Integration of Knowledge and Data in Active Seismology[1]

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Abstract. The paper presents the principles of organization of an information environment providing a holistic view of the subject area and various aspects of scientific activity in active seismology. The subject ontology "Active Seismology" is used as a conceptual basis and information model.
Keywords: active seismology, ontology, knowledge portal

1 Introduction

Since the 1970s a new direction in geophysics has been developing, which has recently been called active seismology, based on powerful controlled vibration sources of seismic waves of the low-frequency range [1].

The use of such sources has opened up new possibilities for investigations of the deep structure of Earth's crust and upper mantle and the geodynamic processes in earthquake-prone and volcanic zones. The active seismology methods have found application in new areas of geophysics and geophysical engineering. Currently, the following new vibrational geotechnologies are being actively developed: active vibroseismic monitoring of earthquake-prone and volcanic zones; vibroseismic action on oil formations to increase oil recovery; vibrational microseismic zoning; study of the stability of deep structures in areas of construction and operation of environmentally hazardous constructions, etc.

During the formation and development of the active seismology methods, numerous theoretical and experimental works have been carried out to substantiate the vibroseismic method, to study the processes of radiation of seismic waves by vibrational sources, the characteristics of their wave fields and physical effects under the vibrational action on the geological medium [2].

Scientific teams of the following institutes of the Siberian Branch of the Russian Academy of Sciences (SB RAS) participated in large-scale experimental vibroseismic investigations in Siberia, the Caucasus, and the Kerch-Taman mud volcanic province: The Trofimuk Institute of Petroleum Geology and Geophysics, the Geophysical Survey and its Altay-Sayan Branch, the Institute of Computational Mathematics and Mathematical Geophysics, and the Chinakal Institute of Mining. Scientists of the Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, the National Nuclear Center of the Republic of Kazakhstan, Japan, USA, and Mongolia took part in a number of experiments [3].

Currently, active seismology works are being carried out in Russia, Japan, China, the USA, and some European countries. In Japan, monitoring of earthquake-prone and fault zones of the Earth's crust is carried out with the ACROSS vibroseismic system. In the USA, the fault stressed state in the San Andreas Fault Zone is monitored using seismic vibrators.

At ICM&MG SB RAS, research works on active seismology were started under the scientific program "Vibrational Earth Sounding" of the Siberian Branch of the Russian Academy of Sciences in the 1970–90s under the leadership of Academician A.S. Alekseev. Experimental works on registration of the wave field from powerful vibroseismic sources have been carried out by the Institute since 1995. More than 50 experiments were performed (in Altai, the Baikal Rift Zone, the Taman Mud-Volcanic Province, Elbrus, and Mongolia). In these studies, a large archive of primary field data (about 100,000 registered seismograms) and the results of computer processing has been formed.

In the last decade, scientists of ICM&MG have been solving a set of problems on modeling of seismic fields in elastic media typical for earthquake-prone and volcanic zones using supercomputers [4, 5]. The results of these studies are not only scientific publications, but also archives of wavefield images and synthetic seismograms. One of the most important directions of the institute is the development of active seismology methods and mathematical modeling of wave fields for the purpose of verification of Earth's geophysical models [6, 7]. To solve this problem, a comparison of theoretical and experimental seismograms is needed.

Mathematical models of the Earth consider specific geological objects. When solving problems of modeling of wave fields, initial data, well logging data, values of the elastic parameters of the medium (the longitudinal and transverse velocities of elastic waves, the elastic medium density, and the geometry of the object of study) are used. The final representation of the Earth model is completed by interpretations (seismic interpretation, geological and geophysical interpretation, stratigraphic correlations, etc.)

These problems integrate successive stages of interpretation and modeling performed by professionals of different qualifications (geophysicists, seismologists, geologists). This raises the problem of explicit presentation of all data, interpretations and representations related to the process of modeling of specific geological objects.

In this paper, a solution to this challenge by formalizing and integrating the knowledge and data on the basis of ontologies is proposed.

2 Components of the Ontology "Active Seismology"

In recent years, ontological models have been increasingly used to integrate scientific knowledge. Much attention of the Earth science community has been given to defining ontologies for geological knowledge. In particular, ontologies based on geological knowledge can now be found on geological maps [8]. An ontology is typically constructed according to a practical purpose. Based on the goal, the subject area experts form a set of concepts (classes); a set of binary links (relations) between the concepts; a set of instances of classes — data records corresponding to a class or relation. Thus, structural models constructed for the oil and gas industry [9] are primarily used to describe the geological history for quantitative determination of hydrocarbons.

To integrate the knowledge of active seismology, we perform ontological engineering of the subject area [10]. In this case, the terms of the upper level, for example, the types of geological objects, are extracted from the known ontologies.

The ontology "Active Seismology" is based on a method [11] developed at the Artificial Intelligence Laboratory of the A.P. Ershov Institute of Informatics Systems SB RAS using two basic ontologies, namely, the ontology of scientific activity and the ontology of scientific knowledge. The ontology of scientific activity includes a set of concepts (classes) related to the organization of scientific activity in the field of active seismology, such as Person, Organization, Event, Activity, and Publication. This set of concepts is used to describe participants of the scientific activities, events, projects, and various types of publications.

Specific classes of the ontology of scientific activity in active seismology are Expedition Works and Field Experiments. In addition to a set of concepts, the ontology has a set of binary links (relations) between the concepts and a set of instances of classes - data records corresponding to a class or relation. Thus, for example, the class Person includes an object Sobisevich Leonid Evgenievich, who is connected by the relation "heads" with the object Complex ecological-geophysical expedition "Mud Volcanoes of Taman" of the class Expedition Works.

The second basic ontology — the ontology of scientific knowledge — contains the following metaconcepts that define structures for describing the subject area under consideration: Science branch (to typify the research being performed), Research method and Research object (to typify the research methods and objects and the structure for their description), Scientific result (to typify and describe the results of scientific activity), and Means of research (to typify the research equipment). The links between the classes are defined by different types of relations.

Figs. 1 and 2 present fragments of the ontology of objects and means of research, which reflects the structure of the classes "Research object" and "Means of research" and their semantic links with other classes and instances.

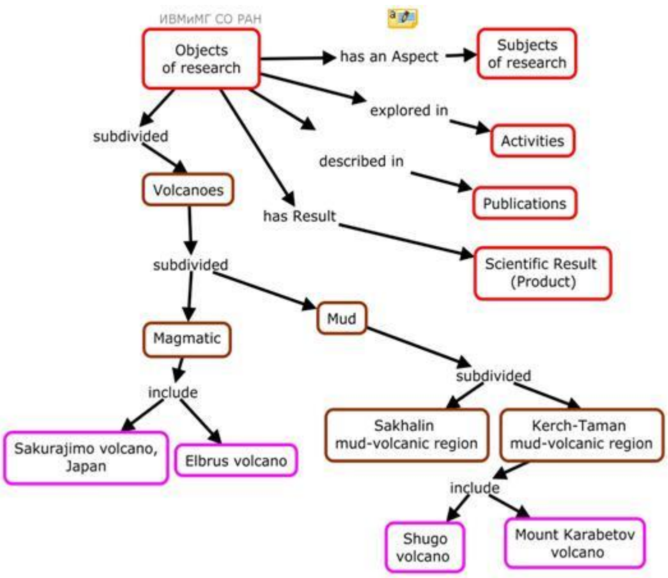


Figure 1. Ontology of research objects (fragment)

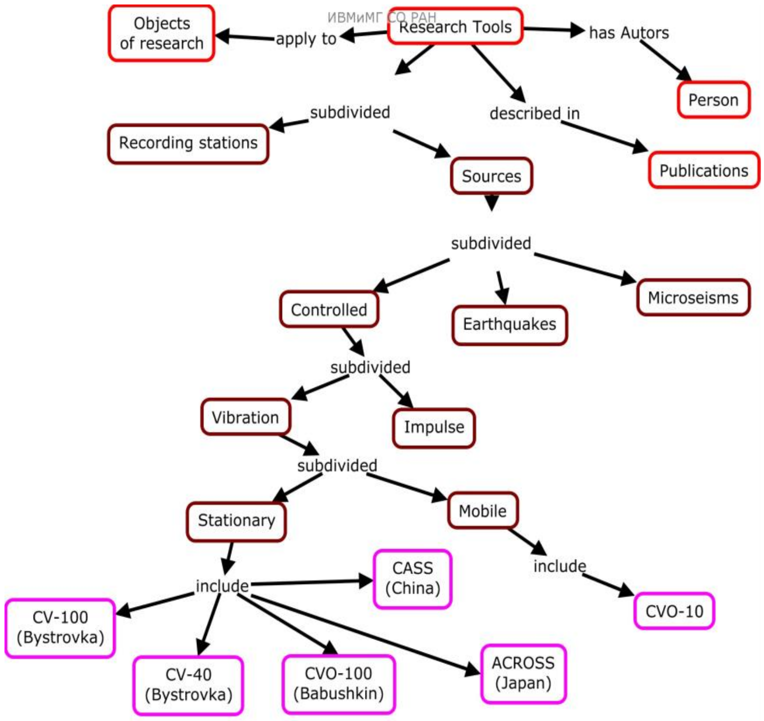


Figure 2. Ontology of means of research (fragment)

On the basis of the ontology, a knowledge portal on active seismology has been developed.

3 Active Seismology Knowledge Portal

The Geophysical Informatics Laboratory of ICM&MG SB RAS has developed an infrastructure to support research in the field of active seismology. The architecture of this environment can be presented as an Internet resource consisting of two interacting subsystems. One of them is the scientific information system (SIS) “Active Seismology” [12], which provides users with access to data obtained during field and computational experiments and means of their analysis, and includes a user-updated thematic digital library containing reports, full texts of articles, and other documents. The other is the knowledge portal.

The “Active Seismology” portal introduces formal descriptions of the subject area concepts in the form of classes of objects and relations between them, thus setting structures for presenting real objects and their relations. In accordance with this, the data on the portal are presented in the form of a semantic network, that is, as a set of different types of interrelated information objects.

Figure 3 shows the portal page containing a description of an object, Shugo volcano, corresponding to the ontology fragment shown in Figure 1. The information objects are represented on the portal page by hyperlinks. The hyperlinks of the knowledge portal make it possible to go to the SIS page “Active Seismology”.

Object properties

Mud Volcano	
Name of the object	Shugo (Shugo volcano)
Description of the object	The active mud volcano Shugo, one of the largest volcanoes in the Taman mud volcanic province.
Geographic Latitude	45°4'14 N
Geographic Longitude	37°36'39 E
Geophysical Model	http://opg.sscc.ru/index.php?option=com_content&view=article&id=101:2015-12-22-09-42-35&catid=25:2015-12-13-12-12-28&Itemid=45

Object communications

has an Aspect
Subject of the study
Anisotropy
Dilatancy
Speed, Propagation velocity
Fluid saturation
Environmental risks

has_result_product
Experimental data (in the VibroSounding ICS)
054-Experimental data Shugo volcano (visualization, analysis)

Reverse object communications

exploresObject
Activity
03-05-65292-a Project "Creation of a seismic method for monitoring the magmatic structures of volcanoes using powerful controlled sources (vibrators)"
07-05-00858-a Project "Research of dilatancy zones of mud volcanoes by vibroseismic methods"
Complex ecological-geophysical expedition on mud volcanoes of Krasnodar Territory (Taman mud volcanic province)-2005
Geophysical data processing
Expert evaluation

describesObject
Publications
Glinsky (B.M.), Sobisevich (A.L.), Fatianov (A.G.), Khairetdinov (M.S.) (Mathematical Simulation and Experimental Studies of the Shugo Mud Volcano)
Glinsky (B.M.), Khairetdinov (M.S.) (Analysis of structural changes in seismic wave fields in heterogeneous media of mud volcanoes and tectonic faults)
Alekseev (A.S.), Glinsky (B.M.), Kovalevsky (V.V.), Khairetdinov (M.S.) (Vibrational geotechnologies in the 21st century: state and prospects)
Sobisevich (A.L.) (The deep structure of mud volcanoes in Taman according to field studies and mathematical modeling)
Mud volcanoes of the Azov-Black Sea basin and the adjacent territory and assessment of their danger to buildings and structures
(Total: 21)

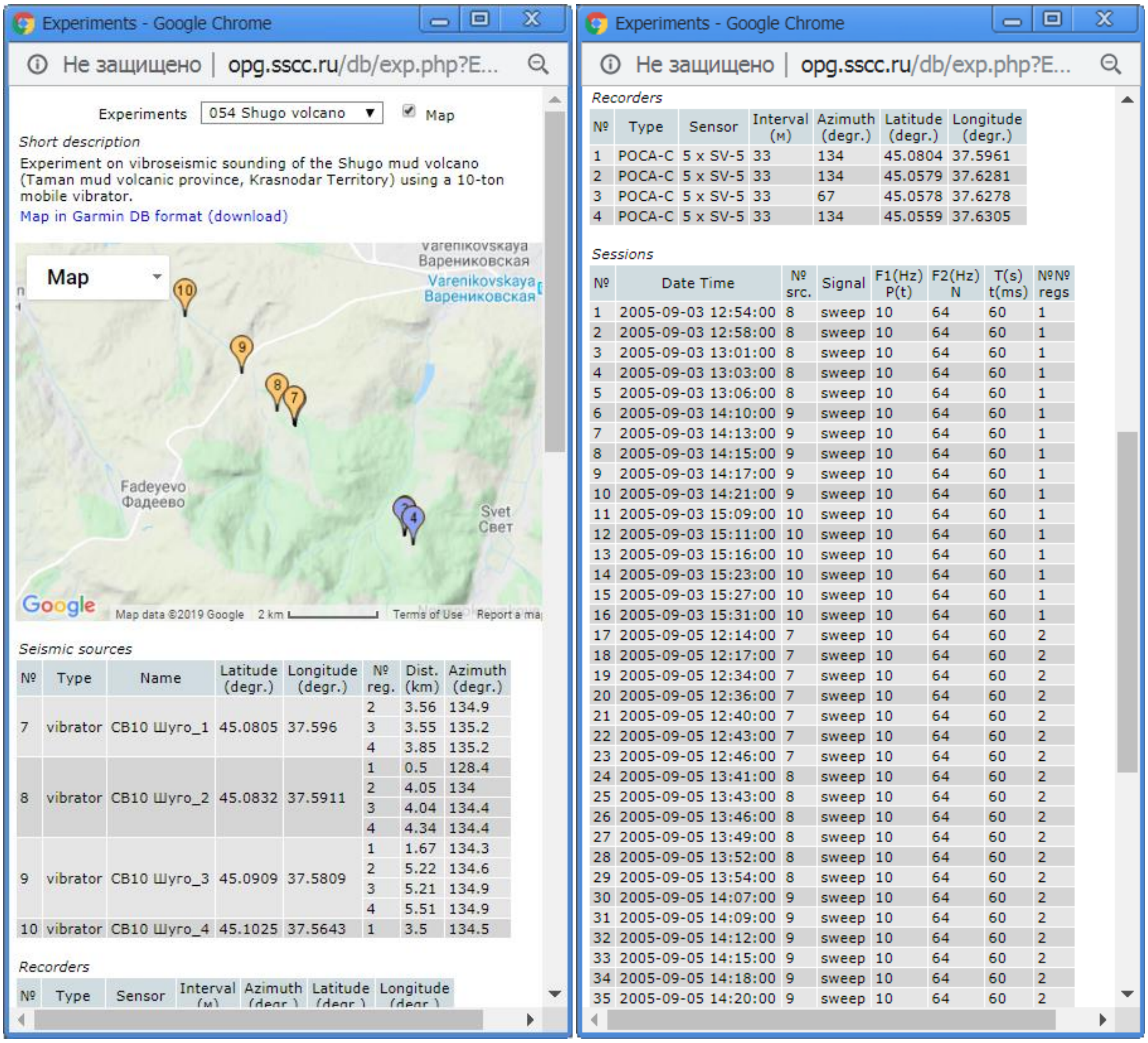
AppliesToObject
Research methods and means
VibroSounding
Geological and geophysical methods
Mathematical modeling of wave fields
Profile registration

doingResearch
Experiments
054-Experiment on vibration sounding of the Shugo mud volcano, which is a part of the Taman mud-volcanic province

isAspect
Subject of research
Amplitude-spectral
Anisotropy
Geological and geochemical properties
Geometry and structure
Resonance properties
(Total: 6)

Figure 3. Portal page

Fig. 4 shows the result of going to the SIS page "Active Seismology" from the portal page. The page contains a detailed description of the "Shugo-2005" experiment.



Seismic sources

№	Type	Name	Latitude (degr.)	Longitude (degr.)	№ reg.	Dist. (km)	Azimuth (degr.)
7	vibrator	CB10 Шуго_1	45.0805	37.596	2	3.56	134.9
					3	3.55	135.2
					4	3.85	135.2
8	vibrator	CB10 Шуго_2	45.0832	37.5911	1	0.5	128.4
					2	4.05	134
					3	4.04	134.4
					4	4.34	134.4
9	vibrator	CB10 Шуго_3	45.0909	37.5809	1	1.67	134.3
					2	5.22	134.6
					3	5.21	134.9
					4	5.51	134.9
10	vibrator	CB10 Шуго_4	45.1025	37.5643	1	3.5	134.5

Recorders

№	Type	Sensor	Interval (м)	Azimuth (degr.)	Latitude (degr.)	Longitude (degr.)
1	POCA-C	5 x SV-5	33	134	45.0804	37.5961
2	POCA-C	5 x SV-5	33	134	45.0579	37.6281
3	POCA-C	5 x SV-5	33	67	45.0578	37.6278
4	POCA-C	5 x SV-5	33	134	45.0559	37.6305

Sessions

№	Date Time	№ src.	Signal	F1(Hz) P(t)	F2(Hz) N	T(s) t(ms)	№№ regs
1	2005-09-03 12:54:00	8	sweep	10	64	60	1
2	2005-09-03 12:58:00	8	sweep	10	64	60	1
3	2005-09-03 13:01:00	8	sweep	10	64	60	1
4	2005-09-03 13:03:00	8	sweep	10	64	60	1
5	2005-09-03 13:06:00	8	sweep	10	64	60	1
6	2005-09-03 14:10:00	9	sweep	10	64	60	1
7	2005-09-03 14:13:00	9	sweep	10	64	60	1
8	2005-09-03 14:15:00	9	sweep	10	64	60	1
9	2005-09-03 14:17:00	9	sweep	10	64	60	1
10	2005-09-03 14:21:00	9	sweep	10	64	60	1
11	2005-09-03 15:09:00	10	sweep	10	64	60	1
12	2005-09-03 15:11:00	10	sweep	10	64	60	1
13	2005-09-03 15:16:00	10	sweep	10	64	60	1
14	2005-09-03 15:23:00	10	sweep	10	64	60	1
15	2005-09-03 15:27:00	10	sweep	10	64	60	1
16	2005-09-03 15:31:00	10	sweep	10	64	60	1
17	2005-09-05 12:14:00	7	sweep	10	64	60	2
18	2005-09-05 12:17:00	7	sweep	10	64	60	2
19	2005-09-05 12:34:00	7	sweep	10	64	60	2
20	2005-09-05 12:36:00	7	sweep	10	64	60	2
21	2005-09-05 12:40:00	7	sweep	10	64	60	2
22	2005-09-05 12:43:00	7	sweep	10	64	60	2
23	2005-09-05 12:46:00	7	sweep	10	64	60	2
24	2005-09-05 13:41:00	8	sweep	10	64	60	2
25	2005-09-05 13:43:00	8	sweep	10	64	60	2
26	2005-09-05 13:46:00	8	sweep	10	64	60	2
27	2005-09-05 13:49:00	8	sweep	10	64	60	2
28	2005-09-05 13:52:00	8	sweep	10	64	60	2
29	2005-09-05 13:54:00	8	sweep	10	64	60	2
30	2005-09-05 14:07:00	9	sweep	10	64	60	2
31	2005-09-05 14:09:00	9	sweep	10	64	60	2
32	2005-09-05 14:12:00	9	sweep	10	64	60	2
33	2005-09-05 14:15:00	9	sweep	10	64	60	2
34	2005-09-05 14:18:00	9	sweep	10	64	60	2
35	2005-09-05 14:20:00	9	sweep	10	64	60	2

Figure 4. SIS page. Result of going to the information-computational system via the hyperlink

Informative access to systematized knowledge and information resources is provided by the advanced navigation and search tools of the portal, which are also based on the ontology. Fig. 5 presents the example of search results. In this example, we search for publications in which the object of research is the Shugo mud volcano. The hyperlinks allow going to a description of the publications. One of the arguments of the object Publication is the URL address of a full-text article in the Internet; in a particular case it can be a page of the SIS library "Active Seismology".

PUBLICATION

hasAuthorPublicationPerson	Publication title	Publication date	Publication type
Glinsky (B.M.) Sobisevich (A.L.) Fatyanov (A.G.) Khairetdinov (M.S.)	Mathematical Simulation and Experimental Studies of the Shugo Mud Volcano 2008	2008	article
Glinsky (B.M.) Khairetdinov (M.S.)	Analysis of structural changes in seismic wave fields in inhomogeneous media of mud volcanoes and tectonic faults	2010	monograph
Alekseev (A.S.) Glinsky (B.M.) Kovalevsky (V.V.) Khairetdinov (M.S.)	Vibrational geotechnologies in the XXI century: state and prospects	2007	article
Sobisevich (A.L.)	Deep structure of mud volcanoes of Taman according to field studies and mathematical modeling	2015	
Sobisevich (A.L.)	Mud volcanoes of the Azov-Black Sea basin and the adjacent territory and assessment of their danger to buildings and structures		
Gubkin (I.M.)	Mud volcanoes of the Soviet Union and their relationship with the genesis of oil fields in the Crimean-Caucasian geological province		
Sobisevich ((L.E.)) Sobisevich (A.L.)	Study of the deep structure of zones of concentrated fluid activity in the Kerch-Taman mud volcanic province		
Glinsky (B.M.) Fatyanov (A.G.)	Study and monitoring of mud volcanoes by active seismic methods	2005	article
Sobisevich (A.L.)	Investigation of the deep structure of the Akhtyr flexure-fracture zone and the mud volcano Shugo		report
Glinsky (B.M.) Sobisevich (A.L.) Fatyanov (A.G.) Khairetdinov (M.S.)	Mathematical modeling and experimental studies of the mud volcano Shugo	2008	article
Shnyukov (E.F.)	On the deep structure of the eruptive channel of mud volcanoes		
Sobisevich (A.L.)	About mud volcanism in the Late Alpine folded structure of the North-West Caucasus (on the example of studying the deep structure of the mud volcano Shugo)	2014	journal
Glinsky (B.M.) Fatyanov (A.G.) Khairetdinov (M.S.)	On the ability to introduce vibroseismic methods for studying fluid-saturated and fractured environments	2006	
Glinsky (B.M.) Sobisevich (A.L.) Fatianov (A.G.)	Experience of the vibroseismic sounding of the complex geological structures (on the example of the Shugo mud volcano)	2007	article
Beloborodov (D.E.)	Features of geological structure and structural position of the largest mud volcanoes of the Kerch-Taman mud volcanoes of the Kerch-Taman region (on the example of mud volcanoes of Jardzhava, Karabetov Mountain, Dzhautepe, Shugo)	2017	journal
Sobisevich (A.L.)	Report on the work of the complex ecological-geophysical expedition on mud volcanoes of Krasnodar Territory (Tamanskaya mud volcanic province)	2005	report
Karavayev (D.A.)	Parallel implementation of the method of numerical simulation of wave fields in three-dimensional models of heterogeneous media	2009	article
Gorbatikov (A.V.)	Development of the deep structure model of the Akhtyrsk flexural-fracturing zone and Shugo mud volcano	2008	article
Sobisevich (A.L.)	Structural position and problems of occurrence of mud volcanic centers in the Late Alpine folded structure of the North-Western Caucasus (on the example of the study of the deep structure of the mud volcano Shugo)	2014	article
Fatianov (A.G.)	Numerical-analytical modeling of wave fields in different-scale zones of volcanic activity	2007	
Karavayev (D.A.)	Numerical modeling and experimental studies of the mud volcano "Karabetova Mountain" by vibroseismic methods	2009	article

Shown objects: 21 from 21

Figure 5. Search results page. Publications in which the object of research is the Shugo mud volcano

4 Conclusions

In this paper, some practical solutions for integrating the scientific concepts in active seismology and related fields of knowledge have been presented. Our solutions are based on the development of ontologies related to the subject area. The presented knowledge portal on active seismology allows linking data obtained in field and computational experiments with detailed information on the activity, persons engaged in the research, and text documents which can be helpful in the subsequent use of the data and interpretation of modeling results.

The ontology development is an iterative process. The above ontology will be supplemented with new concepts with the increasing group of experts engaged in the creation of the ontology. In our opinion, the work done is a first step towards solving the problems of knowledge integration in those Earth sciences which use the results of research in the field of active seismology.

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