Scientific Infrastructure for the Support Studies the Geodynamic Process in the Seismic Prone Zones

Valery V. Kovalevsky, Lyudmila P. Braginskaya, Andrei P. Grigoryuk
Institute of Computational Mathematics and Mathematical Geophysics SB RAS
(ICM&MG SB RAS), Novosibirsk, Russia

Abstract - **The novel geoinformation technology and scientific infrastructure based on the methods of knowledge engineering for performing integrated researches of geodynamic processes in seismic prone zones, for studying the physical laws of geotectonics, based on the investigation of the deep structure and monitoring of the stress-strain state of seismically active regions by the methods of active seismology and mathematical modeling are proposed. Practical implementation of geoinformation technology is based on the data of long-term geophysical studies and vibroseismic monitoring of the Baikal rift zone.**

Index Terms – **Geoinformation technology, geodynamics, vibroseismic monitoring.**

I. INTRODUCTION

The effectiveness of research activities largely depends on the organization of meaningful access to common digital scientific data and to modern information tools that allow storage, retrieval, visualization and high level of data analysis [1]. In addition, the scientific community is experiencing an ever-increasing demand for services that allow researchers to get the fullest idea of both the subject of research and the results of research, and about scientific activity and persons developing various scientific methods in the subject domain.

Such support is necessary for scientists who are engaged in geophysical research and detailed study of such a complex geological structure as the Mongolian-Baikal mountainous region and the Baikal Rift Zone (BRZ). Baikal Rift Zone research by geophysical methods began in the middle of the 20th century [2]. Significant contribution to the study of the Baikal rift was made by the Institute of the Earth's Crust of the SB RAS, which formed a scientific school on the study of continental rifting. Anomalous decompaction in the upper mantle of the Earth was recorded under the Baikal rift from seismic data.

Geophysical methods of research play an important role in understanding the processes of geodynamics and rifting, allowing us to "see" the modern deep structure of the crust and mantle. The velocity model P-wave incision was constructed from seismic tomography data obtained during the Russian-American experiment in 1992 [3-5].

The researchers found that one low-velocity anomaly is located under Baikal. However, the second is located much more south, under the territory of Mongolia, where there is no stretching of the cortex. In other studies, in the works on deep seismic sounding on the profile crossing Baikal, a zone of increased velocities in the lower crust at depths of 30-40 km was identified [6].

Despite the large volume of geophysical studies, the single concept of Baikal Rift Zone rifting has not been developed to date. Most Baikal Rift Zone researchers are convinced that no one of the existing methods is capable of giving a complete and reliable answer to the question of how the processes of formation and evolution of rifts will develop. Only the integration of various research directions will allow scientists to establish which of the mechanisms of rifting predominated, whether their ratio varied with time, whether the processes of crustal expansion and magma formation are related or are two independent processes [7].

The same integration of scientific research is also necessary in solving problems related to the medium-term forecast of earthquakes.

II. PROBLEM DEFINITION

In modern geophysics, existing methods of geodynamic processes studying are based on various physical principles and the study of temporal changes in the parameters of various fields in the Earth's crust: seismic, electromagnetic, thermal, etc.

The study of geodynamics is a large section of geophysics and the results of research are presented in scientific articles and several general monographs on active and passive geophysical monitoring [8-10]. In geodynamics, research is often carried out independently of each other and not united by a common information space.

Most authors link the issues of geodynamics and methods of forecasting seismic hazard with the accuracy of monitoring changes in the structure-sensitive parameters - the velocities of seismic waves: longitudinal Vp and transverse Vs. A number of researchers are studying the relationship of geodynamic processes in the lithosphere in the zones of large active faults and focal regions of strong earthquakes with spatio-temporal variations of the seismic wave absorption field (damping of seismic waves) [11-13].

The use of active methods of vibrational seismic sounding and monitoring is a modern trend in the study of geodynamic processes in Baikal Rift Zone. Studies by the active

978-1-5386-7054-5/18/$31.00 ©2018 IEEE

seismology methodology include experimental work using powerful vibrational sources of seismic waves, recording of vibroseismic fields, processing of vibroseismic data, mathematical modeling of wave fields for realistic velocity models of the Earth's crust, analysis and comparison of experimental data with theoretical results. In these studies, the seismic vibrator CVO-100 of the South Baikal geodynamic test site of the SB RAS is used as a source of seismic waves.

The tasks of large-scale vibroseismic research are: the study of the characteristics of vibroseismic fields, the determination of the structure of the Earth's crust and the verification of existing velocity models, the identification of informative signs of geodynamic processes in vibroseismic monitoring of the geological environment. Vibroseismic methods are the most accurate in the determination of the spectral-temporal and polarization characteristics of the wave field and their changes associated with changes in the stress-strain state of the Earth's crust [14, 15].

The task of a joint study of seismogenesis processes based on estimating the parameters of the state of the medium from the analysis of multidimensional time series obtained by various methods at a large number of observation points has not yet been solved. This is connected, in our opinion, with three main problems.

The first problem is that the results of high-precision instrumental monitoring observations are unavailable for most researchers. On the example of solving the seismic forecast problem, this is expressed in the fact that monitoring systems often simply accumulate huge arrays of experimental data, and theoretical seismic predictions are based either on outdated information or on those pieces of instrumental data that are available to the researcher. Thus, inaccessibility for most researchers of long (long-term) series of seismic monitoring data ultimately hinders the detection of deviations from long-term trends in geophysical fields, which are possible threshold indicators for the occurrence of catastrophic earthquakes.

The second problem is related to the ontological complexity of the systems under study and the multifactor effect of physical fields of different nature on them [16]. As is known, the corresponding definitions are very complex and, what is significant, they are not always unambiguous. In this regard, the methods of artificial intellect and knowledge engineering are of particular relevance, which are capable of solving the problems of the cognitive model of the stress-strain state of the environment and establishing the semantic connection of the investigated objects, methods and experimental and computational data.

The third problem is that a wide range of researchers are not available convenient services for analyzing the parameters of time series, and in particular, vibroseismic wave fields, the recording of which is the main task of active vibroseismic monitoring of seismic prone zones. Therefore, the task of providing web services for visualization and analysis of wave field parameters from the data of multi-year instrumental measurements obtained at a large number of observation points covering the seismically dangerous territory is very actual.

The authors propose a developed infrastructure for scientific research, based on experimental and computational data of active vibroseismic monitoring of the Baikal rift zone. The information infrastructure creates a general informational field of the subject area and represents a set of computer systems, storage systems for the results of experimental and theoretical studies, GIS-services, information and computing.

III. Intellectual Internet-Resource for Integration of Data and Knowledge

In this work, an ontological approach to the information support of research in the field of active seismology is realized. It provides the integration of information resources of the subject domain without their physical merging.

An intellectual Internet resource [17] has been developed, the architecture of which can be represented in the form of two interacting subsystems.

The first of them - the Scientific Information System (SIS) "Active Seismology" - provides users access to data obtained during field and computer experiments on deep Earth sounding, the means of their visualization and analysis, has a cartographic service, and also includes a replenishment of users a thematic electronic library containing reports, full texts of articles and other documents [18, 19].

The basis of the Scientific Information System content is the experimental material accumulated as a result of years of geophysical monitoring of the Baikal rift zone, which has no analogues in the world either in terms of the duration of observations, nor in the regularity, or in the area of coverage of the seismically dangerous territory.

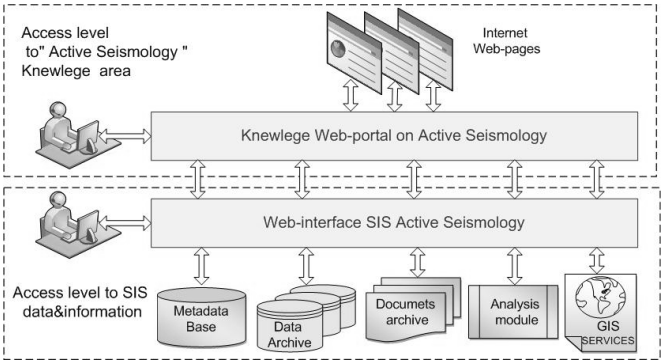


Fig. 1. Architecture of the Internet resource.

The second subsystem is the Knowledge Portal, which is designed both to systematize the subject domain as a whole, as well as heterogeneous data and means of processing them presented in the Scientific Information System (Fig. 1). The knowledge portal is developed by means provided by the Laboratory of Artificial Intellect of the ISI SB RAS [20, 21]. The conceptual basis of the information model of the knowledge portal is the ontology of the subject area "Active seismology" [22, 23].

Portal ontology introduces formal descriptions of subject domain concepts in the form of object classes and relationships between them, thereby setting up structures for representing real objects and their relationships

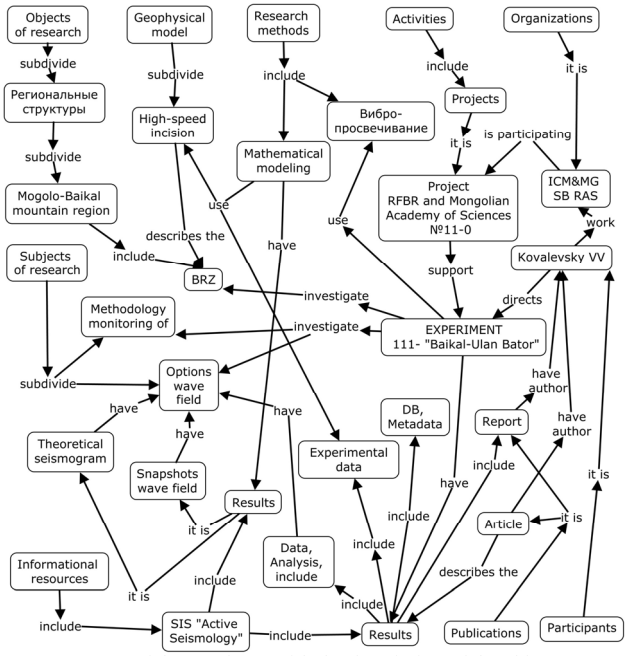


Fig. 2. Fragment of the ontology, with the description of the object "111 Experiment" Profile Baikal-Ulan-Bator ".

In accordance with this, the data on the portal are presented in the form of a semantic network, i.e. as a lot of different types of interconnected information objects (Fig. 2).

Object communications

hasAuthorResultOrganization

Organizations
Geological Institute of SB RAS
Institute of Computational Mathematics and Mathematical Geophysics SB RAS (ICMMG SB RAS)
Buryatia Division of Geophysic Survey of the Siberian Branch of the RAS
Mongolia Research Center for Astronomy and Geophysics (RCAG)

hasAuthorResultPerson

Persons
Avrorov (S.A.)
Braginskaya (L.P.)
Grigoruk (A.P.)
Kovalevsky (V.V.)
Odonbaatar (S.)

conduct research

Object of Study
Baikal rift zone and adjacent Mongolian areas

contains a description (metadata)

Databases
DB "Experiment-111"

contains data

Experimental data
111 - experiment #111 data (analysis, visualization)
101 Elbrus-2010 Experiment. Map. Description.

contains modeling results

ScientificResult_Product
Babushkin (Baikal) - Ulaanbaatar (Mongolia) profile wavefield
Babushkin (Baikal) - Ulaanbaatar (Mongolia) profile theoretical seismograms

contains results

InternetResource
SIS "Active Seismology"

Reverse object communications

usesProjectResult

Project
SB RAS Project 4.9 "Studies of the structure of the earth's crust and geodynamic processes in the southern part of the Baikal rift zone and northern Mongolia by vibroseismic methods"
RFBR and Mongolian Academy of Sciences joint project No. 11-05-92215 "Investigation of the characteristics of the wave field of a powerful vibrator for the purpose of vibroseismic sounding of deep structures of the Mongolian-Siberian region"

describesResult

Publications
H. Thybo Lower crustal intrusions beneath the southern Baikal Rift Zone: Evidence from full-waveform modelling of wide-angle seismic data
Karavaev (DA), Kovalevsky (VV), Fatyanov (AG) Verification of the speed models of the Earth's crust of the Baikal Region, constructed by the experiment BEST and PASSCAL
Braginskaya (LP), Grigoruk (AP), Kovalevsky (VV), Tubanov Vibroseismic research on the 500-km profile of Babushkin (Baikal) - Ulan-Bator (Mongolia)
Braginskaya (LP), Kovalevsky (VV) Report on field expedition work on the Ulan-Ude - Ulan-Bator profile
Mordvinova 3D model of the South of the Baikal Rift Zone and adjacent territories by exchange waves
Total: 6

containsActivitiesRresult

Activities
SB RAS integration project No 54 "Development of methods for mathematical modeling of geophysical fields and experimental studies of geodynamic processes in seismic and volcanic zones"
Presidium of the RAS Program No 4. Natural environment of Russia: adaptation processes in a changing climate and development of nuclear energy. IVM & MG SB RAS Project No 4.9. Natural environment of Russia: problems of modeling of seismic zones, monitoring of environmental pollution and climate change. 2012-2014
SB RAS Project No 4.9 "Studies of the structure of the Earth's crust and geodynamic processes in the Southern part of the Baikal Rift Zone and Northern Mongolia by vibroseismic methods"
RFBR and Mongolian Academy of Sciences joint project No. 11-05-92215 "Investigation of the characteristics of the wave field of a powerful vibrator for the purpose of vibroseismic sounding of deep structures of the Mongolian-Siberian Region"

Fig. 3. Portal page describing the experiment "Profile Baikal-Ulan-Bator".

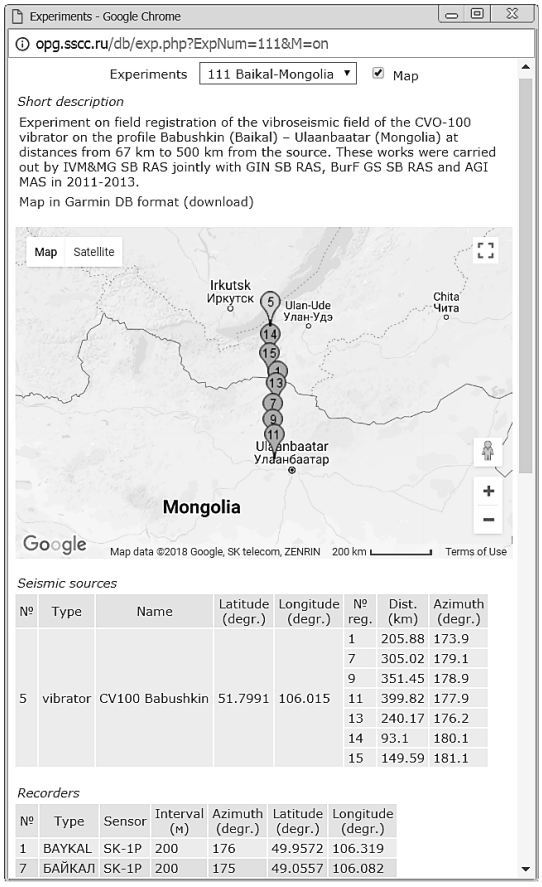
Content-based access to systematic knowledge and information resources is provided through portal-developed navigation and search tools, whose functioning is also based on ontology.

The ontology of active seismology is constructed by expanding two basic ontologies-the ontology of the subject domain and the ontology of scientific activity.

From the content point of view, the ontology of active seismology can serve to represent concepts of active seismology and related scientific fields of geophysics, as well as for activities carried out by persons and organizations within the framework of this scientific direction. Ontology establishes a semantic link between the object and the subject of research, the methods of research, the results of the research, persons, organizations, projects and publications associated with this experiment.

Information objects related to the object are presented on the Portal page with hyperlinks, allowing to go on to describe the organizations and individuals participating in this type of activity, the research methods used, publications, as well as to the experimental data base and the information and computing system. The Portal page "111 Experiment" Profile of Baikal-Ulan-Bator", which realizes the relations specified by the ontology is shown in Fig. 3.

The knowledge portal by hyperlinks allows you to refer to the Scientific Information System "Active Seismology", which contains detailed information (metadata) about the experiment.



№	Type	Name	Latitude (degr.)	Longitude (degr.)	№ reg.	Dist. (km)	Azimuth (degr.)
5	vibrator	CV100 Babushkin	51.7991	106.015	1	205.88	173.9
					7	305.02	179.1
					9	351.45	178.9
					11	399.82	177.9
					13	240.17	176.2
					14	93.1	180.1
					15	149.59	181.1

№	Type	Sensor	Interval (м)	Azimuth (degr.)	Latitude (degr.)	Longitude (degr.)
1	BAYKAL	SK-1P	200	176	49.9572	106.319
7	БАЙКАЛ	SK-1P	200	175	49.0557	106.082

Fig. 4. Page of SIS with the description of the experiment "Profile of Baikal-Ulan-Bator". The hyperlink from the Portal page.

This information includes the experiment map, the coordinates of the seismic signal recording stations, the type of recording equipment, the schedule of recording sessions. Fig. 4 illustrates the display in the user's web browser with information about the experiment "111 Experiment" Profile Baikal-Ulan-Bator ".

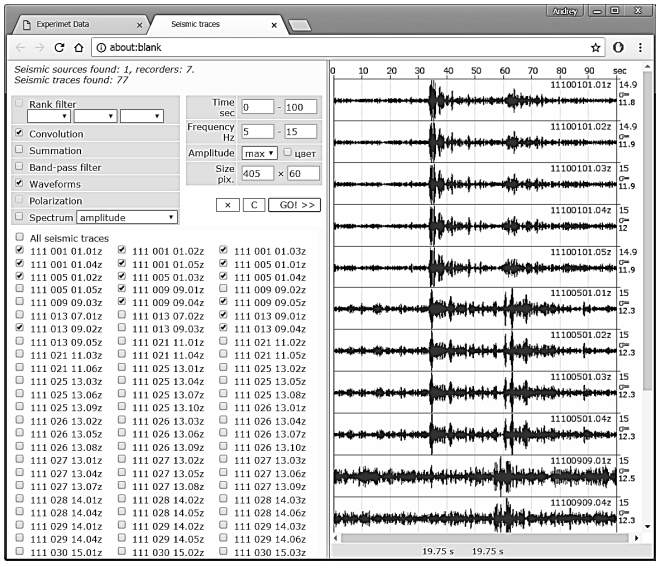


Fig. 5. The page of the SIS. Visualization and analysis of experimental seismograms. The hyperlink from the Portal page.

The reference to the SIS for obtaining information about the experiments is made through the request, which indicates the number and name of the experiment, the type of source, the characteristics of the emitted signal, the location of the source and recorders, and the time of the experiments.

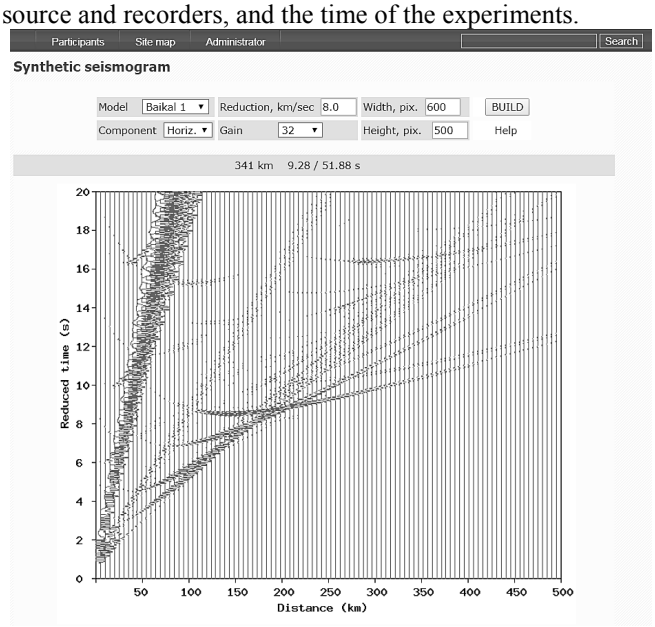


Fig. 6. Synthetic seismograms.

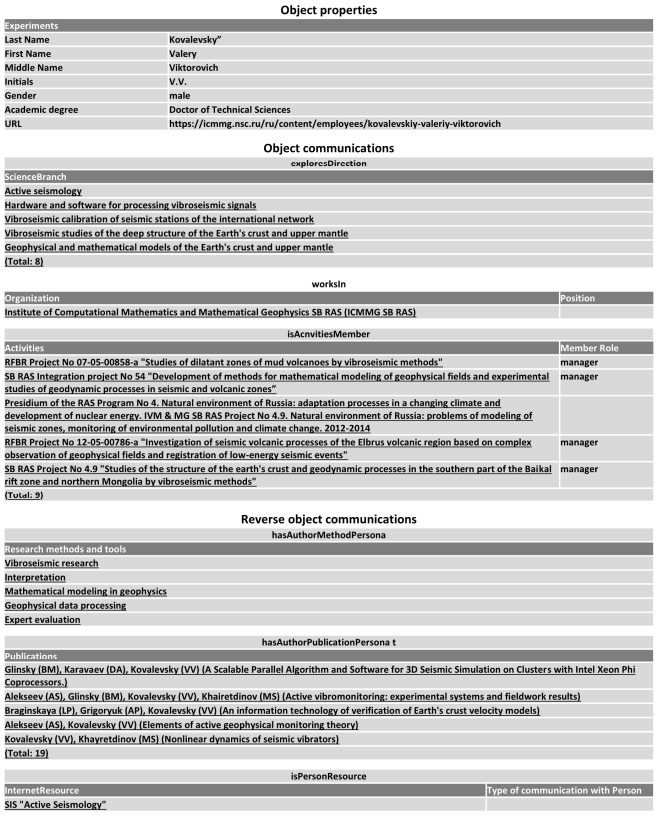
As a result of the processing of the request, a page of SIS is formed, indicating seismogram files, graphical representation of waveforms, spectral and polarization characteristics. An example of processing a request with a representation of the correlation seismograms of the selected sounding sessions on the Baikal-Ulan-Bator profile is shown in Fig. 5. SIS "Active Seismology" includes a section containing velocity models of the Earth's crust and data of mathematical modeling of vibroseismic wave fields [24-27]. This section is directly related to the task of verification of velocity models of the Earth's crust in the Baikal Rift Zone. Existing velocity models are constructed from the data of experiments performed by different methods and have significant qualitative and quantitative differences for the region.

The result of the transition by the hyperlink "Synthetic seismograms" of the Portal is presented in Fig. 6. Synthetic seismograms were obtained as a result of mathematical modeling of the full wave field for the velocity model of the experiment BEST (Baikal Explosion Seismic Transect) performed in the southern part of the RHL.

By hyperlinks from the Portal page, you can also transit to the texts of reports on experimental work on the profile Baikal - Ulan-Bator, full-text articles relating to the subject and object of research, describing the results of the research.

IV. ORGANIZATION OF SCIENTIFIC COMMUNICATIONS

At present, dozens of Russian and foreign teams are engaged in scientific activities related to BRZ research. Professional scientific activity assumes the scientist has a multitude of communicative contacts, and scientific research aimed at a specific object involves addressing a multitude of communication participants, each of which has a role in the process of accumulation and dissemination of scientific knowledge.



Object properties

Experiments	
Last Name	Kovalevsky"
First Name	Valery
Middle Name	Viktorovich
Initials	V.V.
Gender	male
Academic degree	Doctor of Technical Sciences
URL	https://icmmg.nsc.ru/ru/content/employees/kovalevskiy-valeriy-viktorovich

Object communications

exploresDirection

ScienceBranch
Active seismology
Hardware and software for processing vibroseismic signals
Vibroseismic calibration of seismic stations of the international network
Vibroseismic studies of the deep structure of the Earth's crust and upper mantle
Geophysical and mathematical models of the Earth's crust and upper mantle
(Total: 8)

worksIn

Organization	Position
Institute of Computational Mathematics and Mathematical Geophysics SB RAS (ICMMG SB RAS)	

isAcnvitiesMember

Activities	Member Role
RFBR Project No 07-05-00858-a "Studies of dilatant zones of mud volcanoes by vibroseismic methods"	manager
SB RAS Integration project No 54 "Development of methods for mathematical modeling of geophysical fields and experimental studies of geodynamic processes in seismic and volcanic zones"	manager
Presidium of the RAS Program No 4. Natural environment of Russia: adaptation processes in a changing climate and development of nuclear energy. IVM & MG SB RAS Project No 4.9. Natural environment of Russia: problems of modeling of seismic zones, monitoring of environmental pollution and climate change. 2012-2014	
RFBR Project No 12-05-00786-a "Investigation of seismic volcanic processes of the Elbrus volcanic region based on complex observation of geophysical fields and registration of low-energy seismic events"	manager
SB RAS Project No 4.9 "Studies of the structure of the earth's crust and geodynamic processes in the southern part of the Baikal rift zone and northern Mongolia by vibroseismic methods"	manager
(Total: 9)	

Reverse object communications

hasAuthorMethodPersona

Research methods and tools
Vibroseismic research
Interpretation
Mathematical modeling in geophysics
Geophysical data processing
Expert evaluation

hasAuthorPublicationPersona t

Publications
Glinsky (BM), Karavaev (DA), Kovalevsky (VV) (A Scalable Parallel Algorithm and Software for 3D Seismic Simulation on Clusters with Intel Xeon Phi Coprocessors.)
Alekseev (AS), Glinsky (BM), Kovalevsky (VV), Khairetdinov (MS) (Active vibromonitoring: experimental systems and fieldwork results)
Braginskaya (LP), Grigoryuk (AP), Kovalevsky (VV) (An information technology of verification of Earth's crust velocity models)
Alekseev (AS), Kovalevsky (VV) (Elements of active geophysical monitoring theory)
Kovalevsky (VV), Khayretdinov (MS) (Nonlinear dynamics of seismic vibrators)
(Total: 19)

isPersonResource

InternetResource	Type of communication with Person
SIS "Active Seismology"	

Fig. 7. The Portal page containing the description of the Person.

The portal provides quite full information about Baikal Rift Zone researchers developing the scientific direction - active seismology. Fig. 7 shows the page containing the description of the Persona on the Portal page.

The ontological approach to the systematization of information allows us to establish the connection of the Person with scientific activity, scientific events, methods and publications. By a hyperlink you can transit from the Portal page, both to a personal page, and to the site of the SIS "Active Seismology".

Scientific Information System "Active Seismology" is based on the principles of Web 2.0, according to which users directly participate in the creation of content, as well as in the organization of scientific communications. Scientific Information System is built on the basis of Joomla CMS.

Registered users of SIS are provided with the following features:

- additional fields in the user profile;
- advanced registration management
- lists of users;
- contacts between users;
- bookmarks in the user profile defined by the administrator;
- upload images by users;
- ability to manage via front-end;
- integration with many components, such as personal messaging systems PMS, mailing lists, forums, galleries.

Registered users of Scientific Information System can establish contact with site participants, publish their articles, and comment on the works of colleagues.

V. CONCLUSION

In the presented work the following provisions and results are new: the ontological approach to the development of the original infrastructure for studies of the geodynamic processes of seismically active regions.

The developed infrastructure contributes to the successful implementation of interdisciplinary Baikal Rift Zone research, since it solves the following tasks:

- Integration of knowledge and data on geophysical methods of Baikal Rift Zone research without their physical integration;
- creation of a network of communication and interaction of researchers so that they can participate professionally in receiving and discussing information, and also attract their colleagues from relevant disciplines;
- ensuring the transfer of actual scientific results, including experimental data
- provision of information and computing services

REFERENCES

[1] Shokin Yu.I., Fedotov A.M., Zhizhimov O.L., Barakhnin V.B. The Technology of Creating Large-scale Intelligent Information and Analitical Search Engines in Semistructured Data // Proceedings of the International Conference Computational and Informational Technologies in Science, Ingenering and Education (CITech-2015), pp. 78–79.

[2] Sherman S.I., Jin M., Gorbunova E.A. Recent strong earthquakes in Central Asia: regular tectonophysical features of locations in the structure and geodynamics of the lithosphere. Part 1. Main geodynamic factors predetermining locations of strong earthquakes in the structure of the lithosphere in Central Asia // Geodynamics & Tectonophysics. 2015, vol 6 (4), P. 409–436. (In Russian)

[3] Mordvinova V.V., Treussov A.A. Teleseimic tomography at geo transects in Central Asia / National Seismological Review of Russia to the International Association of Seismology and Physics of the Earth's Interior of the International Union of Geodesy and Geophysics 2007–2010. P. 40–44.

[4] Tiberi C., Deschamps A., Déverchère J., Petit C., Perrot J., Appriou D., Mordvinova V., Dugaarma T., Ulzibaat M., Artemiev A. Asthenospheric imprints on the lithosphere in Central Mongolia and southern Siberia from a joint inversion of gravity and seismology (MOBAL experiment) // Geophysical Journal International, 2008. vol. 175. 1283–1297,

[5] Anan'in, L.V., Mordvinova, V.V., Gots, M.F., Kanao, M., Suvorov, V.D., Tat'kov, G.I., Tubanov, T.A. Velocity structure of the crust and upper mantle in the Baikal rift zone from the long-term observations of broad-band seismic stations // Doklady Earth Sciences, 2009. –428(7), 1067–1071.

[6] Nielsen C., Thybo H., Lower crustal intrusions beneath the southern Baikal Rift Zone: Evidence from full-waveform modelling of wide-angle seismic data // Tectonophysics, 470 (2009), 298-318.

[7] Horst J. Neugebauer. Mechanical aspects of continental rifting // Tectonophysics, 94 (1983) 91-108

[8] Alekseev A.S., Tsibulchik G.M., Kovalevsky V.V. The basis of the theory of active geophysical (multidisciplinary) monitoring. Conception of source and surface dilatant zones / Handbook of Geophysical Exploration: Seismic Exploration, Active geophysical monitoring, 2010, vol. 40, pp. 105–133.

[9] Alekseev A.S., Glinsky B.M., Kovalevsky V.V., Khairetdinov M.S. Active vibromonitoring: experimental systems and fieldwork results / Handbook of Geophysical Exploration: Seismic Exploration, Active geophysical monitoring, 2010, vol. 40, pp. 55–71.

[10] Alekseev A.S., Glinskii B.M., Kovalevskii V.V. et al. Active Seismology with Powerful Vibrational Sources. / Editor in Chief G.M. Tsibulchik,. Novosibirsk: Inst. of Comp. Math. and Math. Geoph. SB RAS Publ., GEO SB RAS Publ., 2004 (in Russian).

[11] Aki, K. (1980). Attenuation of shear waves in the lithosphere for frequencies from 0.05 to 25Hz // Phys. Earth Planet. Inter., 74, 615-631.

[12] Dobrynina A.A., Sankov V. A., Chechelnitsky V. V., Déverchère J. Spatial changes of seismic attenuation and multiscale geological heterogeneity in the Baikal Rift and surroundings from analysis of coda waves // Tectonophysics. 2016. V. 675. P. 50-68.

[13] Dobrynina A., Sankov V., Chechelnitsky V. 1D model of codaQ attenuation in the Baikal rift system lithosphere // Abstracts of the Second European Conference on Earthquake Engineering and Seismology (2ECEES), 24-29 August, 2014, Istanbul, Turkey, electronic medium.

[14] Kovalevskiy V., Chimed O., Tubanov Ts., Braginskaya L., Grigoruk A., Fatyanov A. (2017). Vibroseismic sounding of the Earth's crust on the profile Baikal – Ulaanbaatar // Proceedings of the International Conference on Astronomy & Geophysics in Mongolia 2017, p. 261-265.

[15] Suvorov V.D., Mishenkina Z.M., Petrick G.V., Sheludko I.F., Seleznev V.S., Solovyov V.M. Structure of the crust in the Baikal rift zone and adjacent areas from Deep Seismic Sounding data // Tectonophysics, 2002, v. 351, p. 61—74

[16] Shuman V. N., 2011. Geological environment and the seismic process: management problems // Geo-fizicheskij zhurnal 33(2), 16—27 (in Russian)

[17] Ludmila Braginskaya, Valery Kovalevsky, Andrey Grigoryuk. Vibroseismic Monitoring Data Management on Web-Technologies Basis // Proc. 2017 International Multi-Conference on Engineering, Computer and Information Sciences (SIBIRCON 2017)

[18] Kovalevsky V.V., Braginskaya L.P., Grigoryuk A.P. Experimental data management using modern web technologies // The BSU Bulletin, 2, 16-23, February 2013 http://www.bsu.ru/content/page/1466/2_2013.pdf

[19] Grigoryuk A.P., Kratov S.V. Data Experiments Management on Web-Technologies Basis // Proc. 12th Int. Conf. on Act. Pr. of Electr. Instr. Eng., APEIE 2014, Novosibirsk, October 2014, Vol. 3, p. 259–261.

[20] Yury Zagorulko, Olesya Borovikova, Galina Zagorulko. Knowledge Portal on Computational Linguistics: Content-Based Multilingual

Access to Linguistic Information Resources // In Proc. of the 10th WSEAS Int. Conf. on Appl. Comp. Sc.e (ACS10). WSEAS Press, 2010. p. 255–262

[21] Yury Zagorulko, Galina Zagorulko. Ontology-Based Technology for Development of Intelligent Scientific Internet Resources. Intelligent Software Methodologies, Tools and Techniques // Proceedings of the 14th International Conference, SoMet 2015, Naples, Italy, September 15-17, 2015. Communications in Computer and Information Science, Vol. 532, Springer Intern. Publishing Switzerland 2015. p. 227–241

[22] Ludmila Braginskaya, Valery Kovalevsky, Andrey Grigoryuk. Structure and services of the information support system for vibroseismic researches // All-Russian Conference SDM-2017 CEUR Workshop Proceedings, Vol-2033, Published: 2016

[23] Ludmila Braginskaya, Valery Kovalevsky, Andrey Grigoryuk; Galina Zagorulko. Ontological approach to information support of investigations in active seismology // Computer Technology and Applications (RPC), 2017 Second Russia and Pacific Conference on Publication Year: 2017

[24] Fatyanov A. G., Terekhov A. V. High-performance modeling acoustic and elastic waves using the parallel dichotomy algorithm // J. Comp. Phys. (2011) Vol. 230. P. 1992–2003.

[25] Terekhov A. V. Spectral-difference parallel algorithm for the seismic forward modeling in the presence of complex topography // J. of Appl. Geoph., (2015) Vol. 115, P. 206-219.

[26] Karavaev D. A. (2009). Parallel implementation of the method of numerical simulation of wave fields in three-dimensional models of inhomogeneous media. Bulletin of the Nizhny Novgorod State University named N.I. Lobachevsky. № 6 (1). P. 203-209 [in Russian].

[27] Dmitry Karavaev, Boris Glinsky, V. Kovalevsky. A technology of 3D elastic wave propagation simulation using hybrid supercomputers // CEUR Workshop Proceedings of the 1st Russian Conference on Supercomputing - Supercomputing Days Moscow, 2015. Russia, September 28-29. pp. 26-33..

Kovalevsky Valery V., Doctor of Technical Sciences, Deputy Director for Science at the Institute of Computational Mathematics and Mathematical Geophysics SB RAS. Research interests: mathematical simulation in geophysics, vibroseismic investigations, geophysical informatics. Author and co-author of over 150 scientific papers.

Braginskaya Lyudmila P., Leading Programmer at the Institute of Computational Mathematics and Mathematical Geophysics SB RAS. Research interests: geophysical informatics, vibroseismic investigations, processing of vibroseismic data. Author and co-author of over 30 scientific papers.

Grigoryuk Andrey P., Researcher at the Institute of Computational Mathematics and Mathematical Geophysics SB RAS. Research interests: geophysical informatics, vibroseismic investigations, processing of vibroseismic data. Author and co-author of over 30 scientific papers.