УДК 550.343.09
DOI: http://doi.org/10.17721/1728-2713.96.06

R. Piriyev,
E-mail: rahmanpiriyev@bsu.edu.az,
Baku State University, Baku, Azerbaijan

REVIEW OF ELECTROMAGNETIC MONITORING STUDIES IN PREDICTING EARTHQUAKES: RECENT RESULTS AND NEW PERSPECTIVES

(Представлено членом редакційної колегії д-ром геол. наук, проф. М.І. Орлюком)

In order to make comparisons and find new perspectives in terms of electromagnetic phenomena in earthquake prediction, ULF range was chosen. For comparison, tables consisting of the results of studies from previous years and the last 10 years have been compiled. In order to find new perspectives, the graphs were drawn and comparative analysis was carried out on the basis of these results. It was concluded that the ULF precursors can be found before earthquakes reaching up to 30km in depth, and it can be considered a promising effective range in detecting precursors of earthquakes. In addition, due to the connection between the epicenter distances and the depths of the earthquakes and their magnitudes, attempts to detect the precursors have been made so that the epicenter of the earthquakes is ±100km. The article also provides information about ULF networks and about researchers who had critical opinions on electromagnetic phenomena associated with earthquakes.

Keywords: ULF, earthquake, prediction, electromagnetic, precursor.

Intoduction. Earthquake prediction is the human effort to predict the time which is called precursor time, the location where it can occur, and the magnitude, that's how strong an earthquake could be. It is one of the most important problems of modern geophysics (*Hayakawa, 2015*). The problem of prediction is still far from being solved (*Schekotov et al., 2021*). Depending on timescale earthquake prediction can be classified into 3 groups: long-term, medium-term and short-term prediction (Fig. 1). Using an earthquake catalogue it is possible to evaluate the long-term and medium-term occurrence probability of a large earthquake in a certain area during a prescribed period and should not be considered as real predictions. But short-term prediction is the only useful and meaningful form for protecting human lives and social infrastructures. Short-term prediction absolutely requires study of earthquake precursors (*Hayakawa, 2018*). Earthquake precursor data can include geodetic signals such as tilt, GPS (Global Positioning System) data, hydrological data, electromagnetic fluctuations in various frequencies, emission of radon and other ionized gases, and anomalous animal behavior (*Rikitake, 2001*) (Fig. 2). Among these precursor data electromagnetic data take a special place (Fig. 3).

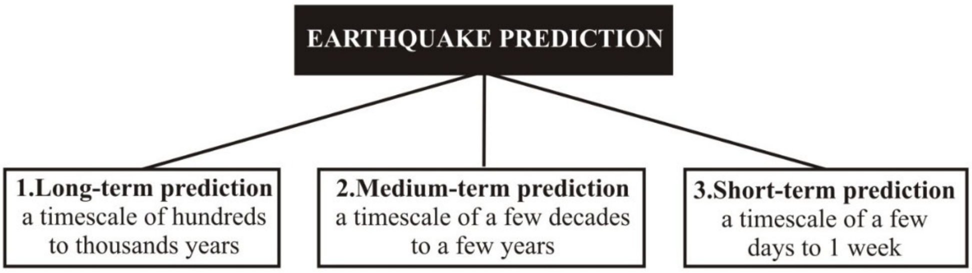

Fig.1. Classification of earthquake prediction (*Hayakawa, 2018*)

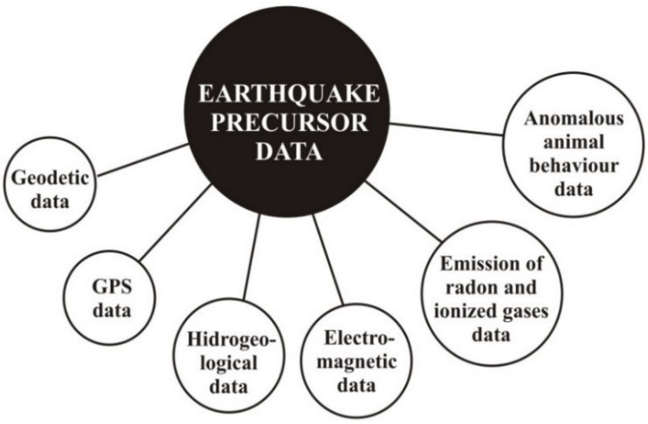

Fig. 2. Classification of earthquake precursor data (*Rikitake, 2001*)

If we take a look at the past, the unique case of the successful earthquake prediction was Haicheng (M=7.3, EQ in China) prediction. The earthquake occurred on February 4, 1975, in the north-east part of China. Scientists were able to predict it. After 1965, activation of seismicity occurred in an area of 120km to SSW from Beijing with several destructive earthquakes with M>6. After this long-term prediction, Chinese government greatly strengthened earthquake study and precursor monitoring attaching to observation experts and also amateurs and scholars. Many middle-term precursors were observed in 1973 and 1974 in a large area of 200x300 km which in December 1974 – January 1975 concentrated in a smaller area. In January 1975, quiescence of seismicity was observed but anomalies of groundwater, telluric currents, radon, tilt, animal behavior, etc. which considered short-term precursors increased till January 23, then slightly decreased, and since February 1 rose in hundreds times. From February 3 to February 4 about 500 earthquakes with magnitude up to 4.2 as foreshocks of strong earthquake. Thousands of buildings collapsed, but hundred thousand lives have been saved by the well-timed prediction (*Rokityansky et al., 2019*).

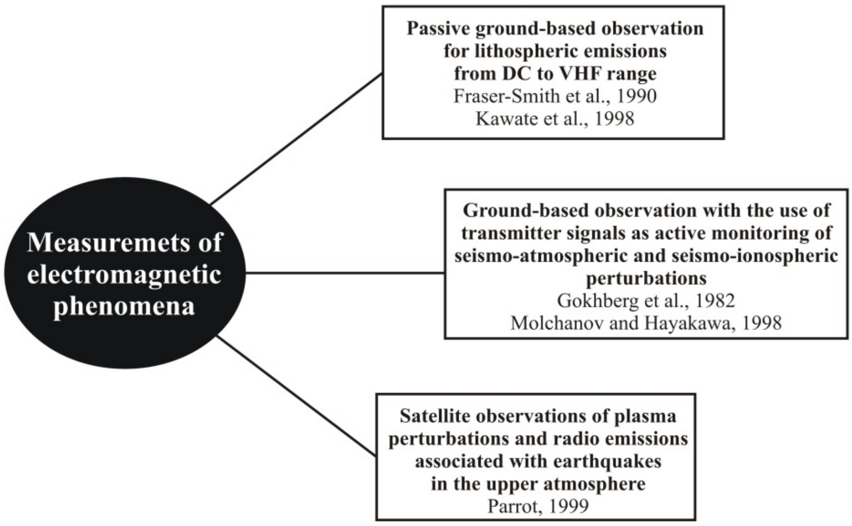

Fig. 3. Classification of measurements of electromagnetic phenomena (*Hattori, 2004*)

The ULF band is of particular interest because only EM signals in the ULF range and at lower frequencies can be easily recorded at the Earth's surface without significant attenuation compared with "high" frequency bands because most of the epicenter depths are at more than 10km, even several hundreds of kilometers, beneath the Earth's surface (*Li et al., 2013*). ULF geomagnetic change is one of the most promising phenomena and it suggests that short-term prediction of earthquakes is realizable. Similar electromagnetic phenomena are associated with volcanic activity. Since source regions are well known for their volcanic activity, observation is easier than in seismic cases. Electromagnetic phenomena associated with volcanic activities have been summarized in the works of Johnston (1997) and Zlotnicki (2003) (*Hattori, 2004*).

Material and methods. The aim of this article is to review ULF electromagnetic phenomena associated with earthquakes, and try to make comparisons and find perspectives. Numerous researches conducted in connection with the study of earthquakes have shown that electromagnetic monitoring studies have led to some important results (*Novruzov and Piriyev, 2015; Piriyev, 2021*). The ULF range can be considered the ideal range for detecting earthquake precursors. This can be easily seen in Table 1.

The emergence of ULF precursors at different times causes scientists not to make accurate prediction. My main goal in describing the graph in Fig. 4, and in Fig. 5 is to see it more clearly. ULF precursors have been detected at different times before the earthquakes of different years since 1964. If we look at the graphs, the ULF precursors appeared before all earthquakes above 5 and at a depth of up to 30km. In addition, the distance between the epicenter of earthquakes and observation points reaches 800km. From here it can be concluded that there is a connection between the epicentral distance and the magnitude. Thus, it is possible to mark earthquakes with a magnitude above 5.0 at a higher epicenter distance. ULF precursors are found more frequently than other ranges at the same time. Most of the earthquakes since 1964 have been recorded in the ULF range. There are also special cases in ULF precursors. For example, ULF precursors appeared three times before the Loma Prieta earthquake. The magnetometer was located only 7km from the epicenter and recorded increased ULF noise reaching 1.5 nT in amplitude during the month before, two weeks before, and a few hours before the earthquake (*Johnston, 1997*). No matter how hard it was to find new perspectives in term of electromagnetic phenomena, I have collected ULF precursory signatures before earthquakes in Fig. 4 and tried to make comparisons with ULF precursors and different frequency ranges, I proposed the graph shown in Fig. 5. As it can easily be seen from the graph, ULF precursors cover many places with respect to LF and VLF precursors. That means that ULF electromagnetic precursors may be associated with all earthquakes with magnitude above 5.0. The only difficult thing is that those precursors appear in different times prior to earthquakes. In Fig. 4 we can easily find the correlation between the magnitudes of earthquakes and their epicentral distances and depths. As the magnitude grows, the epicentral distance grows respectively. The ideal observation distance is ±100km from the epicenter. The other interesting fact is that ULF precursors can be detected by at least 1 observatory station (if there is more than one) prior to all earthquakes with the depth up to 30 km.

There are also ULF networks in different regions for the detection of ULF precursors in order to try to predict earthquakes. ULF networks are known to be installed in the Kanto area in Japan in order to be able to predict any earthquakes with M≥6 (*Hayakawa and Hattori, 2004*), in the Kamchatka area (*Uyeda et al., 2002*), in Taiwan (*Hattori et al., 2002*), in Greece (*Makris et al., 2003*), etc.

There have been published few papers criticizing above mentioned precursors in different years. e.g. the validity of the reported 1989 M7.1 Loma Prieta precursor had been questioned by Thomas et al. (2009) and Campbell (2009), the subject of magnetic precursors remained controversial by Sevgi (2007), Masci and Thomas (2015). But they are very few in contrast with papers which presented electromagnetic precursors of earthquakes since 1964 till now.

Table 1

ULF electromagnetic precursors for different earthquakes

Earthquakes	Date	Magni-tude	Depth	Epicentral distance	Observation station	Frequency range	Precursory time	Inten-sity
Spitak (Molchanov et al., 1992)	07.12.1988	6.9	6 km	128 km	Dusheti (Georgia)	0.0005-5 Hz	4 hours before EQ	0.2 nT
Loma Prieta (Fraser-Smith et al., 1990)	17.10.1989	7.1	15 km	7 km	Corralitos (USA)	0.01-10 Hz	3 hours before EQ	5 nT
Guam (Hayakawa et al., 1996)	08.08.1993	7.7	60 km	67 km	USGS staff GUAM	0.02-0.05 Hz	10 days-2 weeks and a few days before EQ	0.1 nT
Biak (Hayakawa et al., 2000)	17.02.1996	8.2	20 km	1200 km	Biak and Darwin (Australia)	5 mHz-30 mHz	1.5-1.0 months before EQ	0.2-0.3 nT
Chi Chi (Akinaga et al., 2001)	21.09.1999	7.6	11 km	120 km	Lunping	0.01 Hz	2.0 months before EQ	-
Sumatra-Andaman (Saroso et al., 2009)	26.12.2004	9.1	30 km	750 km	Kototabang (Indonesia)	-	1.5 month before the EQ	-
Sumatra-Nias (Saroso et al., 2009)	28.03.2005	8.6	30 km	750 km	Kototabang (Indonesia)	-	1.5 month be-fore the EQ	-
L'Aquila (Prattes et al., 2011)	06.04.2009	6.3	8.8 km	630 km	L'Aquila (Italy)	10-15 mHz	2 weeks before the EQ	-
Sichuan (Li et al., 2015)	12.05.2008	7.9	19 km	80 km	Chengdu (China)	10-20 mHz	A few days before EQ	-
Tohoku (Ohta et al., 2013)	11.03.2011	9.1	29 km	30 km	- (Japan)	01-24 Hz	5 days before EQ	-

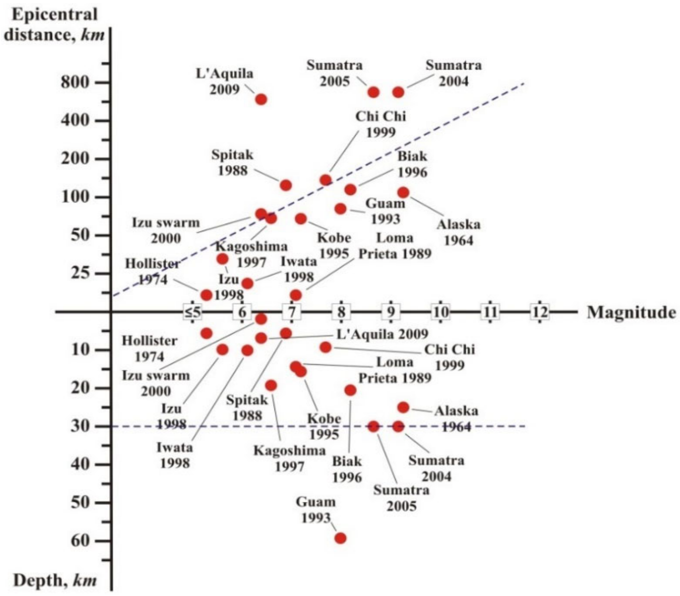

Fig. 4. ULF precursory signatures before earthquakes

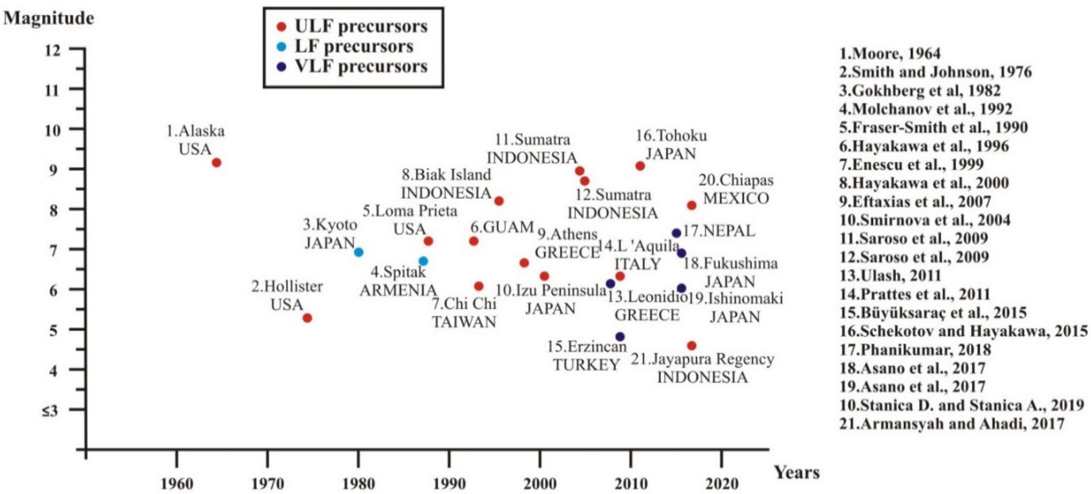

Fig. 5. ULF, LF, and VLF precursors of earthquakes

Recent results.

The study by Schekotov et al. (2021). To solve earthquake prediction problem, we need to be able to estimate its magnitude, time, and position of an upcoming event (*Uyeda, 2013*). This year Schekotov et al. (2021) tried to solve one task – to find the epicenter position of upcoming earthquakes. They used a method for predicting of the epicenter location region of Kamchatka and Commander earthquakes. This method was based on the properties of the precursory atmospheric ULF/ELF (1-30 Hz) radiation and the spatial statistics of local earthquakes in relation to the Kuril-Kamchatka and Aleutian trenches. This statistics showed that more than 90% of events with M_L>5 occur in the gap ~ 150 km west of the Kuril-Kamchatka trench and north east of the Aleutian trench. Therefore, they obtained the approximate location of the epicenter by determining the position of the radiation source. Schekotov et al. (2021) supposed that it was caused by gas eruption from the heart of the earthquake to the trench and had the nearest location to the earthquake epicenter. The main drawbacks of the method were the dependence of its accuracy on the industrial interferences and the ambiguity of determining the epicenter location in the case of single-point registration of radiation when the main lobe of the azimuthal distribution of radiation crosses both trenches (*Schekotov et al., 2021*).

The study by Potirakis et al. (2019). There is another attempt by the scientists from Greece, Russia and Japan to use ULF magnetic field data from space weather monitoring magnetometer array in the study of earthquake precursors in Greece in 2019. They had analyzed the data from 4 stations of the Hell*ENI*c GeoMagnetic Array (ENIGMA) in the search for possible precursors to a strong earthquake that occurred south of Lesvos island on 12 June 2017. The magnitude of the earthquake was 6.3 and focal depth was 12 km. Potirakis et al. (2019) used the analysis which included conventional statistical methods, as well as criticality analysis, using NT-natural time method and MCF-the method of critical fluctuations. From conventional statistical methods, it was found by the scientists that the most convincing ULF precursors were observed in the data of ULF (20-30 mHz) depression of the horizontal component of the magnetic field. It was indicative of lower ionospheric perturbation just 1 day before the earthquake. Therefore, there were indications of a precursor in the direct ULF emission from the lithosphere 4 days to 1 day before the EQ. Their further study in terms of NT analysis identified criticality characteristics from 8 to 2 days before the earthquake both for lithospheric ULF emission and ULF depression. MCF revealed indications of criticality in all recorded magnetic field components, extending from 10 to 3 days before the earthquake. Potirakis et al. (2019) had also analyzed the recordings of the fracto-electromagnetic emission stations of the HELlenic Seismo-ElectroMagnetics Network (ELSEM-Net) in Greece. The MHZ recordings at the station that is located on Lesvos island presented criticality characteristics (NT and MCF) 11 days before the earthquake, while a few days later (7-6 days before the earthquake), the kHz recordings of the same station presented tricritical behavior. It was noted that the magnetosphere was quiet for a period of two weeks before the earthquake and including its occurrence (*Potirakis et al., 2019*).

The study by Schekotov et al. (2017). In April, 2016 a series of large earthquakes attacked the Kumamoto area of Kyusyu Island. The first two foreshocks had the magnitudes of 6.5 and 6.4, and about 1 day later there was the main shock on 15 April with magnitude 7.3 These were fault-type earthquakes, and Schekotov et al. (2017) would expect a variety of electromagnetic precursors to those earthquakes because they had detected different phenomena for the Kobe earthquake, the same fault-type earthquake. As for the lithospheric effect, the ULF data at Kanoya observatory which is about 150 km from the epicenter were used. Schekotov et al. (2017) used two – statistical and conventional analyses in order to provide with any evidence of ULF radiation. Only conventional analyses indicated clear signatures in the atmosphere as ULF/ELF impulsive emissions and also in the ionosphere as observed by means of VLF propagation anomalies and ULF depression. ULF/ELF radiation appeared on 8-11 April, while ULF depression took place on 8 and 10 April, so that both atmospheric radiation and ionospheric perturbation took place nearly during the same time period (*Schekotov et al., 2017*). The other recent works are shown in Table 2.

Table 2

Parameters of EQs

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, and Ahadi, S., 2017
Tohoku (Japan)	9.0	11.03.2011	29	ULF geomagnetic	Geomagnetic observation	Geomagnetic anomalous changes over years	Rokityansky et al., 2019
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., and Stănică D., 2019
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
Lebak, Banten (Indonesia)	6.1	23.01.2018	46	ULF geomagnetic	Fast Fourier Transform (FFT)	2 weeks before the EQ	Febriani et al., 2020
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

References

Akinaga, Y., Hayakawa, M., Liu, J.Y., Yumoto, K., Hattori, K. (2001). A precursory signature for Chi-Chi earthquake in Taiwan. *Natural Hazards and Earth System Sci.,* 1, 33-36.

Fraser-Smith, A., Bernardi, A., McGill, P. (1990). Low-frequency magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake. Geophysical Research Letters, 17, 9, 1465-1468.

Armansyah, Ahadi, S. (2017). Anomalous ULF signals and their possibility to estimate the earthquake magnitude. AIP Conference Proceedings 1857, 020006 (2017). https://doi.org/10.1063/1.4987048.

Campbell, W.H. (2009). Natural magnetic disturbance fields, not precursors, preceding the Loma Prieta earthquake. *J. Geophys. Res.*, 114, A05307. doi:10.1029/2008JA013932.

Febriani, F., Anggono, T., Syuhada, Prasetio, A.D., Dewi, C.N., Hak, A.S., Ahadi, S. (2020). Investigation of the ultra low frequency (ULF) geomagnetic anomalies prior to the Lebak. Banten earthquake (M=6.1; January 23, 2018). *International conference on trends in material science and inventive materials: ICTMIM 2020.* AIP Conference Proceedings 2256, 090002.

Fraser-Smith, A.C., Bernardi, A., McGill, P.R., Ladd, M.E., Helliwell, R.A., Villard, O.G. Jr. (1990). Low-frequency magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake. *Geophys. Res. Lett.,* 17, 1465, 1990.

Gokhberg, M.B., Morgounov, V.A., Yoshino, T., Tomizawa, I. (1982). Experimental measurement of electromagnetic emissions possibly related to earthquakes in Japan. J. *Geophys. Res.*, 87, 7824-7828.

Johnston, M. (1997). Review of electric and magnetic fields accompanying seismic and volcanic activity. *Survey in Geophys.*, 18, 441-475.

Kawate, R., Molchanov, O.A., Hayakawa, M. (1998). Ultra-low-frequency magnetic fields during the Guam earthquake of 8 August 1993 and their interpretation. *Phys. Earth Planet. Inter.*, 105, 229-238.

Hattori, K. (2004). ULF Geomagnetic Changes Associated with Large Earthquakes. *TAO*, 15, 3, 329-360, September 2004.

Hattori, K., Takahashi, I., Yoshino, C., Nagao, T., Liu, J.Y., Shieh, C.F. (2002). ULF Geomagnetic and Geopotential Measurement at Chia-Yi, Taiwan. *J. Atmos. Electr.*, 22, 217-222.

Hayakawa, M. (2015). Earthquake Prediction with Radio Techniques. John Wiley & Sons, Singapore.

Hayakawa, M. (2018). Pre-Earthquake Processes: A Multidisciplinary Approach to Earthquake Prediction Studies. Geophysical Monograph 234. Edited by D. Ouzounov, S. Pulinets, K.Hattori, P. Taylor. American Geophysical Union. John Wiley & Sons, Inc.

Hayakawa, M., Hattori, K. (2004). Ultra-low-frequency electromagnetic emissions associated with earthquakes. *Inst. Electr. Engrs. Japan, Trans. Fundamentals and Materials*, 124, 12, 1101–1108.

Hayakawa, M., Itoh, T., Hattori, K., Yumoto, K. (2000). ULF electromagnetic precursors for an earthquake at Biak, Indonesia on February 17, 1996. *Geophys. Res. Lett.*, 27, 1531-1534.

Hayakawa, M., Kawate, R., Molchanov, O.A., Yumoto, K. (1996). Results of ultra-low-frequency magnetic field measurements during the Guam earthquake of 8 August 1993. *Geophys. Res. Lett.*, 23, 241-244.

Li, M., Lu, J., Parrot, M., Tan, H., Chang, Y., Zhang, X., Wang, Y. (2013). Review of unprecedented ULF electromagnetic anomalous emissions possibly related to the Wenchuan MS = 8.0 earthquake, on 12 May 2008. *Nat. Hazards Earth Syst. Sci.,* 13, 279–286. Retrieved from www.nat-hazards-earth-syst-sci.net/13/279/2013/. doi:10.5194/nhess-13-279-2013.

Li, Q., Schekotov, A., Asano, T., Hayakawa, M. (2015). On the Anomalies in ULF Magnetic Field Variations Prior to the 2008 Sichuan Earthquake. *Open Journal of Earthquake Research*, 4, 55-64. doi: 10.4236/ojer.2015.42005.

Makris, J.P., Vallianatos F., Kopytenko Y., Smirnova N., Korepanov V., Kopytenko E., Soupios P., Vardiambasis I., Stampolidis A., Mavromatidis, A. (2003). ULF Geomagnetic Observations and Seismic Activity on the Southern Part of Hellenic Arc. *Geophysical Research Abstracts 5 (EGS-AGU-EUG Joint Assembly, 06-11 April 2003, Nice, France),* 12338 CDROM.

Masci, F., Thomas, J.N. (2015). Are there new findings in the search for ULF magnetic precursors to earthquakes? *J. Geophys. Res. Space Physics*, 120, 10, 289–10, 304. doi:10.1002/ 2015JA021336.

Molchanov, O.A., Hayakawa, M. (1998). On the generation mechanism of ULF seismogenic emissions. *Phys. Earth Planet. Inter.,* 105, 201-210.

Molchanov, O.A., Kopytenko, Y.A., Voronov, P.M., Kopytenko, E.A., Matiashvili, T.G., Fraser-Smith, A.C., Bernardi, A. (1992). Results of ULF magnetic field measurements near the epicenters of the Spitak (Ms = 6.9) and Loma Prieta (Ms = 7.1) earthquakes: Comparative analysis. *Geophys. Res. Lett.,* 19, 1495-1498.

Novruzov, E.S., Piriyev, R.H. (2015). Efficiency of magnetotelluric monitoring in the study of geodynamic processes. *Gorno-geologicheskiy zhurnal,* (3-4), 36-39. [in Russian]

Ohta, K., Izutsu, J., Schekotov, A., Hayakawa, M. (2013). The ULF/ELF electromagnetic radiation before the 11 March 2011 Japanese earthquake. *Radio Sci.,* 48, 589–596. doi:10.1002/rds.20064.

Parrot, M. (1999). Statistical studies with satellite observation of seismogenic effects. In: M. Hayakawa (Eds.) Atomospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes. TERRAPUB, Tokyo, 685-695.

Piriyev, R. (2021). Effectiveness of electromagnetic monitoring in studying earthquakes. *Geofizicheskiy Zhurnal*, 43(2), 166–177. https://doi.org/10.24028/gzh.v43i2.230195.

Potirakis, S.M., Schekotov, A., Contoyiannis, Y., Balasis, G., Koulouras, G.E., Melis, N.S., Boutsi, A.Z., Hayakawa, M., Eftaxias, K., Nomicos, C. (2019). On Possible Electromagnetic Precursors to a Significant Earthquake (Mw = 6.3) Occurred in Lesvos (Greece) on 12 June 2017. *Entropy*, 21, 241. doi:10.3390/e21030241

Prattes, G., Schwingenschuh, K., Eichelberger, H.U., Magnes, W., Boudjada, M., Stachel, M., Vellante, M., Villante, U., Wesztergom, V., Nenovski, P. (2011). Ultra low frequency (ULF) European multi station magnetic field analysis before and during the 2009 earthquake at L'Aquila regarding regional geotechnical information. *Natural Hazards and Earth System Sciences*, 11, 1959-1968.

Rikitake, T. (2001). Predictions and Precursors of Major Earthquakes: The Science of Macroscopic Anomalous Phenomena. Terra Scientific Publishing Company, Tokyo.

Rokityansky, I.G., Babak, V.I. Tereshyn, A.V. (2019). Low-Frequency Electromagnetic Signals Observed before Strong Earthquakes. Seismic Waves - Probing Earth System. Open access peer-reviewed chapter. Published: September 27-th 2019. DOI: http://dx.doi.org/10.5772/ intechopen.88522

Saroso, S., Hattori, K., Ishikawa, H., Ida, Y., Shirogane, R., Hayakawa, M., Yumoto, K., Shiokawa, K., and Nishihashi, M. (2009). ULF geomagnetic anomalous changes possibly associated with 2004–2005 Sumatra earthquakes. *Physics and Chemistry of the Earth,* Parts A/B/C, 34, 6–7, 343-349.

Sevgi, L. (2007). A critical review on electromagnetic precursors and earthquake prediction. *Turk. J. Elec. Engin.,* 15, 1.

Schekotov, A., Chebrov, D., Hayakawa, M., Belyaev, G. (2021). Estimation of the Epicenter Position of Kamchatka Earthqaukes. *Pure Appl. Geophys.*, 178(3), 1-9. DOI:10.1007/s00024-021-02679-1

Schekotov, A., Izutsu, J., Asano, T., Potirakis, S., Hayakawa, M. (2017). Electromagnetic Precursors to the 2016 Kumamoto Earthquakes. *Open Journal of Earthquake Research*, 6, 168-179. doi: 10.4236/ojer.2017.64010.

Stănică, D.A, Stănică, D. (2019). ULF Pre-Seismic Geomagnetic Anomalous Signal Related to Mw8.1 Offshore Chiapas Earthquake, Mexico on 8 September 2017. *Entropy*, 21, 29. doi:10.3390/e21010029.

Swati, Birbal Singh, Devbrat Pundhir, Ashwini K. Sinha, K. Madhusudan Rao, Anirban Guha, Yashuhide Hobara (2020). Ultra-low frequency (ULF) magnetic field emissions associated with some major earthquakes occurred in Indian Subcontinent. *Journal of Atmospheric and Solar-Terrestrial Physics,* 211, December 2020, 105469.

Thomas, J.N., Love, J.J., Johnston, M.J.S. (2009). On the reported magnetic precursor of the 1989 Loma Prieta earthquake. *Phys. Earth Planet. Inter.,* 173, 207-215. doi:10.1016/j.pepi.2008.11.014.

Uyeda, S., Nagao, T., Hattori, K., Noda, Y., Hayakawa, M., Miyaki, K., Molchanov, O., Gladychev, V., Baransky, L., Schekotov, A., Belyaev, G., Fedorov, E., Pokhotelov, O., Andreevsky, S., Rozhnoi, A., Khabazin, Y., Gorbatikov, A., Gordeev, E., Chevrov, V., Lutikov, A., Yunga, S., Kasarev, G., Surkov, V. (2002). Russian-Japanese complex geophysical observatory in Kamchatka for monitoring of phenomena connected with seismic activity, In: M. Hayakawa and O. Molchanov (Eds.) Seismo Electromagnetics: Lithosphere-Atmosphere -Ionosphere coupling. TERRAPUB, Tokyo, 413-420.

Uyeda, S. (2013). Earthquake prediction in Japan. *Proceedings of the Japan Academy*, Series B, 89(9), 391–400. https://doi.org/10. 2183/pjab.89.391.

Yusof, K.A., Abdullah, M., Hamid, N.S.A., Ahadi, S., Yoshikawa, A. (2021). Correlations between Earthquake Properties and Characteristics of Possible ULF Geomagnetic Precursor over Multiple Earthquakes. *Universe*, 7, 20. https://doi.org/10.3390/ universe7010020.

Zlotnicki, J., Nisida, Y. (2003). Review of morphological insights of self-potential anomalies on volcano. *Surveys in Geophys*., 24, 291-338.

Надійшла до редколегії 01.07.21

Р. Пирієв,
E-mail: rahmanpiriyev@bsu.edu.az
Бакинський державний університет, м. Баку, Азербайджан

ОГЛЯД ЕЛЕКТРОМАГНІТНИХ МОНІТОРИНГОВИХ ДОСЛІДЖЕНЬ У ПРОГНОЗІ ЗЕМЛЕТРУСІВ: ОСТАННІ РЕЗУЛЬТАТИ ТА НОВІ ПЕРСПЕКТИВИ

Для проведення порівняння та пошуку нових перспектив застосування електромагнітних явищ у прогнозі землетрусів було обрано діапазон ультра низьких частот (УНЧ). Для порівняння складено таблиці, що містять результати досліджень минулих років, включаючи останнє десятиліття. Для того щоб знайти нові перспективи, було побудовано графіки та проведено порівняльний аналіз на основі цих результатів. Зроблено висновок, що передвісники УНЧ можуть бути перед землетрусами, що досягають глибин до 30 км,

і цей діапазон можна вважати перспективним ефективним діапазоном виявлення передвісників землетрусів. Крім того, через зв'язок епіцентральних відстаней із глибинами землетрусів та їх магнітудами робилися спроби виявлення провісників так, щоб епіцентр землетрусів становив ±100 км. Також наводиться інформація про мережі УНЧ та про дослідників, які мали критичні погляди на електромагнітні явища, пов'язані із землетрусами.

Ключові слова: УНЧ, землетрус, прогноз, електромагнітне поле, провісник.

Р. Пириев,
E-mail: rahmanpiriyev@bsu.edu.az
Бакинский государственный университет, г. Баку, Азербайджан

ОБЗОР ЭЛЕКТРОМАГНИТНЫХ МОНИТОРИНГОВЫХ ИССЛЕДОВАНИЙ В ПРОГНОЗЕ ЗЕМЛЕТРЯСЕНИЙ: ПОСЛЕДНИЕ РЕЗУЛЬТАТЫ И НОВЫЕ ПЕРСПЕКТИВЫ

Для проведения сравнения и поиска новых перспектив применения электромагнитных явлений в прогнозе землетрясений был выбран диапазон ультра низких частот (УНЧ). Для сравнения составлены таблицы, состоящие из результатов исследований прошлых лет, включая последнее десятилетие. Для того чтобы найти новые перспективы, были построены графики и проведен сравнительный анализ на основе этих результатов. Сделан вывод, что предвестники УНЧ могут обнаруживаться перед землетрясениями, достигающими глубин до 30 км, и этот диапазон можно считать перспективным эффективным диапазоном обнаружения предвестников землетрясений. Кроме того, из-за связи эпицентральных расстояний с глубинами землетрясений и их магнитудами предпринимались попытки обнаружения предвестников так, чтобы эпицентр землетрясений составлял ±100 км. Также приводится информация о сетях УНЧ и об исследователях, имевших критические взгляды на электромагнитные явления, связанные с землетрясениями.

Ключевые слова: УНЧ, землетрясение, прогноз, электромагнитное поле, предвестник.