)

Figure: 4

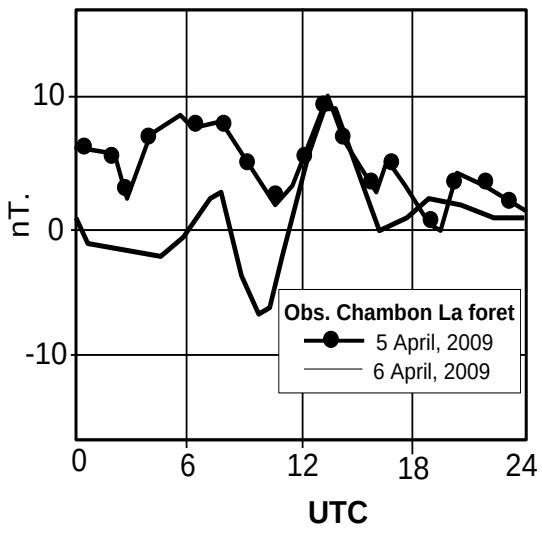


(b)

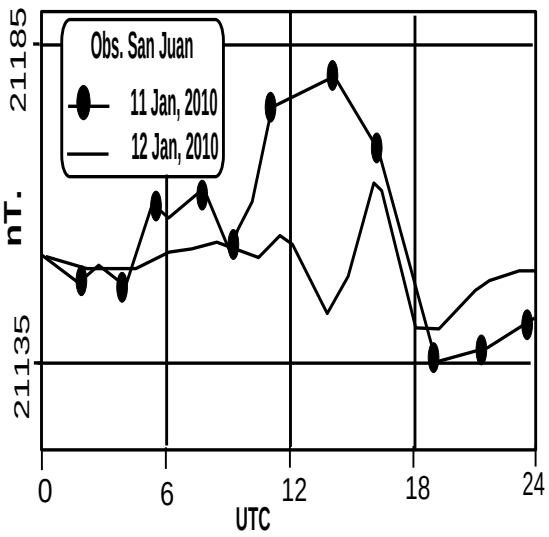


(a)

Figure: 5


10
0
-10
nT.
0
6
12
18
24
UTC
Obs. Chambon La foret
5 April, 2009
6 April, 2009

(b)


21185
21135
nT.
Obs. San Juan
11 Jan, 2010
12 Jan, 2010
0
6
12
18
24
UTC

(a)

Figure: 6

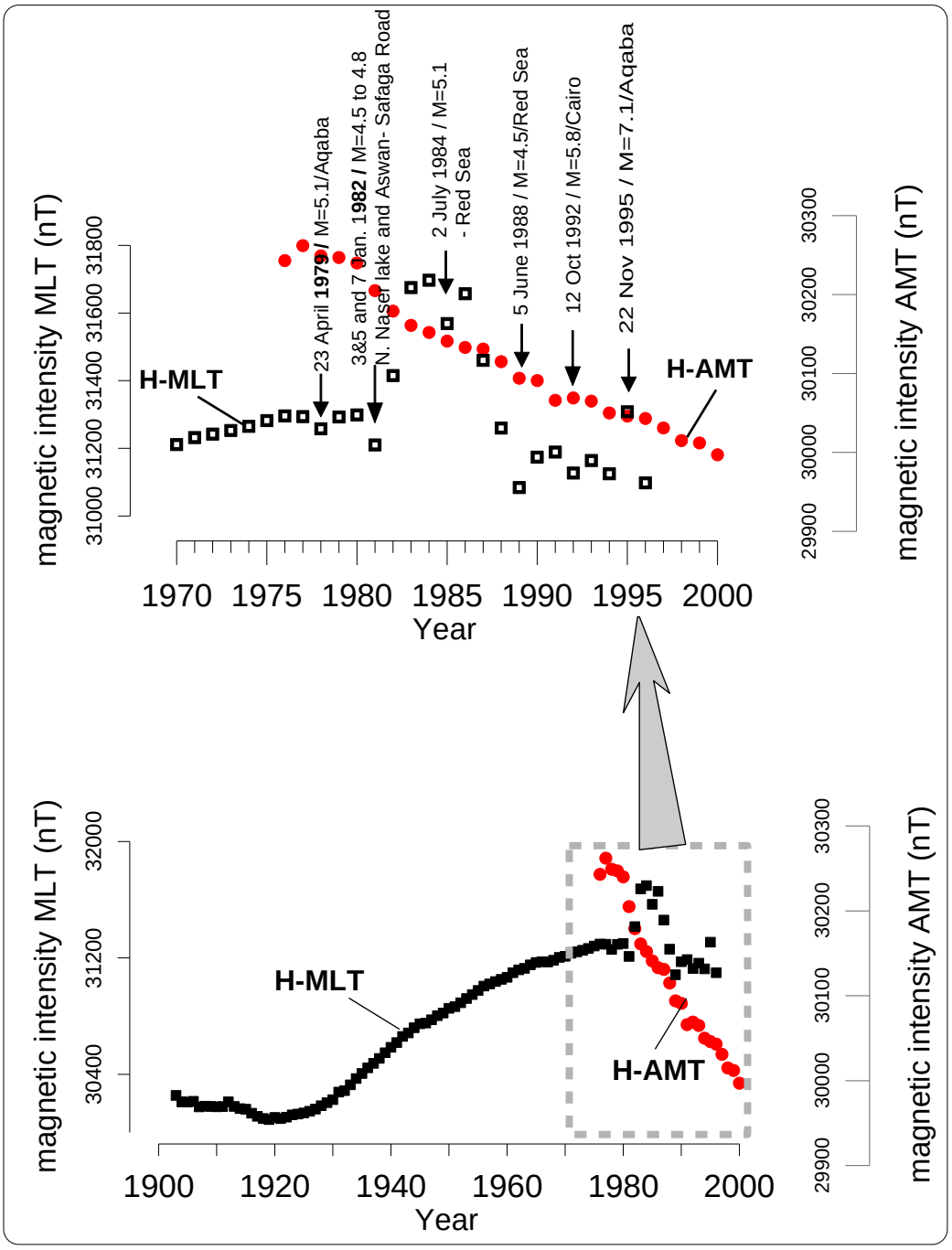
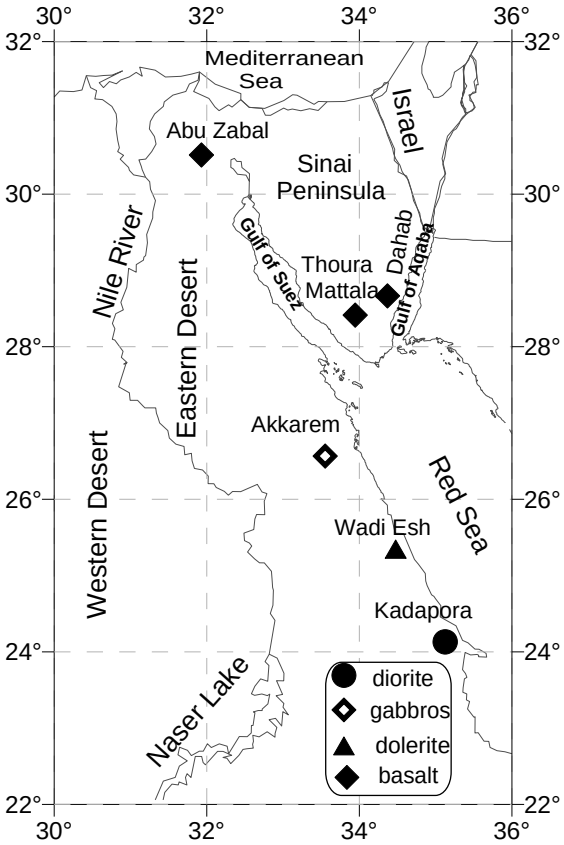
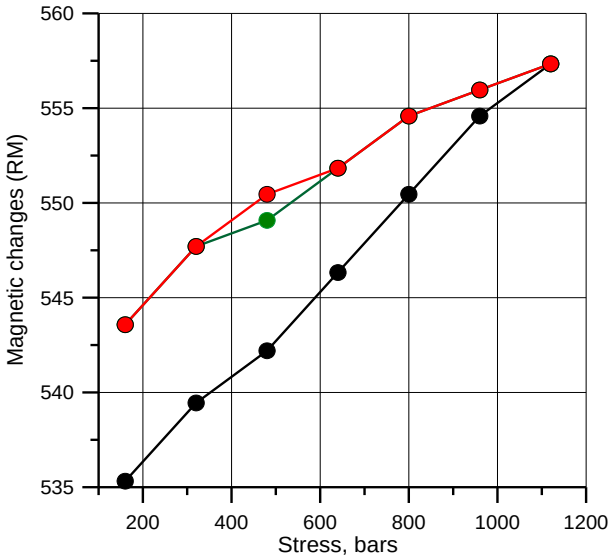
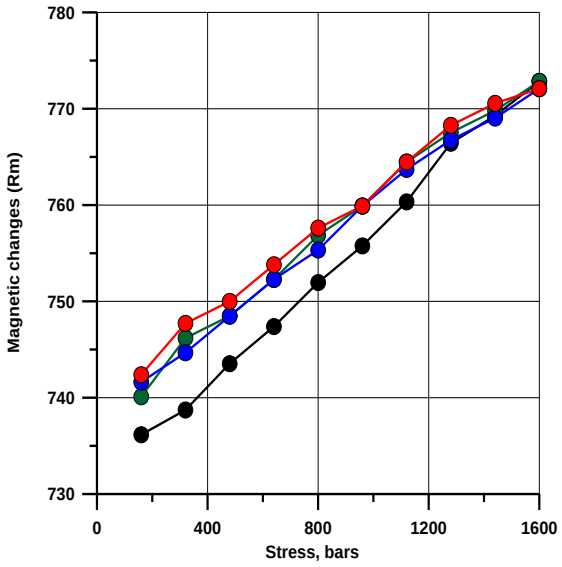

magnetic intensity MLT (nT)
31000 31200 31400 31600 31800
H-MLT
23 April 1979 / M=5.1/Aqaba
3&5 and 7 Jan. 1982 / M=4.5 to 4.8
N. Naser lake and Aswan- Safaga Road
2 July 1984 / M=5.1
- Red Sea
5 June 1988 / M=4.5/Red Sea
12 Oct 1992 / M=5.8/Cairo
22 Nov 1995 / M=7.1/Aqaba
H-AMT
magnetic intensity AMT (nT)
29900 30000 30100 30200 30300
1970 1975 1980 1985 1990 1995 2000
Year
magnetic intensity MLT (nT)
30400 31200 32000
H-MLT
H-AMT
magnetic intensity AMT (nT)
29900 30000 30100 30200 30300
1900 1920 1940 1960 1980 2000
Year

Figure: 7


30°
32°
34°
36°
32°
30°
28°
26°
24°
22°
Mediterranean Sea
Israel
Abu Zabal
Sinai Peninsula
Nile River
Gulf of Suez
Dahab
Gulf of Aqaba
Thoura
Mattala
Eastern Desert
Western Desert
Akkarem
Red Sea
Wadi Esh
Kadapora
Naser Lake
diorite
gabbros
dolerite
basalt

(a)

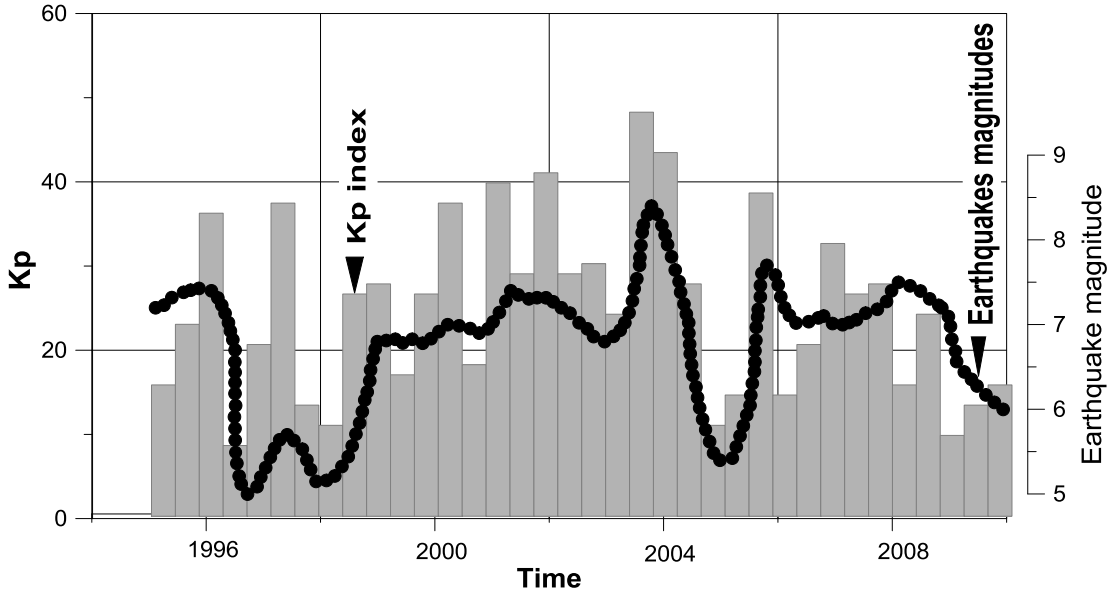

Magnetic changes (RM)
Stress, bars
560
555
550
545
540
535
200
400
600
800
1000
1200


Magnetic changes (Rm)
Stress, bars
780
770
760
750
740
730
0
400
800
1200
1600

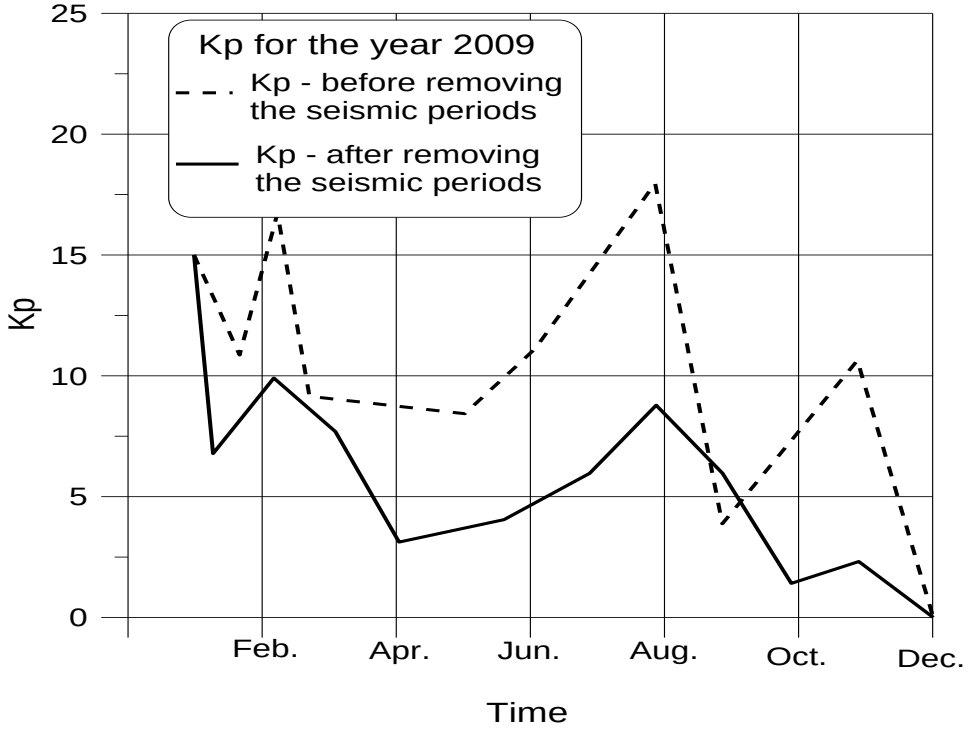
(b)

(c)

Figure: 8

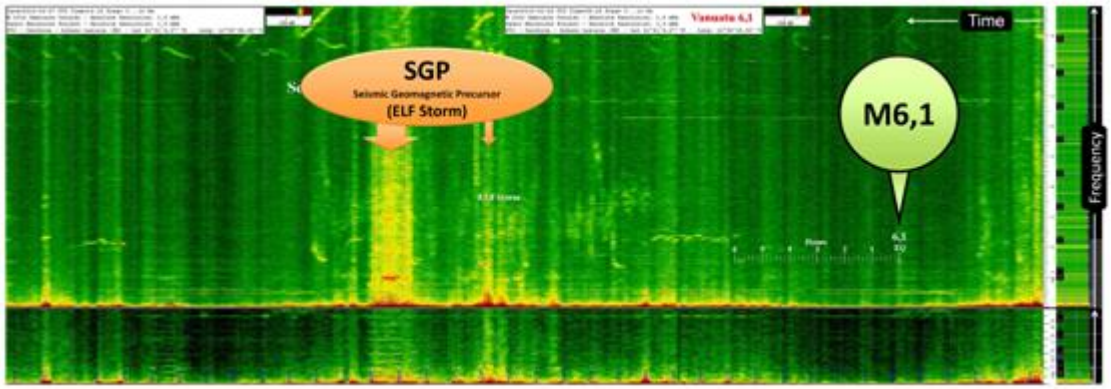

60
40
20
0
Kp
Kp index
Earthquakes magnitudes
9
8
7
6
5
Earthquake magnitude
1996
2000
2004
2008
Time

(a)


Kp for the year 2009
Kp - before removing the seismic periods
Kp - after removing the seismic periods
25
20
15
10
5
0
Kp
Feb.
Apr.
Jun.
Aug.
Oct.
Dec.
Time

(b)

Figure: 9



Radio Emissions Project's magnetometer data, Cecchina, Albano Laziale (RM), Italy.

Table: 1

	Items	Sq	nh
Sq	Pearson Correlation	1	0.813
	Sig. (2-tailed)		0.94
	N (number of correlated points)	150	150
nh	Pearson Correlation	0.813	1
	Sig. (2-tailed)	0.94	
	N (number of correlated points)	150	150

Table: 2

EARTHQUAKE	*EPICENTER*		*OBSERVATORY*	*DISTANCE (KM)*	*ΔH (NT)*
	LATITUDE	*LONGITUDE*			
3 NOV., ALASKA, 2002 (M_w= 7.9)	*63°.51 N*	*147°.45 W*	*VICTORIA*	*2165*	*19.5*
			TEOLOYUCAN	*6119*	*15.0*
25 DEC. 2004, N. SUMATRA, INDONESIA (M_w=9.1)	*3°. 31 N*	*95° .85 E*	*GUANGZHOU*	*2948*	*45.0*
28 MARCH, N. SUMATRA, 2005 (M_w=8.7)	*2°.07 N*	*97°.01 E*	*NOVOSIBIRSK*	*6067*	*26.0*
15 NOVEMBER 2006, KURIL ISLANDS (M_w=8.3)	*46°.60 N*	*153°.23 E*	*MEMAMBETSU*	*805*	*30.0*
			KAKIOKA	*1574*	*22.0*
12 JAN., 2010, HAITI, (M_w=7)	*18°.44 N*	*72°.57 W*	*SAN JUAN*	*96*	*25.0*
11 MARCH, 2011 EAST COAST OF HONSHU, JAPAN (M_w=9)	*38°.32 N*	*142°.36 E*	*KAKIOKA*	*281*	*40.0*

Table 3:

Location	Rock type	Percentage of increasing remanent magnetization values parallel to the stress axis/ 200 bar	Percentage of increasing remanent magnetization values pependicular to the stress axis/ 200 bar	Different between measurements along parallel and perpendicular of the stress axis/200 bar
Kadapora, Red Sea, Egypt	DIORITE	0.4 ± 0.2	0.3 ± 0.1	0.3
Wadi Esh, Red Sea, Egypt	Dolerite	2.4 ± 0.2	2.6 ± 0.2	0.8
Akkarem, Red Sea, Egypt	Gabbros	2.6 ± 0.5	2.8 ± 0.6	1.1
Abu Zabal, Eastern Desert, Egypt	Basalt	1 ± 0.2	1.9 ± 0.1	0.4
Abu Thoura, Southern Sinai Peninsula , Egypt	Basalt	1.2 ± 0.2	1.5 ± 0.3	0.5
Mattala, southern Sinai Peninsula, Egypt	Basalt	1.5 ± 0.2	1.6 ± 0.4	0.65
Dahab, Southern Sinai Peninsula, Egypt	Basalt	1.7 ± 0.4	1.6 ± 0.3	0.6