Rahman PIRIYEV[1,2]

[1] Baku State University, Baku, Azerbaijan
[2] SOCAR's Oil and Gas Research and Design Institute, Baku, Azerbaijan
tel.: +994505150685, +994775150685, e-mail: rahmanpiriyev@bsu.edu.az, rehman_piriyev@yahoo.com, https://orcid.org/0000-0002-1309-6692

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ELECTROMAGNETIC EARTHQUAKE PRECURSORY SIGNATURES IN THE ULF RANGE: PERSPECTIVES OF THE STUDIES

Interest in research on the detection of earthquake (EQ) precursors is growing year by year. In this direction, the paper analysed the results of earlier studies, as well as positive results of some studies conducted in the last 5 years. In particular, during the study of EQs, ultra-low frequency (ULF) precursors attract special attention. The study compared the results of electromagnetic (EM) monitoring studies conducted in the ULF range in earlier years and the results of EM monitoring studies conducted in the last 5 years have been compared. The positive results of the researchers investigating the changes in the EM field before the EQ in the ULF range were reviewed. Thus, ULF anomalies from relatively weak (with 4<Mw<5) and shallow (with a depth of less than 50 km) EQs were repeatedly observed in 2017 in Indonesia. Before strong EQs, ULF promising EQ precursors were revealed. High ULF amplitude anomalies were recorded before the 2011 Tohoku megaEQ. Anomalous changes of the Earth's induction vector were identified in 6 observatories in Japan. Similar anomalies were also recorded in the ULF range (0.001-0.083 Hz) by the Teoloyucan (Mexico) and Tucson (the United States) geomagnetic observatories from August 1 to September 16, 2017, before the Chiapas EQ in Mexico with a magnitude 8.1. On the whole, the research discovered several dozen EM precursors of EQs with different amplitude, spectral and time parameters. The study was based on the analysis of numerous data for the periods 1976–2010 and 2007–2016 conducted by various researchers. In addition, an original approach is proposed. It consists in the study of geoelectric field changes (ULF precursors of EQs) as they are more sensitive. Processing and interpreting these changes can lead to precise detection of EQ precursors. Thus, this makes it possible to identify geodynamic active zones in which an EQ may occur.

Key words: EQ, precursors, ULF, EM, admittance, LF.

Introduction

In modern times, the preparation period of EQs consists of seismic (i.e. tectonic and elastic) as well as EM field changes [Hayakawa, & Fujinawa, 1994; Hayakawa, 1997, 1999]. The problem of EQ prediction is always an actual issue and is one of the long-term problems for Earth Sciences. The consequences of strong EQs are known to everyone. If a short-term EQ prediction was possible, the consequences of EQs could be minimized. In case we knew the time of their occurrence, we would take the necessary measures. Unlike traditional measurement of Earth's crust movements, EM monitoring emerged as a new field of Earth Sciences and numerous findings were achieved in the study of EM EQ precursors during the last 20 years. Findings were presented in the studies by Hayakawa [Hayakawa, 2012, 2013, 2015] and other scientists.

Historical review

The study of EM EQ precursors attracted special attention in the ULF and low frequency (LF) range, because the most promising results were achieved in these ranges [Piriyev, 2018 a,b; 2021]. An example of this is the study of 3 historical scientific discoveries: Spitak EQ [Kopytenko, et al., 1993], 1989 EQ of Loma Prieta [Fraser-Smith, et al., 1990] and 1993 Guam EQ [Hayakawa, et al., 1996].

A few days before the Loma Prieta EQ in 1989 Antony Fraser-Smith, an electrical engineer at Stanford University's Space, Telecommunications and Radioscience (STAR) Laboratory, discovered high radio signals in the ULF range [Fraser-Smith et al., 1990]. Subsequently, at the scientific meeting of the American Geophysical Union in San Francisco, scientists from 5 different countries presented data supporting a connection between ULF radio signals and EQs above magnitude 5.0.

Yuri Kopytenko and other scientists [Kopytenko, et al., 2001] focused mainly on ULF EM waves in their research works, because the ULF range (0.005–10 Hz) is the most promising wave range, in which EM EQ precursors can be detected. The probability of EQ signature manifestation seems to be higher in the ULF range than in the other ranges. That is why the researchers focused on the study of ULF emissions. Based on their research, they came to the conclusion that ULF EM precursors exist. Besides, the development of appropriate observation tools and analysis methods is important in the study of EQ precursors.

Masashi Hayakawa [Hayakawa, 2016] even set up the ULF network in the Kanto (Tokyo) region as shown in Fig. 1 during the years of 1996–2011, taking into account the possibility of using ULF radiation in the prediction of EQs, in addition to monitoring the perturbation in the ionosphere (see Fig. 1). In world experience there was also SAO ULF station equipped with 3-component magnetic field induction coils (0.0001-20 Hz) which was manufactured by EMs Instruments, Inc. (EMI), Richmond, CA, USA [Karakelian, et al., 2002] and ULF Radio Monitoring Network (AeroSolSys) in Vrancea (Curvature Carpathian Mountains) [Toader, et al., 2017].

The DEMETER (Detection of EM emission transmitted from EQ regions) was used to investigate ionospheric perturbations that might be associated with seismic activity. The DEMETER is a micro-satellite built by the Centre National d'Etudies Spatiales (CNES) of France. It was launched on 29 June 2004 and is controlled from Toulouse in France. The first research that showed examples was published in 2006 [Parrot et al., 2006; Mofiz and Battiston, 2009]. With the DEMETER satellite data, many EM pre-earthquake perturbations are found (see Table 1). Xiong et al. [2020] in a letter published in *remote sensing* show many cases of ionospheric perturbations observed on occasion of large seismic events recorded by the low-altitude satellite DEMETER. They explored 16 spot-checking classification algorithms, including the top classifier with low-frequency power spectra of EM fields. It was used for ionospheric perturbation analysis and involved the analysis of satellite continuous data spanning about six and a half years. According to the USGS catalogue (http://neic.usgs.gov/), about 8760 EQs with magnitude greater than or equal to 5.0 and depths less than or equal to 40 km occurred all over the world from January 2005 to December 2010. Investigation of the EQ databases confirmed that some low-frequency electric and magnetic fields' frequency bands were the dominant features for EM pre-earthquake perturbations identification. The results of a number of studies confirm that the DEMETER ionospheric perturbations are useful and sensitive for detecting anomalies related to EQs [Xiong, et al., 2020] (see Table 1).

Recent studies

Indonesian scientists Armansyah and Suadi Ahadi observed ULF geomagnetic data a few days before the EQ occurred in 2017 in Jayapura Regency, one of the Regencies of Papua Province, Indonesia, with the epicentral distance and depth of less than 50 km. The magnitude of the investigated EQ was 4<Mw<5. At the end of the research, interesting results of data processing and analysis were obtained. Thus, there was a high correlation between EQ magnitude and ULF amplitude anomalies. This correlation suggested that there was a possibility of estimating the magnitude of an EQ that is going to occur [Armansyah, & Ahadi, 2017] (see Table 2).

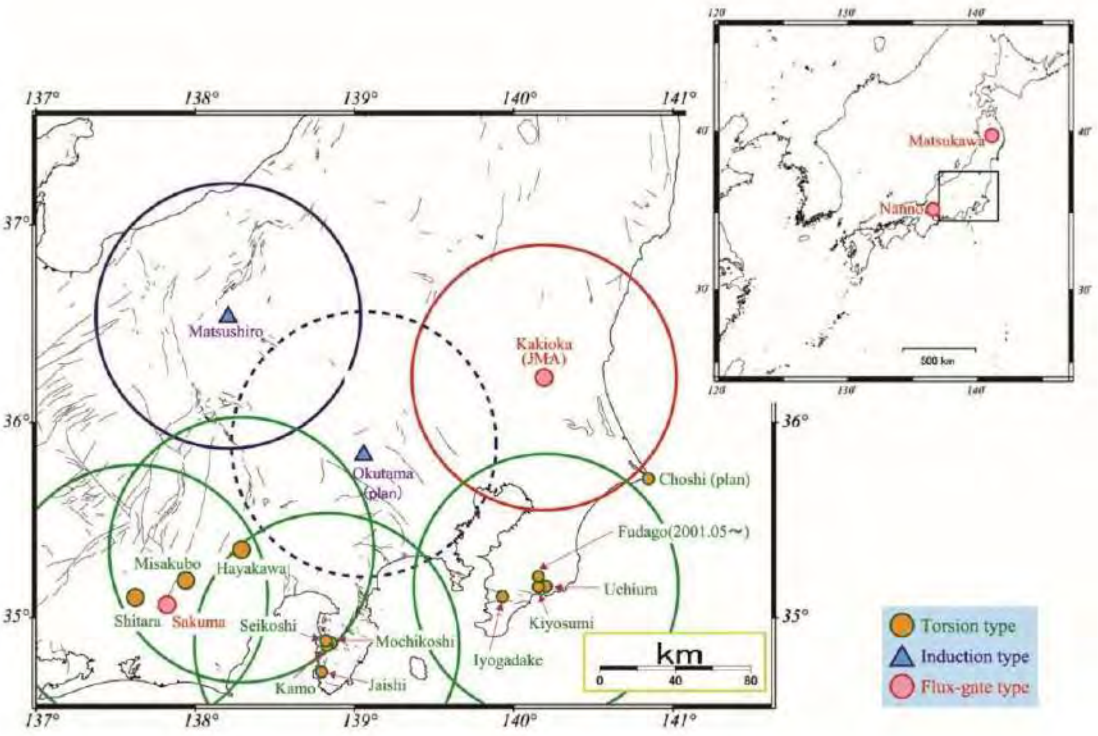

Fig. 1. KANTO-TOKAI ULF observation network (RIKEN-NASDA) [Hayakawa, 2016, see Fig. 8].

Table 1

Pre-earthquake DEMETER ionospheric perturbations

#	EQ	Date	M	EM pre-earthquake processes	Researcher
1.	Jawa region (Indonesia)	17.07.2006	7.7	The emissions have been observed in ULF/ELF range of electromagnetic spectra before a series of Indonesian EQs	Bhattacharya, et al. [2009]
2	The Kii island	–	7.3	Ionospheric perturbations before the EQ	Parrot, et al. [2006]
3	Wenchuan (China)	12.05.2008	8.0	Ion density reached its lowest values 3 days before the EQ and decreased suddenly on the day of the EQ	Zhang, et al. [2009b]
4	Wenchuan (China)	12.05.2008	8.0	Plasma turbulence over the area of EQs 4 to 7 days before the EQ	Bleçki, et al. [2010]
5	Wenchuan (China)	12.05.2008	8.0	Plasma turbulence over the area of EQs together with electric field perturbations 4 to 7 days before the EQ	Sarkar, & Gwal [2010]
6	Wenchuan (China)	12.05.2008	8.0	Anomalies began to appear in the equatorial ionosphere about a month before the EQ and reached to the top 8 days before the main EQ	Ryu, et al. [2014]
7	Wenchuan (China)	12.05.2008	8.0	The electron and ion density at night-time, and ion temperature at daytime dramatically declined and increased, respectively 1-6 days before the EQ.	Liu, et al. [2015]
8	Sichuan (China)	12.05.2008	7.9	A probable increase in the ULF wave power near the epicentre of the EQ	Walker, et al. [2013]
9	CHILE	27.02.2010	8.8	A large increase in the plasma density before the EQ	Pisa, et al. [2011]
10	CHILE	14.11.2007	7.9	LF EM disturbances started to rise on a large scale of latitudes and attained the highest after one week before the EQ	Zhang, et al. [2009a]
11	CHILE	27.02.2010	8.8	Anomalous enhancement of Ti, Ni, and Ne exists particularly around the epicentre area	Ho, et al. [2013 a,b]
12	CHILE	27.02.2010	8.8	Anomalous changes in the computed ULF electric component along the direction of the Z-axis were obviously detected on the 1st, 11th, and 17th days before the EQ	Louerguioui, et al., [2014]
13	Pu'er (Chine)	02.06.2007	6.3	Ion-acoustic soliton formation in the ionospheric perturbations before the EQ	Mofiz, & Battiston [2009]
14	L'Aquila (Italy)	06.04.2009	6.3	Anomalous signal observed on both the electric and magnetic field data 2 days before the EQ	Bertello, et al. [2018]
15	HAITI	12.01.2010	7.0	Energy of ULF waves significantly increased for a period of one month before the EQ	Athanasiou, et al. [2011]

Igor Rokityanski, Valeria Babak and Artyem Teresh, the scientists of the Subbutin Geophysics Institute of the National Academy of Sciences of Ukraine studied changes in the internal EM field of the Earth while trying to detect the pre-earthquake precursory signals. Data from 19 geomagnetic observatories of Japan were analysed during 20 years. In 2008–2010, anomalous changes of the Earth's induction vector were identified in 6 observatories before 2011 Tohoku megaEO [Rokityanski, et al., 2019] (see Table 2).

Dragoş Armand Stanica and Dumitru Stanica, the scientists from the Institute of Geodynamics of the Romanian Academy, studied a 8.1 magnitude EQ on the shores of Chiapas in Mexico from 1 August to 16 September 2017. They analysed the data collected in the Teoloyucan (Mexico) and Tucson (United States) geomagnetic observatories. Daily mean distributions and standard deviation of geomagnetic polarization parameters for both observatories were obtained using a fast Fourier transform (FFT) band pass filtering in the ULF range (0.001–0.083 Hz). Finally, data obtained from the interval between 7–9 September 2017 showed an anomalous signal 5 hours before the EQ [Stănică, D.A., & Stănică D., 2019] (see Table 2).

Swati and other scientists investigated the emission of ULF magnetic field that was followed by 3 powerful EQs in the Indian peninsula. They obtained data from 3 component magnetometers installed at

Indian stations Agra, Shillong and Kachchh. There were no reports of ULF precursors detected at Kachchh station, but 9-16 days before the occurrence of these EQs ULF bursts had periodic EM signals of 10–15 sec (Frequency=0.06 – 0.1 Hz). Thus, long-term analysis of ULF data for 2010–2017 showed that the occurrence of such bursts were accompanied by shallow-depth high-magnitude EQs, or multiple shallow-depth low-magnitude EQs [Swati, et al., 2020] (see Table 2).

Khairul Adib Yusuf and other researchers have improved the methods of processing possible EM signals in the data of the Earth's magnetic field to determine the interaction between the characteristics of various EQs and possible geomagnetic precursors. They used data from 10 magnetometer stations to detect and determine the source direction of 34 EQs in South-West Asia, East Asia and South America between 2007–2016. As a result, 20 possible precursory sources of the EQ have been identified. Overall, it was concluded that while the area of the study was restricted due to the location, the EQ characteristics could correlate with several characteristics of possible precursors [Yusof, et al., 2021] (see Table 2).

The researchers from the Indonesian Institute of Science, Febriani et al. (2020), analysed the three components of geomagnetic data observed from January to February 2018. They aimed to investigate the ULF geomagnetic anomalies related to the Lebak EQ which occurred on 23 January 2018 in the Lebak regency, Banten Province, Indonesia. The EQ caused some losses and casualties. The magnitude was 6.1 and the depth of the EQ was 46 km. Epicentre distance was about 113.99 km. In their study, Febriani, et al. (2020) investigated the energy of the ULF geomagnetic signal at the frequency around 0.02 Hz by applying spectral density ratio based on Fast Fourier Transform (FFT). The result showed that the geomagnetic energy increased about two weeks prior to EQ. When the anomalous geomagnetic energy increased, there were no global geomagnetic activities. Overall, the research suggested that the geomagnetic anomalies like that possibly related to the occurrence of the EQ [Febriani, et al., 2020] (see Table 2).

Table 3 shows comparative results of the above-mentioned studies and the results of the works done until 2015 (see Table 3). The comparison demonstrated that the ULF EQ precursors show themselves most frequently in the period from a few hours to a few months before the EQs. But unfortunately, despite the fact that these precursors playan effective role in studying geodynamic processes, it is currently impossible to say exactly when and where any EQs will occur in the future, and how strong they will be.

Table 2

Parameters of EQs (recent studies)

#	EQ	Magnitude	Date	Depth (km)	Frequency range	Method	Precursory moment	Researchers
	Jayapura Regency (Indonesia)	4.5	2017	<50	ULF geomagnetic	Data processing and analysis polarization power ratio (Z/H) method	A few days before the EQ	Armansyah, & Ahadi, S., 2017
2	Tohoku (Japan)	9.0	11.03.2011	29	ULF geomagnetic	Geomagnetic observation	Geomagnetic anomalous changes over years	Rokityansky, et al., 2019
3	Chiapas (Mexico)	8.1	08.09.2017	72	ULF geomagnetic	Geomagnetic observation Fast Fourier transform (FFT) method	5 hours before the EQ	Stănică, D.A., & Stănică D., 2019
4	Three EQs in the Indian peninsula	–	2010–2017	–	ULF magnetic	long-term analysis of ULF data	9-16 days before the EQ	Swati, et al., 2020
5	Lebak, Banten (Indonesia)	6.1	23.01.2018	46	ULF geomagnetic	Fast Fourier Transform (FFT)	2 weeks before the EQ	Febriani, et al., 2020
6	South-West, East Asia and South America	–	2007–2016	–	geomagnetic	Data processing and analysis	20 possible precursory sources before the EQ	Yusof, et al., 2021

Table 3

Parameters of EQs (former studies)

#	EQ	Magnitude	Date	Depth (km)	Emission type and frequency range	Instrumentation and method	Precursory moment	Researchers
7	Hollister (California)	5.2	28.11.1974	11	ULF magnetic	Array of 7 proton magnetometers Visual observation	7 week before the EQ	Smith, & Johnson, 1976
8	Kyoto (Japan)	7.0	31.03.1980	250	LF electric	Electric antenna Visual observation	1/2 hour before the EQ	Gokhberg, et al, 1982
9	Spitak (Armenia)	6.8	07.12.1988	128	ELF-LF	3-axis magnetometers Visual observation and statistical analysis	4 hours before the EQ	Molchanov, et al., 1992
10	Loma Prieta (California)	7.1	17.10.1989	52	ULF ELF/VLF EM	Ground-based magnetometers Visual observation	3 hours before the EQ	Fraser-Smith, et al., 1990
11	GUAM	7.1	08.08.1993	65	ULF EM	3-axis ring-core-type fluxgate magnetometer Fractal analysis with FFT	1 month before the EQ	Hayakawa, et al., 1996 Smirnova, & Hayakawa, 2007
12	Chi Chi (Taiwan)	6.0	1994-1999	400	ULF magnetic	IPS-42ionosonde Visual observation and statistical analysis	1,3,4 days 3 signals before the EQ	Enescu, et al., 1999
13	Kozani-Grevena (Greece)	6.6	13.05.1995	75	ULF, and LF EM	Electric dipole antennas, magnetic loop antennas Spectrum analysis	3 hours before the EQ	Eftaxias, et al., 2007
14	Biak Island (Indonesia)	8.2	17.02.1996	20	ULF	3 ring-core-type fluxgate magnetometers polarization analysis, fractal analysis	1.5-1.0 months before the EQ	Hayakawa, et al., 2000
15	Athens (Greece)	6.6	07.09.1999	247	ULF, and LF EM	Electric dipole antennas, magnetic loop antennas Spectrum analysis	3 hours before the EQ	Eftaxias, et al., 2007
16	Izu Peninsula (Japan)	6.4	01.07.2000	80	ULF geomagnetic	3-axis ring-core-type fluxgate magnetometer Fractal analysis with FFT	1 month before the EQ	Smirnova, et al., 2004
17	Sumatra (Indonesia)	9.0	16.12.2004	750	ULF geomagnetic	3-axis ring-core-type fluxgate magnetometer Fractal density ratio analysis	1.5 month before the EQ	Saroso, et al., 2009
18	Sumatra (Indonesia)	8.7	28.03.2005	750	ULF geomagnetic	3-axis ring-core-type fluxgate magnetometer Fractal density ratio analysis	1.5 month before the EQ	Saroso, et al., 2009
19	L'Aquila (Italy)	6.3	06.04.2009	630	ULF geomagnetic	3-axis ring-core-type fluxgate magnetometer Spectrum analysis	2 hours before the EQ	Eftaxias, et al., 2010 Prattes, et al., 2011

There is no connection between the hypocentre of EQs and the moments when EQ precursors were observed in the studies done in 1976–2010. That is, for example, EQs occurred at different depths 3 hours after observing the EQ precursory moment. The instrumentation included different types of magnetometers. The study applied such methods as visual observations, statistical, spectral and fractal analysis which led to positive results.

In the last 5 years, the instrumentations and methods used in the studies were mainly a fluxgate magnetometer, 3-component search coil magnetometers, geomagnetic sensor (Magnetic Data Acquisition System), polarization power ratio Z/H, statistical analysis, fast Fourier transform band-pass filtering in the ULF range. Almost the same instrumentations and methods were used in the earlier and recent studies. But the focus was only on the study of the correlation between EQ precursors and the occurrence of an EQ. The efficiency of EM monitoring in the ULF range was shown in all the studies described in this article. In our opinion, these real-time monitoring methods should involve expanding the monitoring area and continuous monitoring with as many stations and equipment as possible. Moreover, the data obtained from the stations should be correctly interpreted and compared with data obtained from stations in other areas.

The studies mentioned above, especially the results of the last 5 years, show that ULF precursors take a special place in the issue of EQ prediction and can be considered to be the most promising precursors. Thus, the effectiveness of ULF EQ precursors demonstrates that the attempts in this direction, being the result of most research work, were not in vain.

The positive results obtained in the above-mentioned studies can be summarized as follows:

– Anomalous changes occurred in the EM field prior to EQs.

– Anomalous changes before the EQs were most often observed in the ULF range.

– Fluxgate magnetometer was the most frequently used tool, which demonstrated its reliability and accuracy.

– The analysis methods used to investigate and explain the anomalous changes observed before the EQs were successful.

However, Fabrizio Masci (National Institute of Geophysics and Volcanology, L'Aquila, Italy) and Jeremy Norman Thomas (NorthWest Research Associates, Redmond, Washington, USA) criticized a number of scientists, including Currie, J. L., and C. L.Waters [2014] and Han, P. et al. [2014] who, in their research tried to prove the existence of EM precursors [Masci, & Thomas, 2015].

Dıscussıon and conclusıon

Fabrizio Masci and Jeremy Norman Thomas [2015] in their article, published in *Journal of Geophysical Research: Space Physics,* discussed the state of the art in the search for ULF EQ precursors, reliability of the polarization ratio as indicator of precursors, and SEA analysis in the context of short-term EQ prediction. They suggested that noise and other sources, both natural and artificial, must first be excluded before any anomaly can be considered a valid EQ precursor. Therefore physical generation mechanisms must be identified, and the anomaly-earthquake relationship must be supported by experimental evidence. In their article they briefly discussed and reviewed the reports of Currie and Waters [2014] and Han et al. [2014] on ULF magnetic precursory signals. Fabrizio Masci and Jeremy Norman Thomas [2015] agreed with Currie and Waters [2014] that geomagnetic indices may not be satisfactory predicting signs of ULF activity. But, at the same time, the polarization ratio cannot be considered as a useful parameter to detect possible seismogenic signals independently of geomagnetic activity. In addition, the seismogenic origin of magnetic anomalies that are unrelated to geomagnetic indices must always be demonstrated, not just conjectured.

Fabrizio Masci and Jeremy Norman Thomas [2015] also discussed the statistical analysis by Han et al [2014]. In their opinion, Han et al. [2014] could not provide any evidence that may have supported a possible relationship between the mechanical energy released during the EQ and the EM energy of possible precursory signals, and also the Superposed Epoch Analysis reported by Han et al. [2014] did not show any ULF magnetic phenomenon for Japanese EQs that occurred during 2001–2010. Therefore, there was no evidence to support the ideas by Han et al. [2014] that could be used in the future to predict EQs.

Apart from these scientists, Levent Sevgi [2007] and Campbell, W. H. [2009] also took critical approaches to the results obtained in this field. But this type of criticism as we can see was made by a very small number of scientists. Most scientists presented the existence of EM precursors to EQs in different years (see Fig. 2, 3).

The problem of accurate prediction of EQs remains unsolved, as anomalous changes occur at different times before the EQs, but attempts have been made. Nevertheless, the effectiveness of EM monitoring in the study of EQs can be explained by the fact that anomalous changes are observed in the EM field before the majority of EQs occur. As a result, if we consider the variety of the research diapason, then the most promising frequency range among them is the ULF range. So, unlike other frequency ranges, precursors in this range can be detected in all cases before EQs (see Fig. 2). In addition, as can be seen from Fig. 2 (no matter it illustrates some EQs), the ULF-precursors can be detected prior to all EQs with a magnitude above 5 (see Figs. 2, 3). Therefore, the use of ULF precursors can be considered for medium- and short-term prediction. Investigations in this direction should be improved in the future in order to get an accurate prediction.

Of course, the processes occurring in the lithosphere are very complex. So, a lot of attempts and a much better approach are needed to solve the EQ prediction problem. We already know that such mechanisms as resistivity changes in response to stress or strain, and stress demagnetization were proven in the laboratory and observed in the field. Thus, experiments designed to detect these precursory changes have a solid basis in laboratory data. However, it is necessary to conduct further laboratory measurements of these changes at stress and temperature conditions found in the Earth. Solid-state mechanisms may also be capable of generating electrical precursors, because the electricfield better reflects the slightest changes than

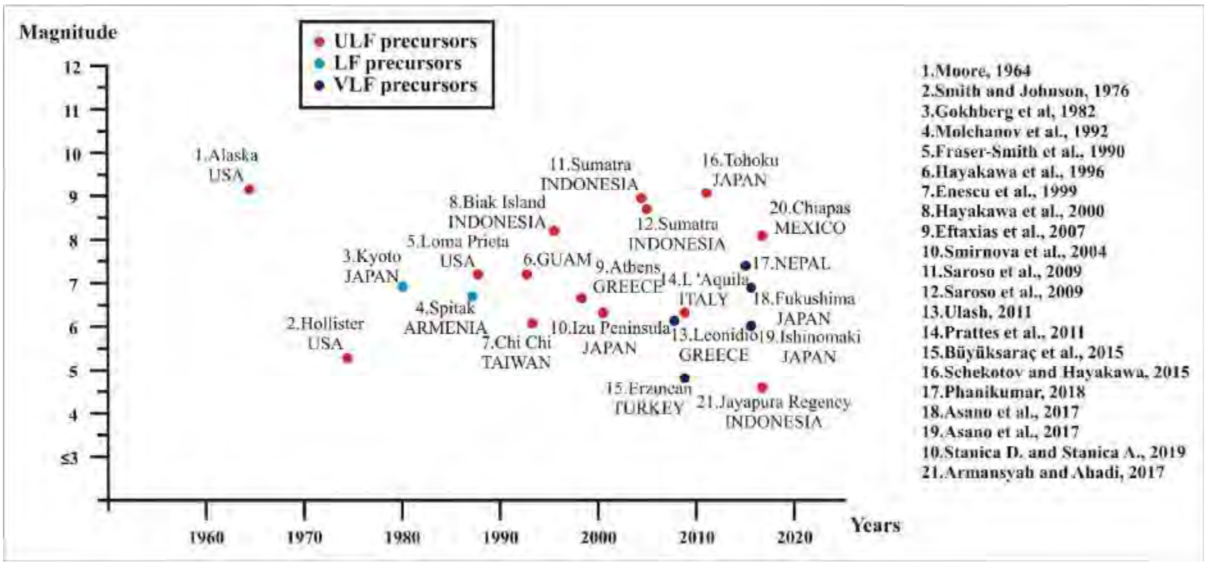

Fig. 2. EM precursors prior to EQs occured in different years.

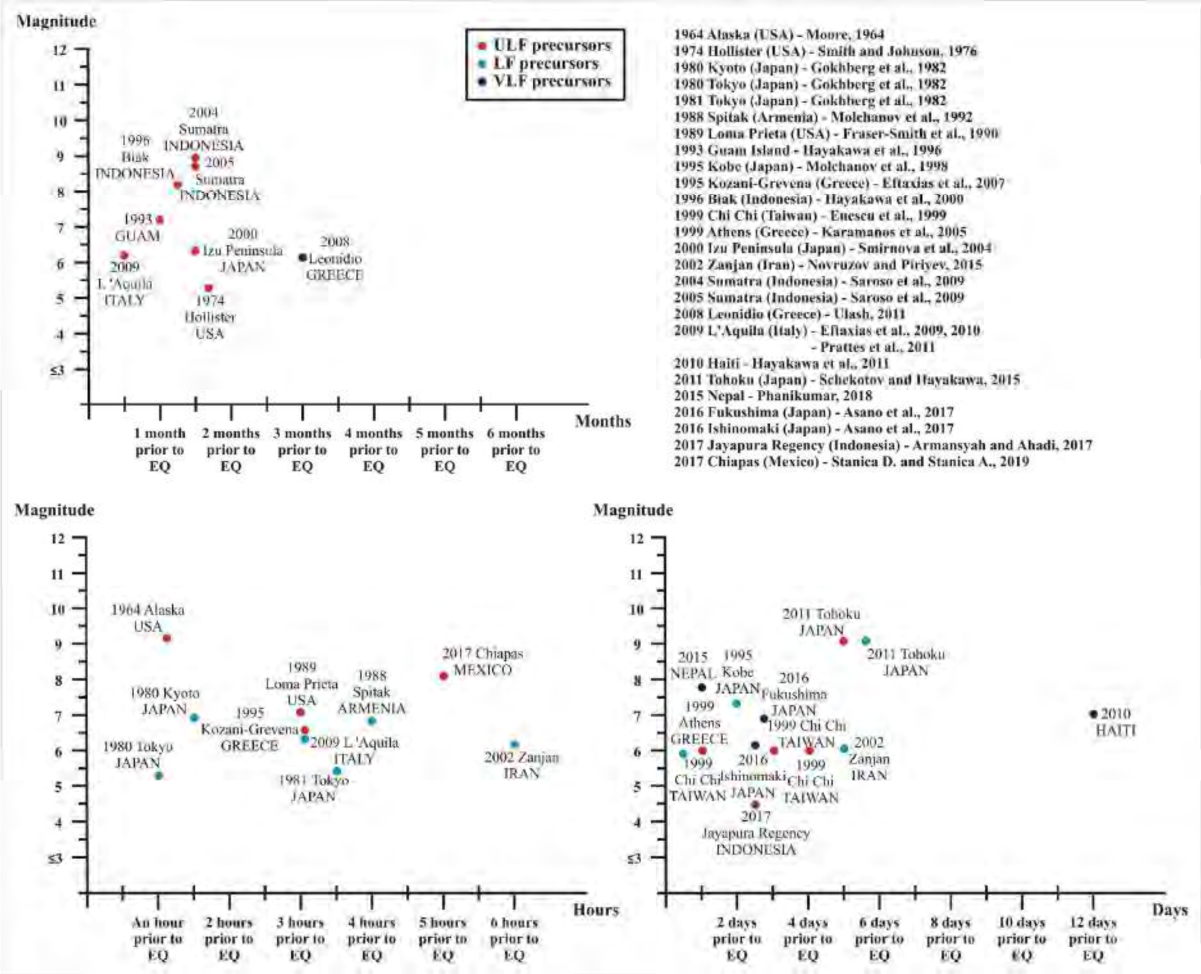

Fig. 3. EM precursory times prior to different EQs.

the magnetic field. But these first need to be observed in rocks with realistic crustal conductivities. So, I suggest an admittance approach that is a promising mechanism for explaining a variety of electric and magnetic field changes and is the generation of streaming potentials by fluid flow. The correct data processing and interpretation of these changes can lead to the detection of EQ precursors. Thus, we will be able to identify geodynamic active zones in which an EQ may occur. If attempts are made in this direction, perhaps much more successful results can be achieved. This method was first used by Azeri

Geophysicists in 2002 and some interesting results were obtained. During the research in Fatmayi geodynamic polygon in the Absheron Peninsula, a strong EQ (M=5.5–6.7) occurred in Zanjan (Iran). A number of attempts were made to predict EQs, as a result of recording 5-component variation of electric and magnetic field, and data processing. The calculation of the phase difference between magnetic components was one of the criteria for predicting EQs in the time interval of 6–106 hours [Novruzov, & Piriyev, 2015].

Overall, with the continuation of research aimed at detecting EQ precursors, it would be possible to get at least one step closer to an accurate prediction in the ULF range, having received successful promising results.

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Рахман ПІРІЄВ

Бакинський державний університет, Науково-дослідний Проектний Інститут Нафти і Газу, Баку, Азербайджанська Республіка, ел. пошта: rahmanpiriyev@bsu.edu.az

ЕЛЕКТРОМАГНІТНІ ПРОВІСНИКИ ЗЕМЛЕТРУСІВ В ДІАПАЗОНІ УНЧ І НЧ: ПЕРСПЕКТИВИ ДОСЛІДЖЕНЬ

Інтерес до досліджень з виявлення провісників землетрусів зростає з кожним роком. В цьому напрямку були виділені результати попередніх досліджень, а потім позитивні результати деяких досліджень, проведених за останні 5 років. Зокрема, при вивченні землетрусів особливу увагу привертають провісники в діапазоні УНЧ. Здійснено порівняння результатів електромагнітних моніторингових досліджень, проведених у діапазоні ULF у попередні роки, і результатів електромагнітних моніторингових досліджень за останні 5 років. Були розглянуті позитивні результати дослідників, які вивчають зміни електромагнітного поля перед землетрусом в діапазоні УНЧ. Наприклад, УНЧ аномалії від відносно слабких (з $4<MW<5$) і неглибоких (з глибиною менше 50 км) землетрусів неодноразово спостерігалися в 2017 році в Індонезії. Перед сильними землетрусами виявлені багатообіцяючі УНЧ-провісники землетрусів. Високоамплітудні УНЧ аномалії зафіксовані перед мегаземлетрусом Тохоку в 2011 році, аномальні зміни вектора індукції Землі виявлені на 6-ти обсерваторіях в Японії. Аналогічні аномалії також зафіксовані в діапазоні УНЧ (0,001–0,083 Гц) геомагнітними обсерваторіями Теолойкана і Тусона в США з 1 серпня по 16 вересня 2017 року, до землетрусу в Чьяпасе в Мексиці магнітудою 8,1. Загалом за результатами аналізу численних даних за періоди 1976-2010 і 2007–2016 рр. різними дослідниками виявлено кілька десятків електромагнітних провісників землетрусів з різними амплітудними, спектральними та часовими параметрами. В результаті проведеного аналізу пропонується новий підхід до пошуків електромагнітних провісників землетрусів. Він полягає у вивченні змін геоелектричних полів (потенційних інфранизькочастотних провісників землетрусів) як більш чутливих. Обробка та інтерпретація цих змін може привести до виділення саме провісників землетрусів. Таким чином, ми також зможемо визначити геодинамічні активні зони, в яких можуть статися землетруси.

Ключові слова: землетрус, провісник, аномальні ультранизькочастотні (УНЧ) сигнали, електромагнітне випромінювання, повна провідність.

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