# THE FIRST RESULTS OF PALEOSEISMOLOGICAL STUDIES BETWEEN OXFORD UNIVERSITY AND REPUBLICAN SEISMIC SURVEY CENTER OF ANAS

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## Introduction

Science is the key to understanding the dangers of earthquakes and reducing the damage and loss of life caused by these events. It was not until the 1960s that seismic waves from earthquakes were proven to be caused by shifts on faults. Today, the knowledge of modern seismology makes it possible to solve a variety of applied and theoretical problems related primarily to the assessment of seismic hazard, based on information about the structure of all active geological structures. This knowledge will allow the creation of maps of risk zones to assess the likelihood of an earthquake, and then take steps to mitigate the associated risk. The methods and tools used in the Republican Seismic Survey Center have already gone far from traditional seismology and now Azerbaijan is investing in these new technologies that simply did not exist 20 years ago.

Paleoseismology is a young field of geosciences based on the contributions of seismology, tectonics, earthquake geology, sedimentology and Quaternary geology. The fundamental importance of the results of paleoseismology for the reliable determination of seismic hazard at a site or in an area has been recognized over the past two decades [4, 5, 7].

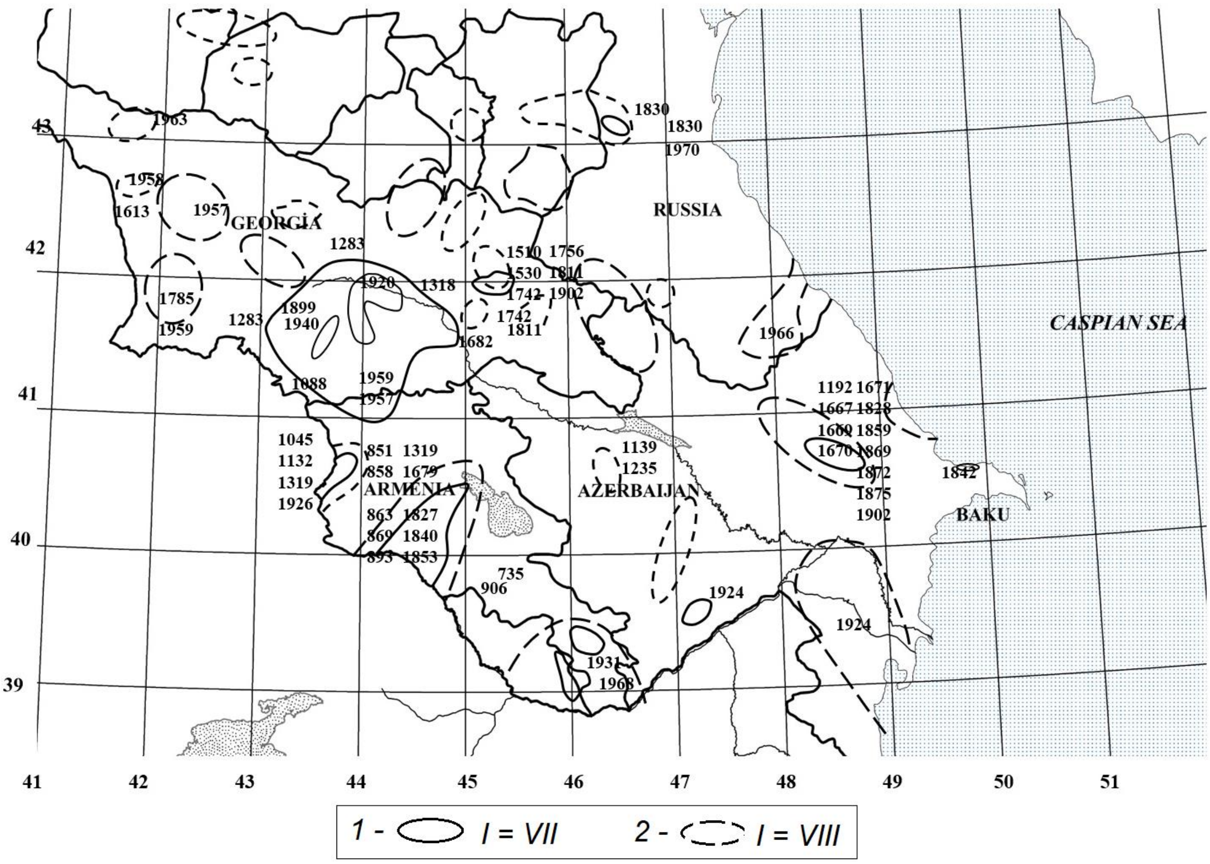


*Figure1. Map of the strongest earthquakes in the Caucasus [8]*

Older seismic dislocations, if they can be identified, cannot be used to determine the level of modern seismicity. In many seismically active zones, the seismic regime changed dramatically during the transition from the Lower to the Upper Holocene (about 5 thousand years ago). Paleoseismology

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makes it possible to determine the upper level of seismicity for the entire region as a whole and especially for specific seismogenic zones, to estimate the frequency of maximum earthquakes, and to trace the evolution of seismicity in separate stages of the Quaternary history. Geological evidence of earthquakes that occurred long ago is the only source of information for establishing the future seismicity of the region for very long periods. This is required by building codes for conventional buildings, as well as regulations for special buildings with a seismic hazard. For example, the new version of the German regulations for the construction and operation of nuclear reactors (called "KTA 2201.1") explicitly requires knowledge of paleoseismic data. Paleoseismology has advanced particularly seriously in California, Italy, Japan, and northern India and makes a significant contribution to our knowledge of the earthquake hazard in these regions [9].

As is known, the junction zone of mountain structures of the Greater and Lesser Caucasus is characterized by high tectonic activity, which is manifested by a variety of discontinuous-folded deformations of young deposits and landforms. Catastrophic destructive earthquakes have repeatedly occurred on the territory of Azerbaijan, such as Gandja in 1139 or Shamakhi in 1667 and 1902. Map 1 shows a macroseismic map of strong earthquakes compiled according to historical data in [8] the Greater Caucasus. Such events are accompanied by mud volcanism (fig. 1, 2), changes in the river network, and local areas of anomalously high activity of denudation processes.

Strong earthquakes of the globe occur in heterogeneous zones that differ sharply in the history of geological development, modern morphostructure, tectonic stress fields, and physical properties of the substrate in the foci. These circumstances have a direct impact on the morphology, morphometry, and genetic types of emerging seismic dislocations and should be taken into account when creating regional seismogeological scales for determining the intensity of earthquakes from residual deformations of the earth's crust [10].

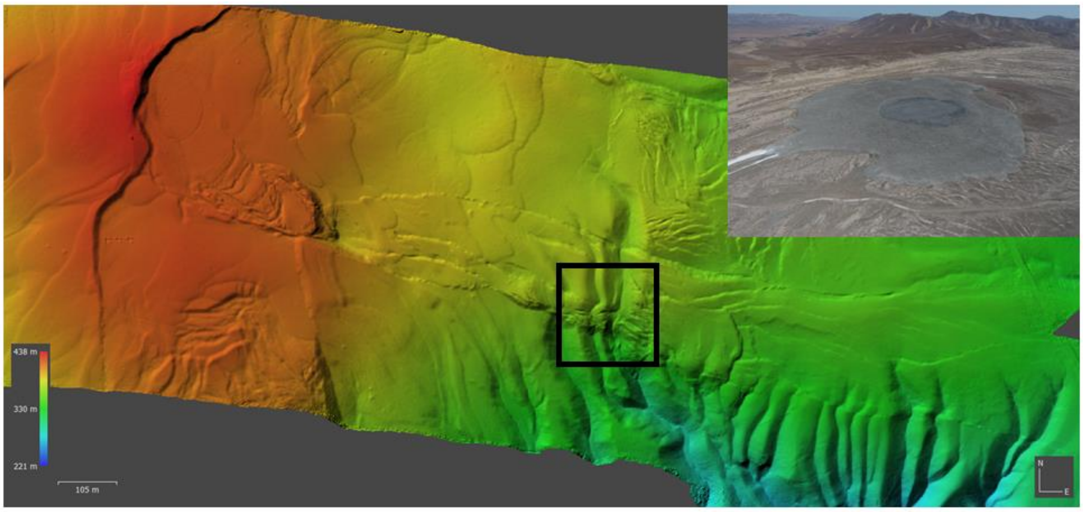


*Figure 2. Gobustan: strike slip fault and mud volcano Akhtarma Pashali*

However, the surface of the region over the past decades has been almost completely changed by human agricultural and construction activities. Capital new buildings - beautiful residential buildings, administrative complexes, and bridges are truly monuments of the revived traditions of national architecture. In such conditions, the integration of geological and geophysical methods is of particular importance. A unique network of seismological, geophysical, geodetic and geochemical studies was created at the RSSC, which makes it possible to study the dynamics of geodynamic processes directly when they occur and quickly respond to changes in the seismic situation in a particular area, which significantly expanded the possibilities of round-the-clock monitoring of the geodynamic situation of the republic.

**The main goals of the project**

In April 2021, negotiations began on the creation of a mega-project to study active tectonics and earthquakes in a vast territory stretching from China, through the Tien Shan Mountains to Kyrgyzstan, Turkmenistan, Iran and Turkey. Azerbaijan's participation in this serious project creates an excellent opportunity for cooperation between young Azerbaijani scientists of the RSSC with scientists from Oxford, Cambridge, California, Arizona and other universities, as well as with leading specialists from BP and SOCAR oil companies.

An important role in Azerbaijan's accession to this megaproject was played by Professor, Correspondent Member of ANAS Rashid Javanshir, Academician Ibrahim Guliyev, general director of the RSSC, Correspondent Member of ANAS, Professor Gurban Yetirmishli, Professor of Oxford University Richard Walker. We note that prof. Richard Walker is the author of numerous papers [1-3, 6] on paleoseismology.

The project will include the study of the history of tectonic development, active tectonics, earthquakes and natural risks and hazards that are possible in the Greater Caucasus and the South Caspian basin. The program includes a full range of studies - from the interpretation of seismic data at sea to tectonic geomorphology and paleoseismology on land.

First of all, it must be taken into account that paleoseismological observations are an integral part of complex seismological, seismogeological and geophysical studies. According to the analysis and interpretation of seismological, geophysical, geodetic data of the Republican Seismic Survey Center, results will be obtained on the history of tectonic development, active tectonism, prognosing of possible earthquakes and potential risks and dangers associated with them both for settlements and for a critical infrastructure network in the region, including pipelines.

During April and May 2022, a team of five scientists from the Department of Geosciences at Oxford, supervised by Professor Richard Walker, in collaboration with the young scientists of the RSSC, conducted the first field geological studies on paleoseismology, earthquake geology and active tectonics of Azerbaijan. Mr. Gurban Yetirmishli, General Director of the RSSC, provides great assistance in this study. The purpose of this study is to understand the possible locations and frequency of highly destructive earthquakes (M7+) that occurred prior to the development of modern seismic networks in the mid-20th century.

**Field work at Aghsu and Salyan sites**

We have focused on active faulting within the Kura basin and along the fold and thrust belt south of the Caucasus range front. We are aided in mapping and site selection through a satellite derived ~1 m digital elevation model obtained through the CEOS program (fig.3). Active faults have been mapped and a number of sites visited in the field, with drone surveys acquired over key sites. Two paleoseismic trenches have been excavated, with several more sites selected for future field visits. Long-term geological slip-rates have been measured from displaced river terraces. This study used advanced technologies including satellite imaging, drone simulation, GPS and InSar technologies, seismic deployment and paleoseismic excavation to study earthquake tectonic faults in Aghsu, Goychay, Ismayilli, Shirvan, Gobustan and Salyan districts. Two main sites were chosen for the initial detailed paleoseismic excavations. The first region was in Aghsu, and the second in the Salyan district.

In Aghsu, a trench was dug across the ledge of the fault, formed by the surface trace of the fault of the Main Caucasian Thrust. This trench found traces of two paleoseismic earthquakes and a total of 6 m of thrust displacement. These earthquakes probably had a magnitude of 7.0 and both occurred within the last 1000 years. It should be noted that this zone is composed mainly of clayey Paleogene and Miocene deposits of great thickness, folded into linear and brachiform folds. Folding in this region was most significant in the Late Miocene. A team of researchers from the University of Oxford will conduct a laboratory analysis of sedimentary rock samples to determine the exact timing of earthquakes. In the Ismayilli district, a temporary network of 30 (at a distance of 2.5 m) portable seismic stations was deployed to record microseismic earthquakes and study the structure of the surface crust.

In the Kura basin, adjacent to Salyan (fig.4), our satellite-based fault mapping revealed a series of very active strike-slip faults in a region with little modern seismicity. It should be noted that the transverse tectonic zone of the territory of the Caucasus, due to the existence of deep faults of the anti-Caucasian strike, is emphasized by the high values of horizontal gradients of isostatic anomalies in the zones of these faults. We have excavated successful trenches across the Kura faults (that reveal multiple surface-rupturing earthquakes. Age dating of these events is in progress (fig.5).

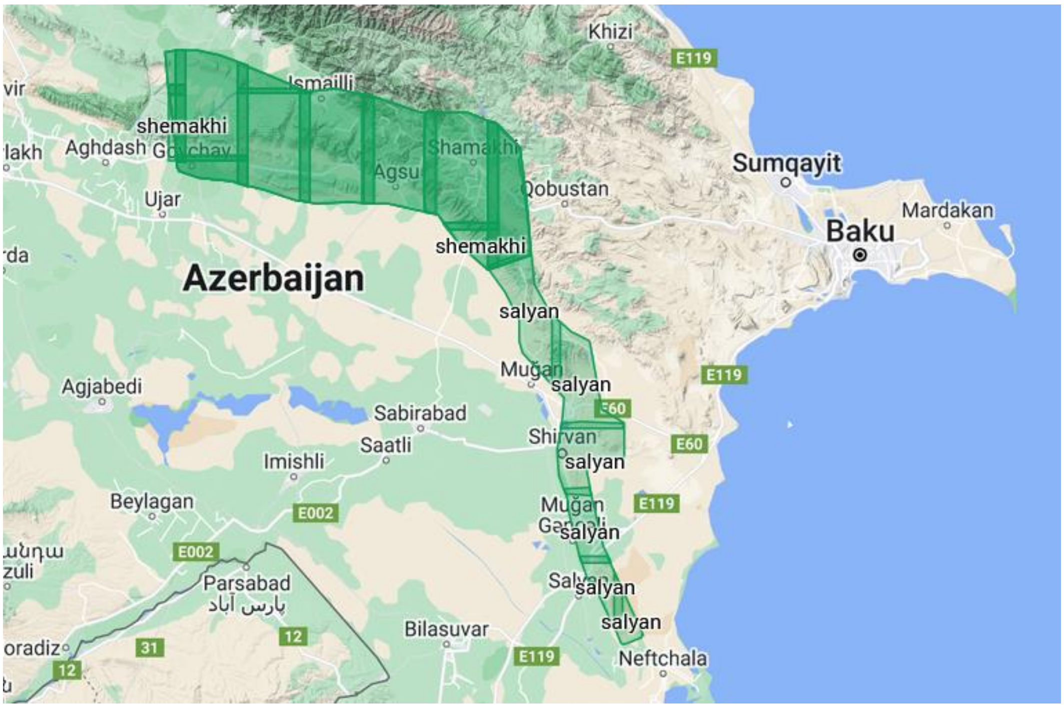


*Figure 3. Coverage of satellite image derived digital topography (area in green) used to map active faulting and select field sites for detailed investigation*

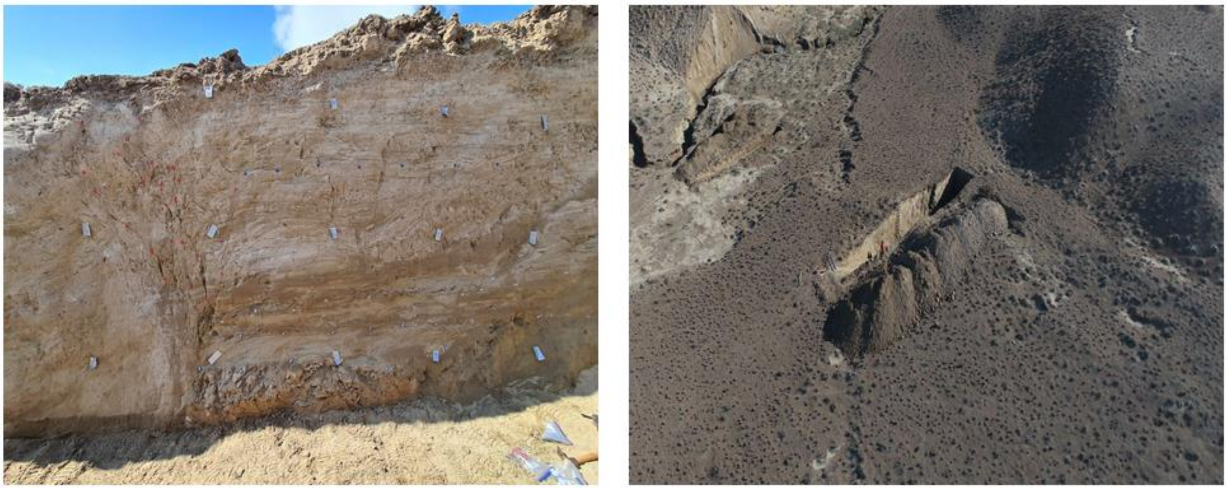

*Figure 4. A trench dug in the Salyan district. There are at least six earthquakes within this fault zone.*

In Salyan, a team of researchers discovered a shear fault that extends from Shirvan to Neftchala and flows into the Caspian Sea. A paleoseismic trench dug across this fault revealed very clear signs of an active fault. These strike-slip faults are potentially important features within the regional tectonics, accommodating relative motion between the South Caspian Basin and the Talesh. The faults constitute a large seismic hazard both to population centres and to infrastructure, including pipeline crossings and terminals.

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A detailed stratigraphic analysis of the Salyan trench has provided evidence of six prehistoric earthquakes that have occurred in the last 10,000 years. Each of these earthquakes had a magnitude from M= 6.5 to 7.5. More research is needed to determine possible magnitudes.

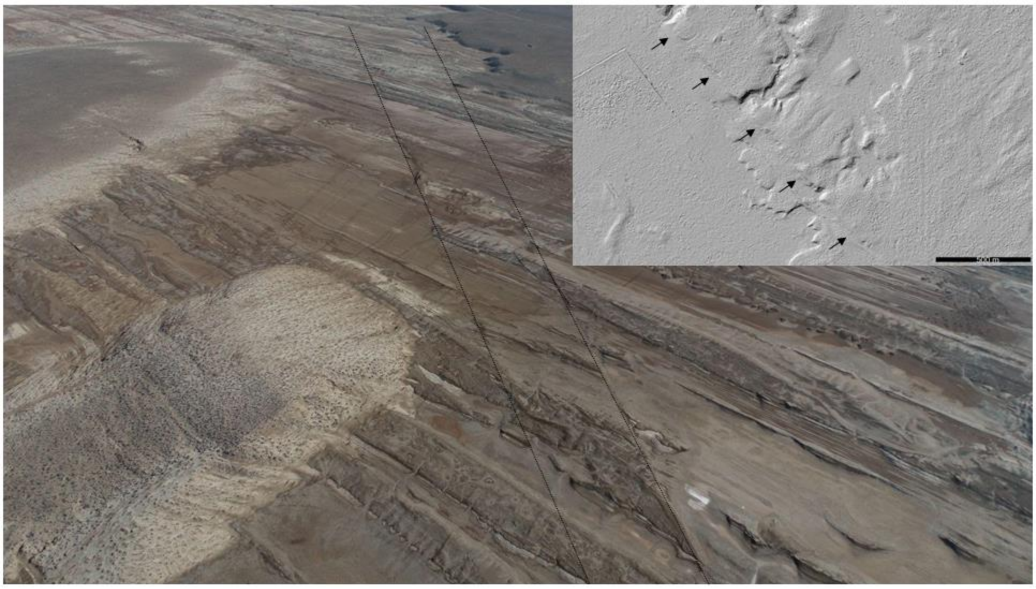

*Figure 5. Optical satellite derived DEM of the Lower Kura fault trace, cutting across an anticline. Data obtained through the Committee for Earth Observing Satellites (CEOS) Seismic Hazard Demonstrator*

The initial stage of interpretation of the 2D seismic reflection data on the shelf allowed us to identify the southward marine extension of strike-slip faults in the Kura basin (yellow, in the Figure 6). As is known, the structures in the offshore region of the Kura differ from the structures located further from the coast, due to their wavelength and asymmetry. It was found that the westernmost anticlines within the area of the study area grew in a short period of time from 1.8 Ma and are now cut by arrays of cracks, interpreted as shear deformation, which can be traced on land to the West Kura shear fault. More easterly anticlines have a longer history of deformation, move eastward, and shift the stratigraphy vertically.

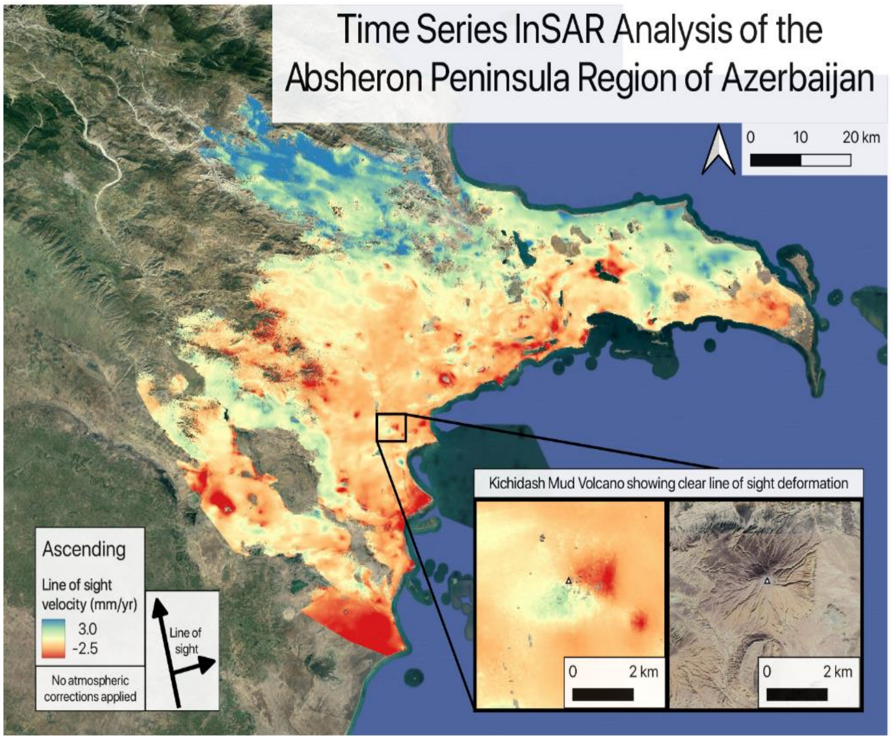


*Figure 6. Line-of-sight velocity map within the Kura basin derived from satellite RADAR. Mud volcano inflation is clearly visible (see inset). It is hoped that corrections for atmospheric noise will allow better imaging of strain accumulation across the active faults.*

**Results**

In Aghsu have excavated a trench across a small fault scarp, revealing rupture in at least two separate earthquake events on a low angle fault that has displaced sedimentary layers approximately 7 m. Initial sample dating suggests rupture occurred during the 1902 and possibly 1667 Shamakhi earthquakes. If confirmed this represents a major result in identifying the causative fault of the destructive earthquakes in Shamakhi.

In the Kura basin, adjacent to Salyan, our satellite-based fault mapping revealed a series of very active strike-slip faults in a region with little modern seismicity. We have excavated successful trenches across the Kura fault that reveals multiple surface-rupturing earthquakes. Age dating of these events is in progress.

We have correlated the Kura faults southwards onto structures visible within seismic reflection data, and also collected samples from displaced river terraces to determine geological rates of slip. The anticipation is to determine a full understanding of the geological development and the role of these strike-slip faults.

The results of the studies are preliminary, and more detailed analysis of the collected data and geological samples is required in order to obtain final results. The results will be published in scientific journals and distributed among the relevant state bodies of Azerbaijan. This first expedition shows that the Oxford method of paleoseismology works very well to determine the seismic and geological parameters of pre-instrumental earthquakes in Azerbaijan. This article describes the initial results of the first paleoseismological research in Azerbaijan, and this research collaboration between the RSSC ANAS and Oxford will last for many years and bring many fruitful results. Future research will include greater exchange of scientific knowledge and training between young staff of the RSSC and the University of Oxford. Improving scientific personnel, developing the knowledge and skills of young scientists to study earthquakes and promoting cooperation with countries with significant potential is a constant priority of the RSSC.

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