Integrated geodynamic studies of the Tien Shan lithosphere: state and prospects

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Abstract. The results of integrated geophysical studies of the Tien Shan lithosphere, including the territory of the Bishkek geodynamic test site (Northern Tien Shan), are considered. The characteristics of the main directions of fundamental research are given and the prospects for their further development are shown. The results obtained during the implementation of a number of large projects on the study of the deep structure of the Earth's crust and the upper mantle of the Tien Shan by the method of magnetotelluric sounding are shown in order to identify the relationship of the near-surface structures of the Earth's crust with deep structures and the deep geodynamic processes responsible for them. The main objects of research were the junction zones of the Pamir and Tien Shan, Tarim and Tien Shan, as well as a series of regional profiles and the territory of the Bishkek geodynamic test site. On this basis, the main regional features of the distribution of geoelectric inhomogeneities in the geological environment were determined and geophysical evidence of the existence of a zone of lateral plastic flow in the Earth's crust under the Alai depression was obtained. To study catastrophic endogenous and exogenous processes, including the problems of forecasting and reducing the level of negative consequences, a system has been created with unique technical characteristics and a methodology for azimuthal magnetotelluric monitoring has been developed. The characteristics of research work on the creation of a system of complex geodynamic monitoring of the state of the Earth's crust in the seismically active Tien Shan region are given. The results of the listed fundamental studies have been published in a large number of Russian and foreign research articles. The breadth of the topics of geophysical research carried out on the territory of the Bishkek geodynamic test site made it possible to obtain significant volumes of new scientific information. The priority directions of improvement and development of the integrated geophysical monitoring system are shown.

1. Introduction
Establishing the Research Station of the Russian Academy of Sciences in Bishkek in 1978, the Academy of Sciences of the USSR, in accordance with its vision of the tasks and prospects of geophysical research at the forecasting areas of Central Asia, laid down a set of geophysical methods necessary for carrying out complex geological and geophysical research. The main goal of studying modern geodynamic processes and the tectonic movements caused by them was to clarify the position and degree of activity of faults and to search for prognostic signs of the seismic events.

An undoubted success of the cooperation of efforts of scientists working in the field of earth sciences in the Tien Shan can be the creation of the International Scientific Research Center - Geodynamic Testing Site (ISRC - GTS) (Fig. 1) and the Center for Collective Use of Equipment. The
main purpose is unification of the scientific potential of creative teams of academic institutions and organizations for joint research.

A significant contribution to the development of earth sciences in the Kyrgyz Republic was made by the collective monograph "Modern geodynamics of the regions of intracontinental collisional orogeny (Central Asia)" published under the editorship of Vladimir Ivanovich Makarov in the publishing house "Scientific World" in 2005. The monograph was dedicated to the memory of Yuri Andreevich Trapeznikov, the organizer of large-scale geodynamic research in Central Asia, the founder and first director of the Research Station of the Russian Academy of Sciences. It combines the results of research of all specialized academic institutions operating in the territory of the Kyrgyz Republic, as well as scientists from the near and far abroad. It so happened that this book reflected in itself all the main directions of research carried out at that time by the institutes, including the Research Station, showed the state of studies and outlined the prospects for further development. Even the table of contents of the monograph indicates to us the commonality of the research being carried out and the cooperation of the creative teams of the academic institutes of the National Academy of Sciences of the Kyrgyz Republic and the Research Station of the Russian Academy of Sciences.

Figure 1. Scheme of the territory of the Bishkek geodynamic test area (rectangular)

It became the first book of the XXI century, characterizing the state of geophysical study of the territory of Kyrgyz Republic, which made it possible to choose the main directions of development and formulate the tasks of further geological and geophysical research in the Tien Shan.

2. Materials and methods
One of the goals of geodynamics is to study the stress-strain state of the Earth's crust in seismically active regions in order to obtain the data necessary for predicting seismic hazard. The Tien Shan is a unique natural laboratory, where it expediently selected the territory on which an integration of geophysical and geodetic observations is carried out (in areas of active faults, at the junctions of individual geological blocks, etc.) using modern geophysical equipment. The geophysical monitoring system of the Bishkek geodynamic test site (BGTS), with the territory of 150x100 km, includes:

- 7 stationary magnetic stations MV-07 (developed by the RS RAS), operating on the principle of nuclear resonance. Full vector, 1 measurement in 20 sec., electronic archive since 1994;
- 2 magnetotelluric stations Phoenix MTU-5D, data recording is carried out day and night in the range of periods 0.01-1000 s;
- a network of KNET seismometers, consisting of 10 broadband seismic stations located on the territory of 40.5° -43.5° N, 72.0° -78.0° E (channels 1Hz, 40 Hz, 100 Hz). Measurements have been carried out since 1999;
gravimeter since 2010, sampling from 15 sec. up to 5 min., which is used to analyze lunisolar tides. A comparison is made with the data on tidal deformations and stresses obtained by calculations and from the data of gravimetric observations;

- 10 permanent GPS stations of the IGS network, registration has been carried out since 2007, 1 measurement per 30 sec., POL3 GLONASS station with 1 Hz resolution;

- electromagnetic observations by the TDES method in the "dipole-dipole" modification. As a source of excitation of the electromagnetic field, the EEGS-600-2 pulse system is used, which sends a series of alternating pulses of ± 600 A with a duration of 5 s, a session duration of 10 minutes, 6 sessions per working day to a supply dipole 4.2 km long. Observations are recorded at 6 stations, the processing result is daily series of apparent electrical resistance.

3. Results

At present, the RS RAS is working in three fundamental areas of research:

- Physical fields, internal structure of the Earth and deep geodynamic processes. Within the framework of this direction, the Research Station is studying the deep structure of the Earth's crust and upper mantle of the Tien Shan by the method of magnetotelluric sounding in order to identify the relationship of near-surface structures of the Earth's crust with deep structures (Fig. 2) and the deep geodynamic processes responsible for them [1-6].

- Catastrophic endogenous and exogenous processes, including extreme changes in space weather: problems of forecasting and reducing the level of negative consequences. The main objects of the study are the variations of physical fields recorded at the monitoring points of the territory of the Bishkek geodynamic test site [7-13].

The scientific base for the development of methods and technologies for studying the surface and interior of the Earth, the atmosphere includes the ionosphere and magnetosphere of the Earth, hydrosphere and cryosphere; numerical modeling and geoinformatics: spatial data infrastructure and GIS technologies. The Research Station pays most attention to the development of mathematical methods in geology and geophysics to improve the unambiguity, reliability and information content of geological and geophysical research [14, 15].

Figure 2. Scheme of magnetotelluric profiles in the Tien Shan: 1 - MTS points, 2 - DMTS (deep magnetotelluric sounding) points, 3 - main fault structures, 4 - border of the Kyrgyz Republic;
What has the Research Station managed to do for the development of earth sciences in the Kyrgyz Republic since the publication of the above-mentioned collective monograph to the present day?

1) In 2007-2008 by joint efforts of Russian, American (USA), Kyrgyz and Chinese organizations and specialists within the framework of the international program "Geodynamics of the Tien Shan", coordinated work on active seismic sounding along the MANAS profile (Middle Asian Active Seismic profiling) was carried out. During seismic sounding along the MANAS profile detailed magnetotelluric sounding, GPS observation of deformations the surface of the Earth's crust and seismic transmissions using natural (earthquakes) and artificial sources (explosions in wells) along a 267 km profile in the Kyrgyz Tien Shan were made. Based on the results of a set of studies, a number of articles [1-4] and a monograph [7] were published, and a completely new direction in the integration of research of the Research Station of the Russian Academy of Sciences – petrophysics was started (Fig. 3) [5].

Another very interesting object for the study of the deep structure was the junction zone of the Pamirs and Tien Shan, where for the period from 2007 to 2013 an extensive range of field geophysical work was carried out, which included GPS observations and magnetotelluric sounding. The main results can be considered as:

- determination of the structure of modern movements of the Earth's crust in the territory of the Pamirs and its near northwestern surroundings according to GPS observations, it is shown for the first time that the Pamir mountain range is not a single block, differences in horizontal velocity vectors of 3-10 mm / year [16, 17];
- on the basis of magnetotelluric and magnetovariational data, a deep geoelectric model of the lithosphere of the Alai junction zone of the Pamir and Tien Shan was constructed [18, 19];
- geophysical evidence was obtained for the existence of a zone of lateral plastic flow in the Earth's crust under the Alai basin, which manifested itself in the form of a lower crustal conductive structure, traced over an area of at least 200 km in the sublatitudinal direction along the strike of the Alai basin [14]. This stage of geophysical research is described in detail in the monograph [20].

2) In the study of the distribution of the speed of modern movements of the Earth's crust in the territory of Central Asia using the means of space geodesy, the main result obtained is associated with the construction of a model for the distribution of modern deformation of the earth's crust in the region under study. Thus, based on the data of long-term GPS measurements, the current deformation of the Earth's crust in the region of the junction of India and Eurasia can be represented as the movement of different-sized minimally deformable domains separated by zones with an increased velocity of displacements. The kinematics of motion within the zones between the domains depends on their spatial direction: NE — left-lateral strike-slip faults, sublatitudinal — transverse shortening, SE — right strike-slip, submeridional — transverse elongation [21].

This corresponds to the regular distribution of fault kinematics in the study region based on geological data. The orientations of such zones of transverse shortening (~ 82 °) and elongation (~ 172 °) coincide with accuracy up to the first degrees with the calculations of the average directions of the principal axes of the horizontal deformation tensor of the velocity field and earthquake focal mechanisms within the Central Tien Shan.

3) In the study of catastrophic endogenous and exogenous processes in order to predict earthquakes and reduce the level of negative consequences, the main result is the development of a system of integrated geodynamic monitoring, the main results of which are the following:

- research work on the creation of a system of complex geodynamic monitoring of the state of the Earth's crust in the seismically active Tien Shan region carried out in the depth range from 1 to 30 km on the basis of deep electromagnetic sounding using powerful sources of electric current. The created system includes a powerful electric pulse installation and a set of receiving electromagnetic stations located in the vicinity of Bishkek (the territory of the Bishkek geodynamic test site) and a modern network of automatic seismic stations. This system has unique technical characteristics and is the only system of this type in the world [23].
The system is designed to carry out work on forecasting topics in seismically active regions in order to reduce seismic risk, search for deep-lying minerals on the continent and in shelf zones, as well as for dynamic impact on the environment in order to discharge accumulated tectonic stresses in the locations of nuclear power plants, large mining and hazardous productions. As a result of regular electromagnetic impact on the Earth's crust using this powerful electric pulse installation, the effect of unloading tectonic stresses in the Earth's crust is revealed, as evidenced by a significant deficit of strong earthquakes (energy class K> 8) on the territory of the Bishkek geodynamic test site after the start of active use of the electromagnetic pulse installation RS RAS.

Such unloading is realized due to the generation of a multitude of micro earthquakes when conducting electric sounding sessions over a large area around the emitting dipole.

Figure 3. Assumed contours of deep massifs of spinel lherzolites, eclogite-like rocks and granulites on the geolectric model along the 76° E profile through the Tien Shan [22]; the numbers above the section show the numbers of the points of the DMTS.

- studies of the seismoelectromagnetic effects of the Kambarata industrial explosion were carried out [12, 13]. A stable response of variations in the apparent electrical resistivity in the range of effective depths from 1.5 km to 5 km to a change in the stress-strain state of the medium, initiated by a large industrial explosion. To explain the registered variations in electrical resistance, a hypothesis on the redistribution of the fluid in the system of connected fractures during deformation of the rock mass.

- laboratory experiments were carried out on rock samples under the influence of uniaxial compression and electrical impulses. It was found that the effect of an electromagnetic field leads to the redistribution and clustering of defects in the region of the future macroscopic discontinuity [11]. Before the electromagnetic effect, defects - sources of acoustic emission signals are diffusely scattered throughout the entire volume of the sample. When electric pulses are applied, the number of acoustic emission events increases, and a large fraction of them is concentrated in a certain region (“cluster”), which is the zone of initiation of the main crack, and where, subsequently, one of the rupture planes is formed.
The accumulation of information on the behavior of variations in electromagnetic parameters raised the question of the development of methods for processing, presenting, and analyzing data [13]. The zones of increased fracturing of the Earth's crust have been determined [13,24], which are the main structural features that affect various physical processes occurring in the Earth's crust.

4) The most important moment in the improvement and development of the integrated geodynamic monitoring system is the development of unique measuring equipment and software, which the Research Station performs on its own. To modernize the current system of active electromagnetic monitoring [14]: installed and introduced into the technology of active electromagnetic monitoring of the Earth's crust, measuring stations, made on a modern element base with the use of new methods and algorithms for signal processing, as well as a software package for the central point of data collection and processing adapted to new measuring stations. High technical characteristics of new stations, such as a large dynamic range (100 dB) and a wide range (0 - 400 Hz) of recorded signals, as well as high accuracy and stability of the synchronization parameters of processed signals (10-8) increased (3-10 times) the accuracy of measuring the electrical resistance of rocks in comparison with the single-channel measuring stations used until now, which makes it possible to expand the range of investigated depths of the earth's crust and the area of the monitored territory [24].

In order to discuss the current state of the problems and results of the study of geodynamics and geoeconomy of inland orogens, including questions about the mechanisms of formation of the structure of the lithosphere, the development of methods, technologies and means for studying the surface and the interior of the Earth, the socio-economic and ecological consequences of endogenous and exogenous catastrophic processes, the Research Station on a permanent basis based on International Symposia (2000, 2002, 2005, 2008, 2011, 2014, 2017, 2021) and International Young Investigator Conferences (annually).

4. Conclusion and Research Prospects
First of all, this is the support and all-round development of fundamental science, since it is this that ensures the acquisition of new knowledge in all fields of science, including the earth sciences. It is very important here to correctly prioritize for further movement forward. For us, such priority areas of activity are:

- Improvement and development of the system of integrated geodynamic monitoring (forecasting research), as the basis for solving the problem of forecasting and reducing the level of negative consequences from catastrophic processes.
- Development of a reliable geological and geophysical model of the structure of the Tien Shan lithosphere at various spatial and scale levels using petrophysical data.
- Expansion of the frequency range of research into the high-frequency region (for magnetotelluric soundings).
- Development of technology to reduce the risk and reduce the consequences of natural and man-made disasters through regular electromagnetic impact on the Earth's crust using a powerful electric pulse installation.
- Increasing the efficiency of using the results of scientific and scientific and technical activities, including their popularization in the media.
- Development of international scientific and technical cooperation.
- Preservation and development of human resources, integration of science and education.

Successful implementation of these priority areas of fundamental research in the field of earth sciences can be ensured by:

- huge scientific potential of creative teams of academic institutes, gathered under the auspices of the International Research Center - geodynamic testing ground;
- the presence of a Center for Collective Use of Equipment, which makes it possible to organize and conduct joint research at a high scientific and technical level;
- close ties with the international scientific community.
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