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EARTHQUAKE FORECASTING POSSIBLE METHODOLOGY

Nino Kachakhidze-Murphy[1], Manana Kachakhidze[2], Pier Francesco Biagi[3]

[1, 2] Saint Andrew the First-Called Georgian University, Georgia
[3] University of Bari, Italy

Abstract
At the present time there are rather diverse and interesting papers, published in the scientific world on the basis of ground-based and satellite data of earth VLF/LF and ULF electromagnetic (EM) emissions observed in earthquake preparation period. These phenomena are detectable both at laboratory and geological scale. In recent decades in many seismic active countries of the world the network for collecting VLF/LF electromagnetic emissions generated in the earthquake preparation period have been organized. Permanent monitoring of frequency spectrum of earth VLF/LF electromagnetic emissions generated in the earthquake preparation period might turn out very useful with the view of prediction of large M≥5 inland earthquakes. The present paper offers a scheme of the earthquake prediction methodology. To prove the prediction capabilities of earth electromagnetic emissions authors have used avalanche-like unstable model of fault formation and an analogous model of electromagnetic contour, synthesis of which, is rather harmonious. According to the opinion of the authors of the present paper EM emissions observed in earthquake preparation period is more universal and reliable than other earthquake indicators. Hypothetically, in case of availability of adequate methodological grounds, in the nearest future, earth VLF/LF electromagnetic emissions might be declared as the main precursor of earthquake.

Key words: *earthquake, avalanche-like model, electromagnetic emissions, precursor, prediction.*

§ 1. Introduction

Studies of earthquake problems in the world were especially intensified from the second half of the past century, since alongside with theoretical studies it became possible to carry out high level laboratory and satellite experiments. Thanks to them in the earthquake preparation process various anomalous changes of geophysical fields have been revealed in lithosphere as well as in atmosphere and ionosphere. Among the anomalous geophysical phenomena preceding earthquake the specific attention is attributed to earth VLF/LF electromagnetic emissions before earthquakes [2, 3, 4, 7, 8, 10, 11, 13, 21, 25, 26, 27, 28, 29, 32, 39].

Observations proved that when a material is strained, electromagnetic emissions in a wide frequency spectrum ranging from MHz to kHz are produced by opening cracks. On the large (geological) scale, intense MHz and kHz EM emissions precede earthquakes that: occurred (i) in land (or near coast-line), were (ii) large (magnitude 6 or larger), or (iii) were shallow [3, 8, 10, 13, 26, 27, 39].

It is known that earthquake prediction implies preliminary defining of the incoming earthquake place, time and magnitude, simultaneously.

At the present time by satellite observations it is possible to differentiate the projection on the ground surface of the perturbed zone in the atmosphere-ionosphere boundary that approximately coincides with a zone of precursory activity. This is evidenced by the results of studies connected with the 2009 earthquake of Italy [29].

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Authors of the present paper have been explained the mechanism of earth EM emissions in the period of earthquake preparation by analogous model of lithosphere-atmosphere-ionosphere (LAI) system's self-generated electromagnetic oscillations based on the classic electrodynamics [16]. The physical analogy with the hypothetic ideal electromagnetic contour, the formation of which is assumed in focal area of incoming earthquake due to earth surface electric polarity changing is used. The presence of such effect is proved in the papers [5, 8]. Alongside with it, due to the fact that electromagnetic emissions disturbance is conditioned by channel [16] in earthquake focus, it might well be that earth electromagnetic emissions is of sector spreading, which, to a definite extent, refers to the main fault direction and epicenter area of incoming earthquake, which is also fixed by observations [13, 17, 23, 29, 30, 32, 33, 34].

§ 2. Discussion

Analogous model submitted by the authors [16] is significant, since, on its base, by monitoring of electromagnetic emissions existing in the period that precedes earthquake, it becomes possible to analyze the process of preparation and occurrence of large shallow, inland earthquake with M≥5.

The above referred work admits the formula (1), which analytically connects with each other the main frequency of the observed electromagnetic emissions and the linear dimension (the length of the fault in the focus) of the emitted body:

$$\omega = \beta \frac{c}{l} \tag{1}$$

where β is the characteristic coefficient of geological medium and it approximately equals to 1. Of course it should be determined individually for each seismically active region, or for a local segment of lithosphere.

Comparing analogous and avalanche-like unstable models of fault formation [20] to determine reliability rate of their conformity to real process, as a example, we rely mainly on the data of earthquake which took place in Italy (L'Aquila) on 6 April, 2009 [7, 26].

It is known that avalanche-like unstable model of fault formation is divided into three main stages [20] (Fig.1)

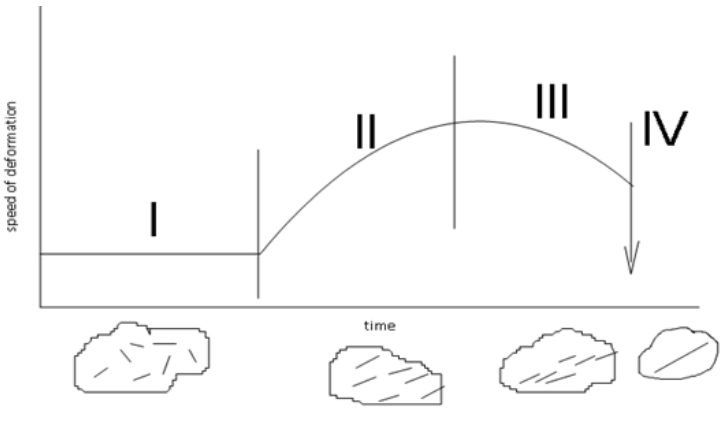

Fig. 1 Scheme of avalanche-like unstable model of fault formation

In case large earthquakes the first stage can go on for a several of months [24]. At this stage chaotic formation of microcracks without any orientation takes place.

This stage of formation of microcracks is reversible process - at this stage not only microcracks can be formed but also their the so-called "locked" can occur. Cracks created at this stage will be small (several hundred meter order) because the weak foreshock sequence may occur spatially distributed within the entire seismogenic area. For example, such process was developed in case of earthquake of Italy in 2009: by the end of October 2008 the seismicity entered in the state of weak foreshock sequence which lasted up to the 26 March 2009. It is characteristic that the weak

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foreshock activity which developed from 28 October 2008 to 26 March 2009 spatially did not concentrated around the main shock epicenter but it was widely distributed within the seismogenic area. This stage was fixed in case of L'Aquila earthquake: from 25 January 2009 to 26 March 2009 (including this day) [26] (Fig.2).

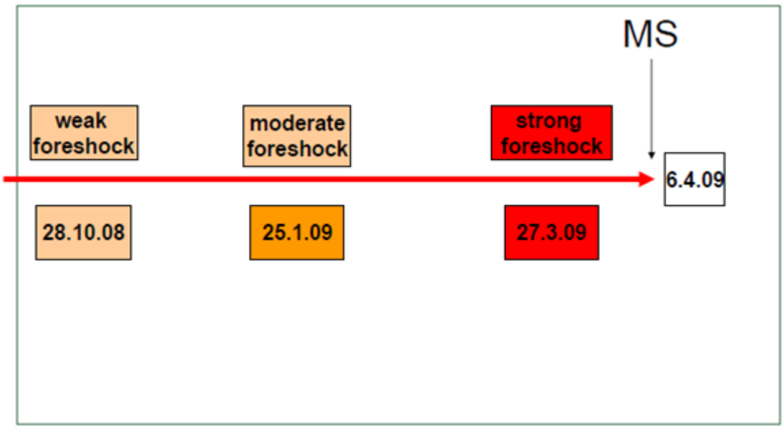

Fig.2 Evolution of foreshock activity

Such foreshocks can be called conditionally the "regional foreshocks" [14]. Because of short length of microcracks and process reversibility first stage in the electromagnetic emissions frequency range, according to our model [16] should be expressed by the discontinuous spectrum of MHz order emissions (in radio diapason), which is proved by the latest special scientific works [8, 26].

Thus, on the basis of analogous model, it can be stated that having of intermittent, high value MHz electromagnetic emissions refers only to weak and moderate earthquakes (foreshocks), and it is not necessary for these foreshocks to be near the epicenter of the incoming main earthquake.

The second stage of the avalanche-like unstable model of fault formation is an irreversible avalanche process of already somewhat oriented microstructures, which is accompanied by inclusion of the earlier "locked" sections.

Based on the analogous model [16], we have to suppose that this stage in the emissions frequency spectrum should be expressed by MHz continuous spectrum already. Although, the values of electromagnetic emissions frequency must gradually decrease. According to the avalanche-like unstable model, this process takes place few days (about 10-14) before earthquakes, which is proved clearly by observations [26].

According to the avalanche-like unstable model, at the very stage gradual increase of cracks occurs (up to the kilometers order) at the expense of their uniting, to which, according to our model, from the formula (1) corresponds to the transition of MHz to kHz emissions in the electromagnetic emissions frequency spectrum.

If a rather large earthquake is prepared, of course, foreshock $M \geq 5$ is not excluded (as it was in case of L'Aquila earthquake) [26, 35, 37]. Because of this, electromagnetic spectrum can have VLF and LF frequency substitutions [16, 26] (Fig.3).

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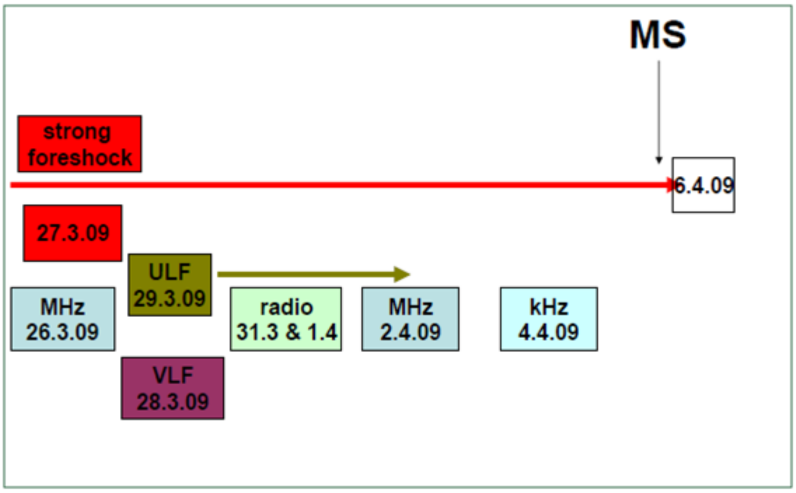

Fig. 3 Evolution of EM emissions

At the final, third stage of the avalanche-like unstable model of fault formation the relatively big size faults use to unite into one - the main fault.

This process, according to our model, in case of emissions spectrum monitoring should correspond to gradual fall of frequencies in kHz, which according to the formula (1) refers to the increase of fault length in the focus.

Increase of crack length in focus refers to the increase of magnitudes of the expected earthquake by Ulomov's [31]:

$$lg\ l = 0.6M_s - 2.5 \quad (2)$$

and by moment magnitude formula [36]:

$$M_w = 4.38 + 1.49 * \log l \quad (3)$$

In formulas (2 and 3) l is numerical value of the length in km. It must be noted that these formulas are just for large earthquakes. M_s is the surface wave magnitude and M_w is the moment magnitude.

In case of L'Aquila earthquake, due to the fact that on 4.04.2009 the main frequency kHz was already fixed in the electromagnetic emissions spectrum [26], the main fault in the earthquake focus should have been of kilometer order already.

Of course, association of cracks into one fault, which at the final stage of earthquake preparation proceeds intensely, will use definite part of energy accumulated in the focus and therefore, will result in its decrease.

In such situation a period settles before a large earthquake (which can last from several hours to even 2 days), when in the focus a fault is already formed, while earthquake has not occurred yet, since accumulated tectonic stress is not yet sufficient to overcome the limit of strength of geological environment (of course, later, at the approach of critical value of tectonic stress, the balanced state in the system will be deranged and the earthquake will occur).

The system, which is waiting for further "portion" of tectonic stress, is in the so-called "stupor" condition, in the principle, the process of main fault formation is not going on in it anymore, and respectively, electromagnetic emissions would not take place. This is proved by experiments [9].

This process is expressed correspondingly in the electromagnetic emissions spectrum: some hours before the earthquake (up to 2 days) in the spectrum the emissions intermittence is observed.

Up to interruption of electromagnetic emissions, by the using of final value of the main frequency (on the basis of the formula (1)) we can determine, by a rather high accuracy, the length of expected fault of the future earthquake, that is, a magnitude of the incoming earthquake [15,16,31,36]. We can expect renew of electromagnetic emissions immediately before the earthquake.

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In the period of electromagnetic emissions monitoring the moment of interruption of emissions spectrum is urgent for determination of time of occurrence of incoming earthquake, since at the final stage of earthquake preparation, very short time is needed to fill in the critical reserve of tectonic stress needed for main fault realization. It should be noted that this fact was experimentally proved for L'Aquila earthquake.

As for determination of expected earthquake location, many interesting works are devoted to this subject but at the present time we do not mention about them. We would like to represent possibility of our theoretical model [16] in this topic.

According to model the epicenter area will be approximately limited to the territory where the earth surface will have positive electric potential towards atmosphere. This theoretical conclusion is proved in cases of earthquakes in nature [5].

Often, in cases of rather large earthquakes we observe large ($M \geq 5.0$) foreshocks too. The main shock can follow large foreshock rather swiftly. In this case, there is no reliable criterion, which can distinguish large foreshock from incoming earthquake. Example of this is L'Aquila earthquake, when it was considered that the large foreshock was the main shock.

This issue can be resolved by rather high accuracy on the basis of analogous model by EM emissions monitoring: If after this shock electromagnetic emissions still continues to exist and the frequency data still tend to decrease, it means that the process of fault formation in the focus of the earthquake is not completed yet and we have to wait for the main shock to occur.

Generally we should not expect stopping of electromagnetic emissions after large earthquake but the frequency values in the spectrum must grow, which will refer to the fact that we should not expect the larger than the occurred earthquake but we have to wait for a series of aftershocks.

Since the processes of developing of foreshocks and aftershocks generally are connected with the fault formation process, it is clear that at this time too, VLF/LF electromagnetic emissions will take place [13, 26, 29]. Analogous model [16] on the basis of electromagnetic emissions enable us to evaluate magnitude of each separate foreshock and aftershock.

Thus, good conformity of the above referred two models and capabilities of analogous model are evident on the example of real earthquake too.

The present paper offers general, that is, "classical" picture of earthquake preparation and occurrence (foreshock – main earthquake – aftershock) on the basis of analogous model and avalanche-like unstable model of fault formation.

And finally, by the use of the formulas (1, 2, 3) for inland large earthquakes we can make the scale of dependence of incoming earthquake magnitude (even by the 0.1 accuracy) on the final, main frequency of electromagnetic emissions fixed immediately before the earthquake (Table II, Table III).

Thus, monitoring of electromagnetic emissions before the earthquake, on the basis of the offered models, enables us to follow, step by step, the process of earthquake preparation and make prognostic conclusions by definite precision.

According to analogous model [16], it is possible to detect the territory on the surface of the earth in advance, where an earthquake is expected - the epicenter area of an incoming earthquake will be approximately limited to the territory where the earth surface will have positive potential towards atmosphere.

Electromagnetic emissions in kHz should take place namely on the territory adjoining the epicenter of a future large earthquake. Our opinions have been experimentally confirmed [8].

It should be stated that during electromagnetic VLF/LF and ULF emissions fixed before earthquake, there is a problem of differentiation of ground-based electromagnetic emissions from magnetospheric emissions, because of which it is impossible to prove reliably cause-and-effect relations among seismic and atmospheric (ionospheric) phenomena [1, 19, 22, 38]. Of course, this problem must be taken into consideration.

The current seismological understanding is that earthquake preparation and energy accumulation processes are same for large and weak earthquakes and any earthquake happens when accumulation energy is sufficient to overcome the limit of strength of geological environment.

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We would like underline that difference is in frequency diapason - in case of weak earthquakes we have to wait the electromagnetic emissions in high frequency (MHz) diapason.

Besides it is considerable that_high frequency waves attenuate so rapidly that they cannot be observed on the earth's surface (Table I):

Table I

M_w	**Frequency diapason (kHz)**
1	55664,41-51604,99
2	12823,12-11004,01
3	2734,34-2346,44
4	583,06-500,34

Table I. M_w moment magnitude dependence on the EM emissions frequency diapason for weak earthquakes

We should also note that because weak earthquakes are not so dangerous the networks do not fix VLF/LF emissions relevant to diapason for weak earthquakes.

§ 3. Conclusions

VLF/LF EM emissions that is considered as earthquake indicator is namely the main precursor, which "brings" for large inland (M≥5) earthquake prediction the rich information about the stages of earthquake preparation process going on in the focus and in case of its permanent monitoring enables us to predict incoming earthquake by definite precision:

- Appearance of intermittent electromagnetic emissions spectrum in seismically active region, mainly in MHz range, refers to the fact that the process of large earthquake preparation has been started in the region; at this time, it is possible to fix the so-called "regional foreshocks" of relatively small magnitude and it is not excluded that this process will start several months before the earthquake;
- Due to the formation of significant size faults in focus, few days (approximately a fortnight) before earthquake, uninterrupted electromagnetic emissions appears in MHz, kHz and ULF spectral range; In the spectrum initially MHz and ULF range emissions should prevail, but periodically we should expect kHz range electromagnetic emissions too;
- On the next stage, in electromagnetic emissions spectrum mainly kHz range frequencies dominate, which denotes that kilometer order main fault is in the process of formation in the focus already; Shortly before the occurrence of earthquake, electromagnetic emissions spectrum is only of kHz order and it decreases swiftly; In case of the devastating earthquakes (M≥8.3) the main value of electromagnetic emissions falls even to Hz order;
- Few hours before the earthquake, or maximum 2 days before it, electromagnetic emissions interrupts at all, which enables us to predict time of earthquake occurrence. At the moment of emissions restarting, the earthquake occurs;
- Value of the final main frequency of the spectrum emitted just before interruption of emissions will enable us to define fault length in the earthquake focus, that is, the earthquake magnitude, by rather high precision;
- Still more decrease of the main frequencies in electromagnetic spectrum after any large shock implies that the larger earthquake is expected and that the occurred shock was only a foreshock. We can consider that a shock is the main earthquake if after it the main frequencies values in the emissions spectrum begin to increase significantly. This effect is a prerequisite of starting of a series of aftershocks. Thus, the analysis of electromagnetic emissions spectrum enables us to differentiate clearly foreshocks and aftershocks from the main shocks;

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- The essential condition for determination of epicenter area of incoming earthquake, alongside with other possible methods, is that earth surface in this area should have positive potential permanently, for a rather long period (though for some weeks). Besides in addition to it, electromagnetic emissions in kHz should take place namely on the territory adjoining the epicenter of an incoming large earthquake.

Table II

M_s	L (km)	ω (kHz)
5	3,16-3,38	94,87-88,66
5,1	3,39-3,89	88,536-77,218
5,2	3,89-4,46	77,112-67,254
5,3	4,47-5,12	67,162-58,576
5,4	5,13-5,88	58,495-51,018
5,5	5,89-6,75	50,947-44,435
5,6	6,76-7,75	44,373-38,701
5,7	7,76-8,9	38,647-33,707
5,8	8,91-10,2	33,661-29,358
5,9	10,2-11,7	29,317-25,569
6	11,7-13,5	25,534-22,27
6,1	13,5-15,5	22,239-19,396
6,2	15,5-17,8	19,37-16,894
6,3	17,8-20,4	16,87-14,714
6,4	20,4-23,4	14,693-12,815
6,5	23,4-26,9	12,797-11,161
6,6	26,9-30,9	11,146-9,7212
6,7	30,9-35,4	9,7078-8,4668
6,8	35,5-40,7	8,4551-7,3743
6,9	40,7-46,7	7,3641-6,4228
7	46,8-53,6	6,4139-5,594
7,1	53,7-61,6	5,5863-4,8722
7,2	61,7-70,7	4,8654-4,2435
7,3	70,8-81,2	4,2376-3,6959
7,4	81,3-93,2	3,6908-3,219
7,5	93,3-107	3,2146-2,8036
7,6	107-123	2,7998-2,4419
7,7	123-141	2,4385-2,1268
7,8	141-162	2,1238-1,8523
7,9	162-186	1,8498-1,6111
8	186-214	1,6089-1,4032
8,1	214-245	1,4013-1,2221
8,2	246-282	1,2205-1,0644
8,3	324-324	1,063-0,9271
8,4	324-372	0,9258-0,8075
8,5	372-427	0,8063-0,7033
8,6	427-490	0,7023-0,6125
8,7	490-562	0,6117-0,5335
8,8	563-646	0,5327-0,4646
8,9	647-741	0,464-0,4047
9	742-1585	0,4041-0,189

Table II. Dependence table between M_s magnitude, fault length and frequency diapason estimated by formula (2)

Table III

M_w	L (km)	Frequency (kHz)
5	2,413-2,812	124,33-106,7
5,1	2,816-3,282	106,53-91,41

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5,2	3,287-3,830	91,27-78,32
5,3	3,836-4,470	78,20-67,11
5,4	4,477-5,217	67-57,5
5,5	5,225-6,089	57,41-49,27
5,6	6,099-7,107	49,19-42,21
5,7	7,112-8,295	42,15-36,17
5,8	8,307-9,681	36,11-30,99
5,9	9,696-11,298	30,94-26,55
6	11,32-13,197	26,51-22,75
6,1	13,217-15,4	22,72-19,49
6,2	15,41-17,96	19,46-16,70
6,3	17,99-20,97	16,68-14,31
6,4	21-24,47	14,29-12,26
6,5	24,51-28,56	12,24-10,51
6,6	28,60-33,33	10,49-9
6,7	33,38-38,9	8,99-7,71
6,8	38,96-45,4	7,7-6,61
6,9	45,47-52,99	6,6-5,66
7	53,07-61,84	5,65-4,85
7,1	61,94-72,18	4,84-4,16
7,2	72,29-84,24	4,15-3,56
7,3	84,37-98,31	3,56-3,05
7,4	98,47-114,74	3,05-2,61
7,5	114,92-133,92	2,61-2,24
7,6	134,13-156,30	2,24-1,92
7,7	156,54-182,42	1,92-1,65
7,8	182,70-212,91	1,64-1,41
7,9	213,24-248,87	1,41-1,21
8	249,26-290,46	1,20-1,03
8,1	290,91-339	1,03-0,88
8,2	339,53-395,65	0,88-0,76
8,3	396,27-461,77	0,76-0,65
8,4	462,49-538,94	0,65-0,56
8,5	539,77-629	0,56-0,48
8,6	629,98-734,13	0,48-0,41
8,7	735,26-856,81	0,41-0,35
8,8	858,14-1000	0,35-0,3
8,9	1001,56-1167,1	0,3-0,26
9	1168,9-1260,9	0,26-0,24

Table III. Dependence table between M_w moment magnitude, fault length and frequency diapason estimated by formula (3)

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