Bull. Nov. Comp. Center, Math. Model. in Geoph., 10 (2005), 1–9

Effectiveness of Alpha and Itanium microprocessors for the numerical modeling of vibroseismic monitoring of magmatic volcanic chambers*

Boris M. Glinsky, Alexey G. Fatyanov, Nikolay V. Kuchin

Abstract. The paper considers theory, methods and experiments aimed at creation of a monitoring system of active volcanos with the use of powerful vibroseismic sources. We propose a concept of creation of a system for studying the geometry of magma chambers, deep faults in the neighborhood of volcanos, dynamics of eruption processes using the methods of vibroseismic sounding, the latter based on powerful controlled sources with the force, acting on the ground.

The results of calculation of a seismic field for a medium, which is elliptic inclusion into a homogeneous half-space simulating a magma region, are presented. In this case, a volcanic medium is approximated with the help of a number of rectangular plates. Special attention is being given to development of method of vibroseismic monitoring of living volcanos, which, in our opinion, will help in measuring the rates of magma elevation in channels and in predicting the time of eruption of a volcano in question in combination with other geophysical, geochemical and geological methods. The comparison of computational effectiveness on processors Alpha and Itanium was carried out.

1. Introduction

Currently, in the world there are about 700 volcanos considering being active. Annually, on the average, 55–60 volcanos are erupting. Many big cities and villages inhibited with millions of people have been constructed in the immediate vicinity from living volcanic, which can be a real hazard for their lives. In Russia, among such regions are Kamchatka, the Northern Caucuses. Similar regions are, also, Philippine, Hawaii, Italy and other parts of the planet. Disastrous, volcanic eruptions are difficult to predict, and represent a serious hazard for population inhibiting near to volcanos. In addition, volcanic activity has a serious impact on the environment. Disastrous eruption of volcanos are often associated with "extinct" volcanic, for example, volcanos Bezymyanny, Sent-Helens, the events occurred Kamchatka, in the "ancient" Calder (Crater) of the Academy of Sciences, in 1996. As for the European part of Russia, Elbrus can be referred to potentially active volcanos [1, 2]. It is significant that the area of its glaciers is 139 km^2 and the

*Partially supported by the Russian Foundation for Basic Research under Grants 03-05-65292, 03-05-64402.

total volume of ice is 6–7 km^3 [3]. If this volcano manifests its activity, large territories of Krasnodar and Stavropol regions can be flooded.

However, as in forecasting earthquakes, the problem of establishing the time, character and intensity of volcanic eruption remains extraordinary complicated. For example, any volcano is known to be characterized by peculiarity of interconnection between seismic and volcanic activity. Thus the earthquakes preceding the eruption of volcano Visuvy had begun 16 years before this eruption, and volcano Gekla erupted only 20 minutes after the local earthquakes occurred [4].

2. Grounds of the vibroseismic monitoring

The proposed system for active monitoring of magma structures with a controlled vibroseismic source will enable us to gain knowledge of the volcano structure and of dynamics of behavior of magma structures of living volcanos. This approach to monitoring of volcanos is the new one, and to the authors' knowledge, it was not proposed before. Creation of grounds of the active vibroseismic monitoring of living volcanos demands carrying out realization of difficult numerical calculations, theoretical, and experimental studies. Let us consider some aspects of constructing a vibroseismic method and the system for monitoring volcanos.

A specific feature of the proposed approach is application of controlled vibration sources, which allow carrying out radiation of seismic waves in various modes: monochromatic, sweep-signals, etc. with a high degree of precision. This is a difference of the method in question from other active methods based on earthquakes and explosions earlier used as seismic sources for studying volcanos.

It is known that it is impossible to have identical seismic actions for explosions, and for earthquakes there is a problem of exact determination of coordinates, time and force of a seismic event. In our opinion, the method in question allows the use of the main advantage of the modern vibration technology of seismic sounding with powerful sources for detection and subsequent observation of changes in the state of sesmoacoustic parameters of volcanic channels and their neighborhood. This advantage is based on a high and long-term stability of radiation parameters of vibration signals provided by modern systems of computer-aided control of vibrators [5].

The generalized model of the information system for the active vibroseismic monitoring is described in detail in [6–8]. According to this model, the major components of this system are: powerful vibroseismic source, generating mechanical oscillations within a given frequency range and preassigned form; off-line seismic modules (OSM), intended for recording seismic signals; a field computer system (FCS) for collecting data from OSM, for calculation of controlled characteristics, guttering statistics and, finally, forecast of

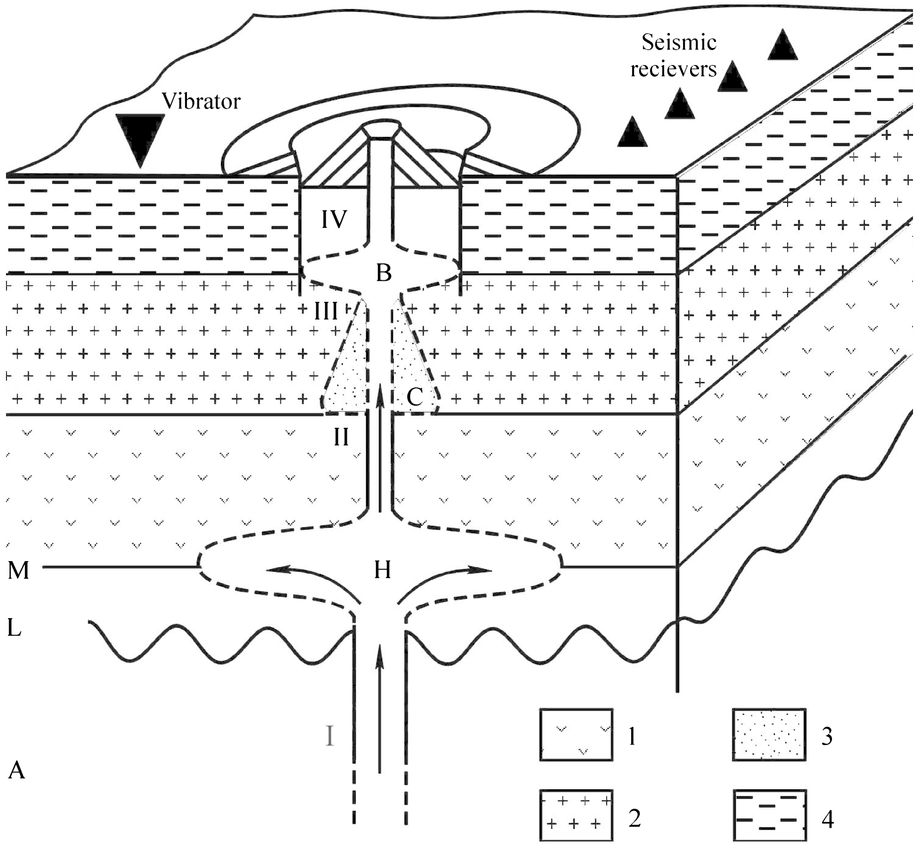

Figure 1. A scheme of the developed system of magma channels and magma chambers for volcanos of the central type, notations: A — astenosphere; L — the lithosphere boundary; M — the Earth crust's boundary; H — a subcrustal or lower-crustal magma charuber; 1 — "basaltic" layer; 2 — "granite" layer; 3 — a potential area of melting in the "granite" layer aracsed a magma channel; 4 — a sedimentary layer; I — a magma astenosphere column; II — a part of a feeding channel in the "basaltic" layer, III — a part of a feeding channel in the "granite" layer, IV — between a "peripheral" chamber and crater

danger of eruption by controlled parameters. The given model can underlie the creation of the monitoring system living volcanos.

Figure 1 presents a scheme of the developed system of magma channels and magma charubers for volcanos of the control type. It is precisely these structures, which are peculiar "heart" of volcanos and determine their lives cycles. According to existing opinion, the size of magma chambers of volcanos of the control type mast transform in time. This is determined, in the first place, by the time variation of expenses of the mantle magma during the volcanos life [9].

Figure 1 also shows an approximate scheme of vibroseismic gaendings with the use of one powerful vibrator and three-component seismic recording devices. With such an observation system, the source as if "illuminates" magma channels and magma chambers in a periodic mode, which allows tracing the dynamical changes occurring in a volcanic zone. A scheme of spacing and the observation period depend on the geometry of a volcano and its activity. If needed, it is possible to use a few sources and an area observation system. It should be noted that the methods of monitoring could be completed after carrying out numerical experiments and observations on really acting volcanos.

Currently, in our Department of Geophysical Informatics, ICM&MG SB RAS, we have developed basic components for creation of a prototype of on instrumental system of monitoring of magma structures of volcanos. For recording seismic fields from different sources (industrial explosions, earthquakes, vibro-sources, seismic noise), several recoding stations have been developed which make it possible to use small-aperture seismic groups with three-component seismic receivers. It is possible to apply the RefTek type recorders.

A few types of radiators have been developed and installed on Bystrovka fest site near to the city of Novosibirsk. The most powerful stationary vibrator CV-100 produces the force acting on the ground up to 100 tons in the frequency band 5–8.8 Hz. Based on this principle, a dismountable, mobile source CV-40 provides the force up to 40 tons within 6–10 Hz [5]. It is these sources, which can be used for studying volcanic structures. To synchronize the processes of radiation and receiving vibroseismic signals, the GPS-receivers are used. We have gained sufficient experience in using vibration systems in the very complicated noise situation. Special methods, sounding modes and data processing algorithms have been developed which enable us to reliably detect and measure small variations due to the changes in the state of a medium under sounding of information parameters of recorded vibration signals. In particular, control of parameters, of a signal, radiated by a vibrator using the measuring systems in the near zone, suppression of the impulse noise, the phase method with extraction of exact data with their minimum volume, etc. Similar systems of observation, recording and processing of data can be applied to construct a system of monitoring of magma structures of volcanos.

At the first stage, a magma chamber is taken as ellipse-shaped. A medium a volcanic as well, is approximated with the hob of an arbitrary number of rectangular units. In this case, its certain area can represent a layered medium with an arbitrary number of layers. Layer thickness can be arbitrary both in the layered and in the units media. This allows modeling the structure of an arbitrary geometry, with appropriate selection of values and number of approximating rectangular units. In order that wave fields for an arbitrary number of sources and receivers be simultaneously calculated, the algorithm of calculating the Green function has been developed. The mathematical problem formulation for P-SV waves, in this case, looks as follows:

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} = \rho \frac{\partial^2 u_x}{\partial t^2} + F_x(x - x_0) f(t),$$
$$\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} = \rho \frac{\partial^2 u_y}{\partial t^2} + F_y(x - x_0) f(t),$$
$$\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} = \rho \frac{\partial^2 u_z}{\partial t^2} + F_y(x - x_0) f(t),$$

$$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{yz} \\ \tau_{xz} \\ \tau_{xy} \end{pmatrix} = \begin{bmatrix} \lambda + 2\mu & \lambda & \lambda & 0 & 0 & 0 \\ \lambda & \lambda + 2\mu & \lambda & 0 & 0 & 0 \\ \lambda & \lambda & \lambda + 2\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu \end{bmatrix} \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \varepsilon_{yz} \\ \varepsilon_{xz} \\ \varepsilon_{xy} \end{pmatrix},$$

$$\varepsilon_x = \frac{\partial u_x}{\partial x}, \quad \varepsilon_y = \frac{\partial u_y}{\partial y}, \quad \varepsilon_z = \frac{\partial u_z}{\partial z},$$

$$\varepsilon_{yz} = \frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y}, \quad \varepsilon_{xz} = \frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}, \quad \varepsilon_{xy} = \frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}.$$

Here x_0 is a horizontal localization of the source. Inside each unit, $c(x, z)$ is a constant value. On the boundaries of discontinuity of parameters, well-known conjugation conditions are introduced. The desired solution is sought for as the Fourier transform in the variables t and x. As a result of solution using the convolution formulas, we obtain the Green functions with an arbitrary function of the time action $f(t)$ [10–12]. This opens the way to the simulation in various vibration modes. Finally, we obtain the solution of the problem in question for arbitrary locations of a vibrator, recording system and parameters of a magma chambers.

3. Numerical experiments

The comparison of computational effectiveness on Alpha and Itanium processors was made. The calculation was carried out for a medium, representing an elliptic inclusion into an inhomogeneous half-space that simulates a magnetic domain. In this case, the medium is approximated using a certain quantity of rectangular plates.

The graphs in Figures 2, 3 are given with the same scale with a significant amplification of the amplitude. The numerical modeling shows that the calculation results with the use of one program on different processors are

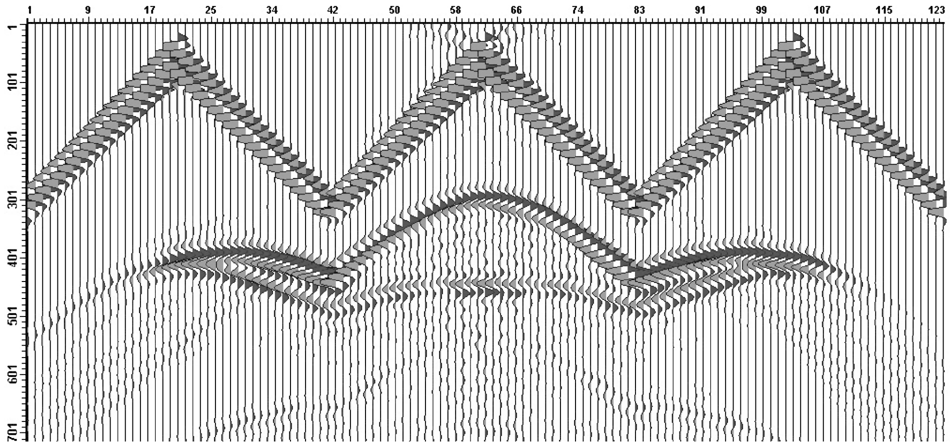

Figure 2. Calculation on Alpha processor

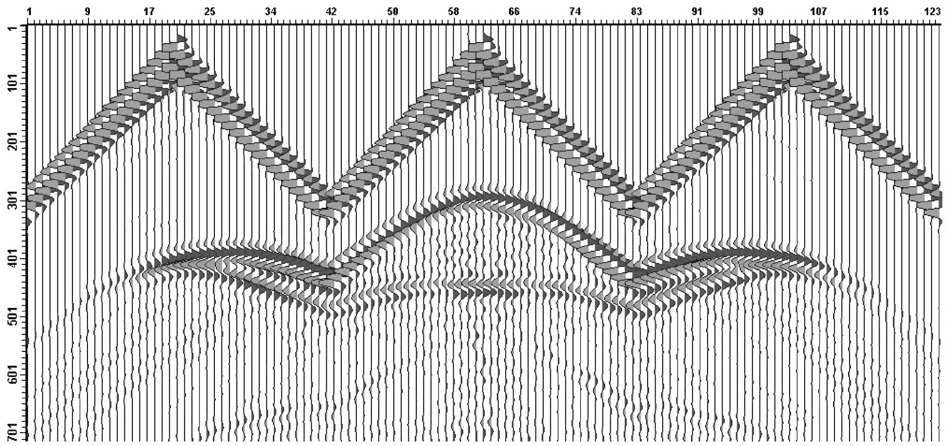

Figure 3. Calculation on Itanium processor

distinct. This is, apparently, associated with peculiarities of complicated diffraction problems. In this case, in particular, in the algorithm of finding a solution, the linear algebra procedures are exploited: the matrix inversion, finding eigenvalues, etc. In terms of physics it is clear that the computational accuracy on Itanium is higher than that on Alpha. With the qualitative similarity of wave fields, when using Itanium there are no, for example, noise associated with a direct wave. In addition, the first wave arrival is more distinct. It should also be noted that the results of modeling reveal a higher throughput of the processor Itanium. The modeling on Itaniume three-fold faster than on Alpha. The translation on both processors was carried out with the same key.

All the above said enables us to conclude that the modern architecture of Itanium is better adapted for solving complicated problems of mathematical

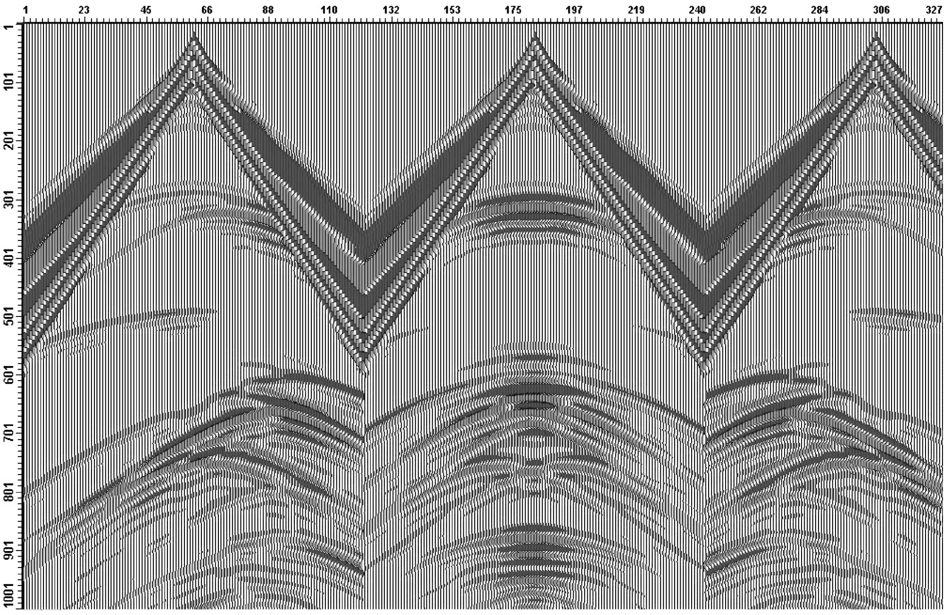

Figure 4. Wave fields for a source zone

physics. For the numerical simulation of real source zones, below there is given an example of calculation of wave fields for a magmatic chamber of the active volcano Elbrus. A complex geological geometry of Elbrus's construction and an insufficient volume of information about physical and mathematical features of magma make it difficult to construct a real model of the event in question.

Figure 4 presents the wave fields for the source zone of the volcano Elbrus. This model is characterized by a bench of layers consisting of sediments, granites and basalts. A magmatic chamber is taken as a square inclusion. In this case, the source zone is not em pty but is filled in with a medium of a lower velocity.

For comparison, Figure 5 presents wave fields for the same model as in Figure 4. However in this case the source zone of the volcano Elbrus is absent. From the comparison of Figures 4 and 5 it is clear that in the presence of a source zone the wave picture has a far more complicated character and can yield a greater volume of information.

At realization of numerical calculations the compared computer platforms are MVS-1000 cluster with 32 processors Alpha 21264 / 833 MHz / 4 Mb SLC, 2 Gb RAM, with OS Red Hat Linux 7.2, Compaq Fortran cfal-1.2.0-4 compiler and HP Integrity rx5670 server with 4 processors Intel Itanium 2, 1.3 GHz, 3 Mb a cache, 4 Gbytes RAM, Red Hat Linux Advanced Server release 2.1, Intel Fortran v. 8.0 compiler.

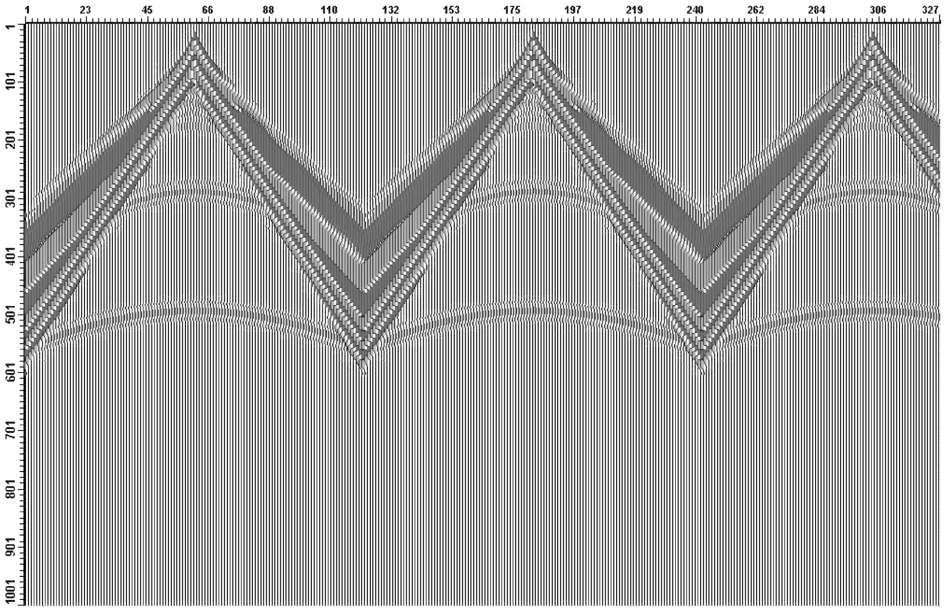

Figure 5. Wave fields without a source zone

In the described computing experiment were estimated as performance of processors Alpha 21264 and Intel Itanium 2, and programs portability between these platforms. For the porting the program on Itanium 2 platform it was required only recompilation the program source text, without any changes in it. Calculation was carried out on the same data, the program entirely placed in the main memory without swapping. Therefore program acceleration only in part speaks higher clock frequency of processor Itanium 2 (in 1.56 times).

Computing resources of Siberian Supercomputer Center (SSCC) are used as the tool for the scientific problems solving. Tuning the program and algorithm under a concrete computing platform is not included into sphere of scientific interests of SSCC users.

The computer platform base on Itanium 2 processor architecture successfully approaches for the scientific computation in the mathematical physics area, provides an essential prize in performance and more exact (from the end user point of view) result. As it was marked above, at calculation on Itanium this problem was solved in 3 times faster, than on platform Alpha though on clock frequency they differ approximately in 1.56 times.

The conducted numerical experiments have underlied the development of the cluster on Intel Itanium 2 with the performance 1 TFlops for the Supercomputer Center SB RAS. At the first step of this project it is planned to build the cluster, consisting of 30 two-processor computing nodes, the expected performance being 380 GFlops. As its final version the system will contain 80 computing nodes that, according to preliminary estimations, are to provide the expected performance using the test High Performance LINPACK.

References

[1] Laverov N.P., Bogatikov O.A., Gurbanov A.G. et al. Geodynamics, Seismotectonics and Volcanos of Central Caucuses // Global Changes of an Environment and a Climate. — Moscow: Nauka, 1977. — P. 109–130.

[2] Bogatikov O.A., Gurbanov A.G., Melekestsev I.V. et al. Problem of activization of volcano Elbrus (Northern Caucuses) and its possible consequences // Global Changes in Environment. Min. of Science and Technologies of RS, RAS. — Novosibirsk: SB RAS, NITs, OIIGM, 1998. — P. 153–164.

[3] Bogatikov O.A., Nechaev J.V., Sobisevich A.L. Improvement of Structural Features of the Maternal Magma Source and Volcanic Chamber of Elbrus. — Moscow: RAS OIFZ, 2001. — P. 223–249.

[4] Ract X. Volcanos and Volcanism. — Moscow: Mir, 1982.

[5] Alekseev A.S., Glinsky B.M., Emanov A.F. et al. New geotechnologies and complex geophysical methods of studying the interior structure and dynamics of geosphere / Ed. by acad. N.P. Laverov. Regionalnaya obschestvennaya organizatsia uchenykh po problemam prikladnoy geofiziki. — Moscow, 2002.

[6] Glinsky B.M. Method and technology for large-scale vibroseismic experiments // ICT 2000. Collection of papers NSTU. — Novosibirsk, 2001. – P. 52–56.

[7] Glinsky B.M. Architecture of computer-telecommunication systems for active seismology //Proc. 15th IMACS World Congress, Berlin. — 1997. — Vol. 6. — P. 353–358.

[8] Glinsky B.M., Kovalevsky V.V., Varlakhov A.V. Distributed system for vibroseismic monitoring // Proceedings of the 5th International Seminar "Distributed Information Processing", Novosibirsk. — 1995. — P. 350–355.

[9] Disastrous processes and their impact on environment. Vol. 1. Volcanism. M. 6 Regional noncommercial organization of scientists on problems of applied geophysics. — 2002.

[10] Mikhailenko B.G. Seismic Fields in Complex Subsurface Geometries. — Novosibirsk, 1988.

[11] Fatyanov A.G., Mikhailenko B.G. Method of calculation of no stationary wave fields in nonelastic layered-inhomogeneous media // DAN. — 1988. — Vol. 301, No. 4. — P. 834–839.

[12] Fatyanov A.G. Mathematical simulation of wave fields in media with curvilinear boundaries // DAN. — 2005. — Vol. 401, No. 4. — P. 529–532.