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

Taha Rabeh¹, Gabriele Cataldi² and Valentino Straser³

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 ($\Delta H$) that is added to the main magnetic field. Also analysis of the Kp and the variations of geomagnetic background (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 $5 \geq$ 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 $5 \geq$. 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 3° 316’ N and 95° 854’ E (cf. Figure 3a). It caused an increase in $\Delta H$ 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 $\Delta H$ of about 40 nT at Kakioka geomagnetic observatory of about 281 km away (cf. Figure 3b). Figure 4a shows $\Delta H$ 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 $\Delta H$ 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 $\Delta H$ 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 $\Delta H$ 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 $5 \geq$ 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 $\Delta H$ 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 ($\Delta H$) 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
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 \( \geq 4.0 \) 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 $\Delta H$ 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 ($\Delta H$) 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
London and New York.

Karstländern gefühlten Erdbeben in den Jahren 1897 bis 1907, Mitteilungen
der Erdbeben-Kommission, Kaiserliche Akademie der Wissenschaften, Neue
Folge, No. XXXVI, pp. 1–23.

Conrad, V., (1932): Die zeitliche Folge der Erdbeben und bebenauslösende
1007–1185.

la variation seculaire du champ magnetique terrestre. C.R. Hebd. Seances


Erdbebensicherheit, Schweizerischer Ingenieur- und Architektenverein,
Dokumentation D0145, SIA Zürich.

relation to solar flux and the variations of the Earth’s magnetic field, Phys.

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


Figure Caption:

**Figure -1: Correlation between:**

**a)** Correlation between the mean average of annual earthquake frequency (nh) of \( 4 \geq \) 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 \( (5 \geq) \) 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 \((5 \geq)\) at Gulf of Suez and diurnal magnetic variations \( S_q \) from Misallat geomagnetic observatory along 1960 to 2000 period.

**b)** Correlation between the mean average of earthquakes \((5 \geq)\) at Gulf of Aqaba and Gulf of Suez and diurnal magnetic variations \( S_q \) 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 3 November, 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)

(b)
Figure: 2

(a)

(b)
Figure: 3

(b)

Figure: 4

(b)

(a)
Figure: 5
Figure: 6

Figure showing magnetic intensity MLT (nT) and magnetic intensity AMT (nT) over the years 1970 to 2000. Key points include:
- 22 April 1970 / M=5.1/Aqaba
- 23 January 1982 / M=4.5 to 4.8
- 30 May 1984 / M=4.8
- 2 July 1984 / M=5.1
- Red Sea
- N. Nasser Lake and Aswan - Salaraga Road
- 5 June 1988 / M=4.5/Red Sea
- 12 October 1992 / M=5.8/Cairo
- 22 November 1995 / M=7.1/Aqaba

Key events with magnetic intensity MLT (nT) and magnetic intensity AMT (nT):
- H-MLT
- H-AMT

Additional information:
- 3 and 5 January 1982 / M=4.5 to 4.8
- N. Naser Lake and Aswan - Safaga Road
Figure: 7

(a) Map of the region showing locations such as Red Sea, Nile River, dikes, gabbros, and basalt.

(b) Graphs showing magnetic changes (RM) plotted against stress, with various markers for different materials.

(c) Close-up graphs showing magnetic changes (Rm) plotted against stress.
Figure: 8

(a) Kp index

(b) Kp for the year 2009

- - - Kp - before removing the seismic periods

--- Kp - after removing the seismic periods

Kp - before removing the seismic periods
Kp - after removing the seismic periods
Figure: 9

Radio Emissions Project’s magnetometer data, Cecchina, Albano Laziale (RM), Italy.
Table: 1

<table>
<thead>
<tr>
<th>Items</th>
<th>Sq</th>
<th>nh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sq  Pearson Correlation</td>
<td>1</td>
<td>0.813</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>0.94</td>
</tr>
<tr>
<td>N (number of correlated points)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>nh  Pearson Correlation</td>
<td>0.813</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>N (number of correlated points)</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

Table: 2

<table>
<thead>
<tr>
<th>EARTHQUAKE</th>
<th>EPICENTER</th>
<th>OBSERVATORY</th>
<th>DISTANCE (KM)</th>
<th>ΔH (NT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LATITUDE</td>
<td>LONGITUDE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 NOV., ALASKA, 2002 (M_w = 7.9)</td>
<td>63°.51 N</td>
<td>147°.45 W</td>
<td>VICTORIA</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TEOLOYUCAN</td>
<td>6119</td>
</tr>
<tr>
<td>25 DEC. 2004, N. SUMATRA, INDONESIA</td>
<td>3°.31 N</td>
<td>95°.85 E</td>
<td>GUANGZHUO</td>
<td>2948</td>
</tr>
<tr>
<td>(M_w=9.1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 MARCH, N. SUMATRA, 2005 (M_w=8.7)</td>
<td>2°.07 N</td>
<td>97°.01 E</td>
<td>NOVOSIBIRSK</td>
<td>6067</td>
</tr>
<tr>
<td>15 NOVEMBER 2006, KURIL ISLANDS</td>
<td>46°.60 N</td>
<td>153°.23 E</td>
<td>MEMAMBERTSU</td>
<td>805</td>
</tr>
<tr>
<td>(M_w=8.3)</td>
<td></td>
<td></td>
<td>KAKIOKA</td>
<td>1574</td>
</tr>
<tr>
<td>12 JAN., 2010, HAITI, (M_w=7)</td>
<td>18°.44 N</td>
<td>72°.57 W</td>
<td>SAN JUAN</td>
<td>96</td>
</tr>
<tr>
<td>11 MARCH, 2011 EAST COAST OF HONSHU, JAPAN</td>
<td>38°.32 N</td>
<td>142°.36 E</td>
<td>KAKIOKA</td>
<td>281</td>
</tr>
</tbody>
</table>
### Table 3:

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