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DISPLAY OF SESMIC EVENTS IN ELECTROMAGMETIC FIELD AND IONOSPHERE

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Contents

Abstract. The results of experimental and theoretical studies of the problem of manifestation of seismic events in the electromagnetic (EM) field and in the Earth's ionosphere are presented. The Section 1.1 of the book presents the results of laboratory investigations in the ELF and VLF frequency ranges with use of the experimental complex specially developed. The possibility of the occurrence of pulsed electrical signals excited by mechanical impacts is shown. Thus, it has been found that, at least for rocks containing crystalline quartz, such impacts excite low-frequency signals caused by the piezoelectric effect. It is also shown that upon sample destruction, radio-pulse signals are generated. It is noted that when impacted on samples of other quartz-containing rocks, similar responses are also observed, but their level is 3-10 times lower. The results obtained can be considered as some ideological premise for explaining the nature of some radiophysical precursors that are observed both directly in the earthquake preparation zone and are manifested in ionospheric processes.

The description of the obtained results on studying the structure of EM emissions generated by shock and explosive impacts on large monolithic blocks of rocks of complex structure, and also at power industrial explosions is presented in Sections 1.2 and 1.3 of the book. The mechanisms of excitation of seismic emission (for various sources) and the generation of the EM response at propagation of seismic wave are considered in Sect. 1.2. The fact of generation of the EM responses at impacts on various widespread quartz-containing rocks was confirmed; it has been established that the source of the EM emission in the ELF-VLF frequency range are the inclusions of a crystalline piezoelectric excited by a seismic wave.

The existence of low and high-frequency parts of the response in the lower part of the ELF range of the EM emission generated by impact, and the arising of modal structures in the high-frequency responses at impact to rocks in real conditions were detected. The proportionality of the piezoelectric response to seismic one, and an increase of the response amplitude due to the presence of an additional massive piezoelectric excited by means of a seismic wave are shown. No noticeable role of the structural destruction of the rock samples in the generation of responses was found, that gives a chance to their detection not only under hard impact (mechanical shocks, explosions), but also during natural seismic processes, that opens the perspectives for using the methods of prediction of seismic phenomena using the EM precursors of the earthquakes.

The results presented in Section 1.2 are in good agreement with the results obtained in laboratory experiments (Sect. 1.1 of the book). They are an intermediate stage between laboratory research and registration of the EM responses at powerful industrial explosions.

A description of the results obtained when studying the structure of EM emissions caused by strong impacts at industrial explosions is presented in Sect. 1.3 of the book. The investigations described in this Section are logical prolongation of previous

laboratory and field experimental investigations described in Sections 1.2 and 1.3, and presents the results obtained on real geological objects on studying the structure and intensity of the EM responses generated in the ELF-VLF frequency range in dependence on a character and power (energetic characteristics) of seismic impact. In the investigations both the seismo-electromagnetic and the radio-impulse methods realized in the field experimental complex were used. At the explosive impacts on rocks and ore bodies at distances of 100-200 m from the point of explosion, the intense signals in the ELF (1-30 Hz) and VLF (1-20 kHz) frequency ranges were registered in the experiments, and the cause of this was the piezoelectric effect, arising as a result of the impact of a shock wave to quartz inclusions in rocks. Studies have shown that similar responses in the ELF and VLF ranges can be observed (in the presence of quartz-containing ore bodies) at natural seismic events – the earthquakes of the 9-13 energetic class.

Note, that besides of registration of the seismic responses in the EM field, the results obtained in Section 1.3 can also be useful when performing direction finding works to ore deposits using spatially diversited ELF-VLF receiving stations.

The results of our studies of displaying of seismic activity in variations of both the EM field and the basic ionospheric characteristics were presented in Part 2 of the book. The 3D case has been considered taking into account the effects of weak nonlinearity, dispersion and dissipation in medium, that has allowed us to obtain more accurate results for both the near and far zones of the earthquake epicenter. In study of the seismic response in the EM field (Sect. 2.2), it was shown that a precursor arises ahead the front of seismic wave, its amplitude decreases exponentially with distance. In case of a single compression pulse, the precursor is negative, and its amplitude depends on the medium conductivity and the parameters of the wave. With increasing conductivity, the amplitude of precursor increases, and its characteristic scale decreases. Regarding the response at ionospheric heights, the seismo-ionospheric post-effects have been studied (Sect. 2.3), which are of great interest, in particular, for a better understanding of relationships in the system "solid Earth – atmosphere – ionosphere" and for identification of seismically caused oscillations in the spectrum of the ionospheric fluctuations, etc. The effect of the acoustic impulse caused by the Rayleigh wave on the ionosphere's neutral component near the epicenter was considered, and further formation of the solitary internal gravity waves (IGWs) and the travelling ionospheric disturbances (TIDs), which are caused by them, at the *F*-layer heights in the far zone. The results obtained are in good agreement with the results of our radiophysical experiments during seismic events at the Russia Far East region.

The solution of direct and inverse problems arising in investigations of the internal gravity waves (IGWs) dynamic via recording of the Doppler frequency shift (DFS), is presented in Part 3 of the book. The direct problem is to determine the response of the DFS to IGWs in the region of the radio wave reflection point; the inverse problem is the determination of IGW parameters from experimental data on the DFS. Solutions were obtained in an approximation of the isothermal ionosphere for the heights of the *F*-region. They are presented in a form convenient for their practical use and can have a wide range of applications, including the detection of soliton-like wave structures in the *F*-region of the ionosphere.

The results presented in the book were obtained during the field experimental investigations at the North-Eastern Complex Research Institute of the Far Eastern Branch of the Russian Academy of Sciences and processed jointly with the Tbilisi State University, Georgia.

Key words and phrases

EM field, EM emission, piezoelectric method, radio impulse method, seismic wave, EM response, shock impact, earthquake, Rayleigh wave, near and far earthquake zones, experimental complex, theoretical estimates, laboratory experiments, field experiments, industrial explosions, ELF-VLF frequency range, spectrograms, Doppler frequency shift method, ionosphere, precursor, IGW and TID solitons

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Preface

The book presents the results of experimental and theoretical studies of the problem of manifestation of seismic events in the electromagnetic (EM) field and in the Earth's ionosphere. The first part of the book is devoted to the study of the EM responses under mechanical shock action on rock samples of various compositions and sizes. Section 1.1 presents the results of laboratory studies in the ELF and VLF frequency ranges using a specially designed experimental complex. The possibility of the appearance of pulsed electrical signals excited by mechanical influences is shown. It has been found that, at least for rocks containing crystalline quartz, such influences excite low frequency signals caused by the piezoelectric effect. It is also shown that when the sample is destroyed, radio-pulse signals are generated. It is noted that when the samples are exposed to other quartz-bearing rocks (granite, mudstone, siltstone), similar responses are also observed, but their level is 3-10 times lower. The results obtained can be considered as a kind of ideological prerequisite for explaining the nature of some radiophysical precursors, which are observed both directly in the zone of preparation for an earthquake and are manifested in ionospheric processes.

The description of the experiments and the results obtained in the study of the structure of EM radiation under shock-explosive (low-power) impacts on large monolithic blocks of rocks of complex structure, as well as during powerful industrial explosions, are presented in Sections 1.2 and 1.3 of the books.

The mechanisms of the excitation of seismic radiation (for various sources) and the generation of an EM response during the propagation of a seismic wave through a mechanical system, for example, rocks, are considered. The fact of generation of EM-responses at impacts against various common quartz-containing rocks has been confirmed. It has been established that the source of EM radiation in the ELF-VLF range is crystalline piezoelectric inclusions excited by a seismic wave.

The presence of low-frequency and high-frequency parts of the response in the lower part of the ELF range of the EM radiation from impact, as well as the appearance of modal structures in high-frequency responses when rocks are struck in real conditions. are demonstrated. The proportionality of the piezoelectric response to the seismic response and an increase in the response amplitude at presence of an additional massive piezoelectric, excited by the seismic wave, are shown. A noticeable role of structural destruction of rock samples in the generation of responses was not found, which makes it possible to detect them not only under strong influences (mechanical shocks, explosions), but also under natural seismic processes, which opens up prospects for use of methods for forecasting seismic phenomena using EM precursors of earthquakes.

A description of the results obtained in the study of the structure of EM radiation generated under strong shock effects arising from industrial explosions is presented in Section 1.3 of this book. This is a logical continuation of previous laboratory and field experimental studies described in Sections 1.1 and 1.2, and presents the results of field studies obtained on real geological objects, while studying the structure and intensity of the EM responses generated in the ELF and VLF frequency ranges depending on the nature and power (energy characteristics) of the seismic impact. The studies used both seismic-electromagnetic and radio-pulse methods implemented in the field experimental complex. During explosive impacts on rocks and ore bodies at a distance of 100-200 m from the explosion site, intense signals were recorded in the experiments in the ELF (1-30 Hz) and VLF (1-20 kHz) frequency ranges. The reason for this was the piezoelectric effect resulting from the impact of a shock wave on quartz inclusions in rocks. Studies have shown that similar responses in the ELF and VLF ranges can be observed (in the presence of quartz-bearing ore bodies) during natural seismic events – the earthquakes with an energy class of 9–13. It is necessary to note that the results obtained in Sect. 1.3 can be useful when performing direction finding works to ore deposits using spatially diversited ELF-VLF receiving stations besides of registration of the seismic responses in the EM field.

Part 2 of the book presents the results of our investigation of displaying of seismic activity in variations of both the EM field and the basic ionospheric characteristics. The 3D case is considered taking into account the effects of weak nonlinearity, dispersion and dissipation in medium, that allows us to obtain more accurate results for both the near and far zones of the earthquake epicenter. In study of the seismic response in the EM field (Sect. 2.2), it is shown that a precursor arises ahead the front of seismic wave, its amplitude decreases exponentially with distance. In case of a single compression pulse, the precursor is negative, and its amplitude depends on the medium conductivity and the parameters of the wave. With increasing conductivity, the amplitude of precursor increases, and its characteristic scale decreases. Regarding the response at ionospheric heights, the seismo-ionospheric post-effects have been studied (Sect. 2.3), which are of great interest, in particular, for a better understanding of relationships in the system "solid Earth – atmosphere – ionosphere" and for identification of seismically caused oscillations in the spectrum of the ionospheric fluctuations, etc. The effect of the acoustic impulse caused by the Rayleigh wave on the ionosphere's neutral component near the epicenter is considered, and further formation of the solitary internal gravity waves (IGWs) and the travelling ionospheric disturbances (TIDs), which are caused by them, at the *F*-layer heights in the far zone. The results obtained are in good agreement with the results of our radiophysical experiments during seismic events at the Russia Far East region.

Part 3 of the book presents the solution of both direct and inverse problem arising in the study of the dynamics of internal gravity waves (IGW), excited by seismic events, by registering the Doppler frequency shift (DFS). The direct problem is to determine the DFS response to IGW from a seismic source in the region of the radio wave reflection point; the inverse problem is the determination of the IGW parameters from the experimental data on the DFS.

The solutions were obtained in the approximation of the isothermal ionosphere for the heights of the *F*-region. They are presented in a form convenient for their practical use, and can have a wide range of applications, including the detection of soliton-like wave structures excited by seismic events in the *F*-region of the ionosphere.

The results presented in the book were obtained during the field experimental investigations at the North-Eastern Complex Research Institute of the Far Eastern Branch of the Russian Academy of Sciences and processed jointly with the Tbilisi State University, Georgia.