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CHRONICLE

Mikhail V. Gzovskii and Creation of Tectonophysics (On the 80th Anniversary of His Birth)

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STAGES OF THE SCIENTIFIC ACTIVITIES AND EARLY HISTORY OF TECTONOPHYSICS

1. The Personality of the Scientist

On December 17, 1999, the scientific community celebrated the 80th anniversary of the birth of Professor Mikhail Vladimirovich Gzovskii, outstanding geologist and geophysicist, a founder of the new discipline in the Earth sciences, active organizer and acknowledged leader of tectonophysical research in our country, head of the Laboratory of Tectonophysics at the Institute of Physics of the Earth.

Mikhail Gzovskii was a scientist of diverse abilities. After overcoming the contradictions in the perception of nature by a geologist and mathematical physicist, he showed the capacity for both intuitive and deterministic thinking and the abilities of a tectonic geologist, a geophysicist, and a specialist in mechanics. He combined the qualities of a superb field investigator, a serious experimenter, a theoretician capable of broad generalizations, and a practitioner who always sought to put his results into practice. Along with his great scientific talent as a researcher went truly extraordinary efficiency and energy, owing to which, after framing the logic of his studies, he brilliantly conducted them, and, having analyzed their results, he advocated them with the clarity of a philosopher, the accuracy of a mathematician, and the conclusiveness of an experimenter.

He lived for science. It was amazing how many things he managed to do simultaneously and how efficiently he worked even when he happened to be ill. He was a man of rare mental beauty and nobleness, a model of a real scientist and human being. His willpower, strength of character, principled attitude, and uncompromising demands on both himself and others harmoniously combined with simplicity, gentleness, and an inexhaustible reserve of human warmth. He was ready at any moment to help his comrades and willingly shared his knowledge and experience with anyone who turned to him. At the same time, he was a bright and cheerful person who loved humor and a good joke. In his presence, people became better, kinder, and more intelligent. He was admired by all those who knew him well.

2. Years of Training and Work at the Moscow Geological Exploration Institute and Geological Research

After finishing school, the young man had no hesitation in choosing a walk of life: he had been deeply interested in geology since his childhood, and in 1938 he enrolled at the Moscow Geological Exploration Institute (MGEI), where he studied easily and devotedly. According to his instructors (V.V. Menner and others), he was one of the most talented students of his generation. In 1941, while still a student, he participated in the MGEI research program and compiled a geological map of the northeastern Cis-Elbrus Region. Upon graduation in 1943, Gzovskii joined the Spetsgeo military geological unit on the Central Front as a military geologist. He was attacked by a severe illness there and was taken to a hospital. After his recovery, he pursued postgraduate studies at MGEI under the guidance of V.V. Belousov. As a postgraduate student, Gzovskii conducted regional investigations in the Lesser Caucasus, providing justifications for new theories of the structure and evolution of the Somkhet–Karabakh zone in the Lesser Caucasus. Results of this work were incorporated in about ten highly informative field reports, which could not be published because the project was classified. In the spring of 1947, using this evidence, Mikhail Gzovskii brilliantly defended his candidate-of-science dissertation entitled *The Relationship between Folding and Oscillatory Motions: A Case Study of the Lesser Caucasus.*

In 1947, Gzovskii together with Belousov and A.V. Goryachev worked in the Eastern Alps and Hungary. He elaborated a new concept of the geological structure of Hungary, for which purpose a vast mass of materials had to be translated from the Hungarian language. The main publication on this subject was the 1950 article "On the Geology of Hungary" in the *Great Soviet Encyclopedia*.

In 1949, Gzovskii joined the expedition of the R/V *MGRI* in Karatau (Baidzhansai anticlinorium, Kazakhstan) as one of its main participants. At about the same time, he began his teaching activities. From 1944 to 1950, he taught general geology, structural geology, and geotectonics at MGEI. His lectures and lessons were always popular, and not only with students. When, much later, he gave geologists and physicists lectures on geotectonics and—for the first time in the Soviet Union—on tectonophysics at Moscow State University, the lecture room became quickly packed with not only students but also lecturers. Mikhail Gzovskii was appreciated and loved at MGEI.

M.V. Muratov, one of Gzovskii's instructors, wrote: "In these years (1947–1950), M.G. Gzovskii had already shown himself to be an original and talented geologist, combining enormous erudition and profound knowledge of the geology of the Soviet Union and foreign countries with excellent spatial imagination, the ability to think broadly, and, most importantly, the rare gift of geological intuition."

3. Work at the Institute of Physics of the Earth and Development of the Basic Principles of Tectonophysics

In 1950, Gzovskii went to work at the Geophysical Institute, Academy of Sciences of the USSR, where he started to work on the basic aspects of tectonophysics. The need for this new discipline was very large at that moment both in the context of geotectonic and geodynamic problems and in view of various requirements in mining, engineering geology, and seismic zoning.

One cannot say that Gzovskii started from nothing in his tectonophysical research: it was as long ago as the middle of the 19th century that, in order to determine the factors responsible for the formation of tectonic structures, experiments to reproduce them were conducted by geologists such as Favre, Daubrée, Willis, Cloos, and Riedel. At the end of the 19th century, the American scientist Bekker attempted to relate the orientation of tectonic faults to the deformation ellipsoid.

In the mid-1940s, Belousov founded the first Soviet laboratory of experimental tectonics, which would later turn into the Department of Geodynamics, and researchers faced the challenge of creating tectonophysics as a scientific discipline through the synthesis of geological and physical concepts and methods. When young Gzovskii joined Belousov's Department of Geodynamics at the Geophysical Institute, this challenge confronted him as well.

After coming to the Geophysical Institute, he felt the need to study the physics of structure-forming processes and to develop the physical basis and new methods of tectonophysical investigations, in short, with the need to create a new line of research. How this task was being dealt with was well described by Belousov:

"In order to assess the great deed accomplished by M.V. Gzovskii during his short life, one should recall what kind of ideas on the mechanics of tectonic deformations existed in the late 1940s, when Gzovskii began working in this field. This was a very strange mixture of some elementary facts taken from physics and mechanics, which were not always correctly understood, and judgments, frequently incorrect from the standpoint of physics. Gzovskii undertook the titanic task of clearing this area of study, freeing it from delusions and fallacies, and transforming it into a real science. He carefully perused the relevant divisions of physics and mathematics, established contacts with leading specialists in solid-state deformation and fracture, and, a few years later, he was already a universally recognized expert in these problems. During the subsequent years, he applied the knowledge thus gained to explaining the conditions under which tectonic deformations develop and laid the foundations of the new discipline, tectonophysics. This is a rare example of a whole scientific discipline having been created by one person. The specific conditions under which tectonic processes develop required due reworking of the available knowledge and its substantial extension. Since these specific tectonic conditions defy precise calculation, one should rely on experiment, which serves here as an equivalent of a computer. This was yet another task undertaken by M.V. Gzovskii, who, within a short time, developed the theory of tectonic modeling based on the similarity principle and enriched with elements that render this well-known physical principle applicable to tectonics. Many efforts were spent to create an equivalent material that would most closely resemble rocks in its properties. Gzovskii devoted 25 years of his life to tectonophysics, his brain-child. His efficiency was amazing. He worked all the time … This was the reason why, despite the brevity of his life, Gzovskii managed to accomplish so much. Today, 25 years after Gzovskii started his tectonophysical research, the regularities of tectonic deformations appear to have been always known. Yet, in reality, this simplicity was the result of the colossal work of the man whose research talent and energy we should worship."

Compared with the achievements in physics and mathematics, the treatment of some geological problems occasionally seemed primitive, particularly, in reconstructing the mechanisms responsible for the formation of tectonic structures.

Gzovskii's works were from the outset geared to the solution of practical problems, primarily, to the reconstruction of mechanisms responsible for specific tectonic structures. Therefore, in all his studies, geological field data were always taken as input information; on the other hand, in his conclusions on the essence of a given tectonic process or phenomenon, he always sought to find proofs, and this required the support of physical regularities and quantitative investigations. Ultimately, this scientific attitude dictated the content of his studies, their harmonious structure, and the choice of methods. In our opinion, it was in this respect that his studies differed from the models developed abroad and that attracted numerous Soviet and foreign researchers (from Germany, Bulgaria, Czechoslovakia, China, Japan, etc.).

MAIN AREAS OF TECTONOPHYSICS DEVELOPED BY GZOVSKII

1. Content of the Discipline

All the results of Gzovskii's studies and thoughts are reflected in his books: *Voprosy tektonofiziki i tektonika Baidzhansaiskogo antiklinoriya* (Aspects of Tectonophysics and the Tectonics of the Baidzhansai Anticlinorium; 1963), *Matematika v geotektonike* (Mathematics in Geotectonics; 1971), and *Osnovy tektonofiziki* (Principles of Tectonophysics; 1975).

Gzovskii considered it his primary task to create a physical theory of tectonic processes, giving the highest priority to the study of mechanisms responsible for the formation of tectonic structures and to the development of physical principles of tectonophysics. This defined the main problems of this science, the direction for its development, and its methodology.

Gzovskii's tectonophysical interpretation of tectonic processes is reflected in his subdivision of tectonic structures into the three types, namely, the morphological, physical–genetic, and geological–genetic types. Figuratively speaking, they reflect three types of approach to the investigation of tectonic structures: pretectonophysical, tectonophysical, and transitional. The morphological classification reflected the absolutely necessary geological approach to the study of a structure: it is described as it appears from observations. In order to categorize this approach according to the physical–genetic classification, one should conduct additional *tectonophysical* investigations and elucidate the kinematic and dynamic environment of its origin, i.e., in fact, to determine the mechanism of its formation. Finally, the geological–genetic classification makes it necessary to elucidate the causes of its formation. Here, the researcher once again changes over to the language of geology, speaking about the relationship between the tectonic structure and other elements of the Earth's crust, about the age of the structure, etc. Yet, one can see that here again tectonophysical characteristics are implied, namely, the correlation between the physical environment in which the structure formed (local field of tectonic stresses) and the field of other objects of larger scale related to the regional or crustal structure. Considering the difficulty and complexity of this new problem, Gzovskii limited himself to the requirement of purely geological characteristics, leaving room for future studies. Thus, as we examine the classifications proposed by Gzovskii for folds, faults, and mechanisms responsible for tectonic structures, together with his commentaries, we already find the entire program of tectonophysical research on tectonic structures: the study of the physical environment in which structures of different types and scales originated and developed and their interrelationship and, if possible, the common causes of their formation. All these characteristics should be gained from special *in situ*, experimental, and theoretical studies and should be supported by factual evidence, as Gzovskii conclusively showed in his case study of the Baidzhansai anticlinorium and subsequently confirmed in his book *Matematika v geotektonike* (Mathematics in Geotectonics).

2. General Features of Tectonophysics According to Gzovskii and the Main Areas of Study

To begin with, the researcher had to analyze the history and status of tectonophysical research, criticize some erroneous ideas (such as Bekker's hypothesis), and develop the scope and content of the new discipline. In 1954, the journal *Izvestiya Akad. Nauk SSSR, Seriya Geofizicheskaya* published three fundamental papers by Gzovskii: "On the Tasks and Content of Tectonophysics," "Tectonic Stress Fields," and "Modeling of Tectonic Stress Fields and Faults." These works initiated the modern stage in the development of tectonophysics. According to Gzovskii, the main lines of tectonophysical research should be as follows:

(a) development of the physical basis of tectonophysics;

(b) study of the folding mechanism;

(c) study of the faulting mechanism;

(d) study of the mechanism underlying the formation of large complex structural units of the crust.

Thus, we can see, in keeping with Gzovskii's formulation, that the mechanism responsible for the formation of tectonic structures is the central and top-priority study object in tectonophysics. Its study is related to the investigation of a whole series of other phenomena because, according to Gzovskii, the deformation mechanism of tectonic structures is characterized by (a) a system of external deforming forces applied to a given rock mass with a tectonic structure initial for the mechanism considered; (b) the initial stress field; and (c) certain physicomechanical properties, or rheology. The system of forces applied under these conditions causes kinematic and deformational processes that alter not only the tectonic structures themselves but also their properties such as their stress fields, kinematic characteristics, etc. Proceeding from these considerations, one can define the structure of the discipline, consisting of several blocks of research.

1. Stress field. First of all, it was essential to develop the basic ideas of tectonic stress and strain fields—a phenomenon that had not hitherto been studied in geology. Their concept was introduced, and ways for their investigation were examined; these include (a) reconstruction of natural stress fields of different ages and scales (in particular, from fracturing data); (b) determination of the influence of various structures on the stress field of a higher rank (in particular, from model data); and (c) the problem of the hierarchy of stress fields and their age differentiation. For the first time, stress fields were described, and their trajectories were constructed for some natural tectonic structures, including the Baidzhansai anticlinorium structures;

model data were used to describe ideal stress fields of some fold types, as well as stress fields in a deformable layer for some very simple deformation mechanisms.

2. Kinematics. Cinematic characteristics were the second important study object for elucidating the deformation mechanism. They were the subject of several papers written with coauthors and devoted to movement fields and their characteristics, as well as their variation during the evolution of a tectonic region. Another important problem was to reduce diverse observational data on movement rates to the same scale of averaging; this problem was solved, and the influence of the averaging scale on final results was elucidated.

3. Mechanical properties of rocks. The difficult problem of studying mechanical (particularly rheological) properties of rocks in rock masses was posed; an interesting method of applying geophysical data and using their correlation with mechanical properties was suggested.

4. Mechanisms of formation of tectonic structures. Finally, it was possible to discuss examples of research on the mechanisms responsible for the formation of tectonic structures using theoretical, experimental, and modeling (reconstruction) methods. A new branch of research in folding mechanisms was initiated; it consisted of combined examination of kinematics, deformation, stresses, and ruptures appearing in folds in the course of their evolution. Three folding mechanisms were distinguished: transverse bending, longitudinal bending, and longitudinal flattening.

Within the framework of the theory of faulting mechanisms, the ideas on the physical conditions of simple faulting were generalized and substantially extended by synthesizing strength theories developed by various authors. Specific examples were used to examine the relationship between individual, simultaneously formed structures; to investigate complex structures; and to elucidate the mechanism of long-lasting large-scale faulting through the joining of small, initially isolated faults. The case study of the Baidzhansai anticlinorium was the first investigation of the mechanism responsible for the formation of a large regional structure.

5. Physical principles underlying tectonophysics. Tectonophysical research not only relied on available works in the fields of physics (primarily, mechanics) and mathematics, but also made it necessary to conduct new investigations on specific problems in these fields of science or to adapt available results to the conditions of geological phenomena. Research was conducted on the rheological properties of rocks; methods of their laboratory and *in situ* study over long time periods were elaborated; rheological models for theoretical research were selected; numerical modeling techniques were developed; the method of equivalent modeling was invoked and adapted to geological structures and deformation processes; and methods for quantitative study of modeling results were created. Particular attention during that period was given to three topics:

(a) Basic possibilities for assessing rheological properties of rocks *in situ*. Viscous properties of rock sequences of various lithologies were estimated for the first time.

(b) Development of the similarity theory for modeling tectonic processes based on analysis of relevant equations from mechanics of deformable media. Theoretical requirements for physicomechanical and rheological properties of equivalent materials that could be utilized in tectonic simulation experiments were obtained on various temporal and geometric scales.

(c) Application of the optical method to the modeling of tectonic stress fields. The photoelastic technique was introduced into tectonics for the first time, and a method for studying stresses in elastic and inelastic (viscous and viscoplastic) models was developed.

This stage in the life and work of Gzovskii was summed up in his two-volume treatise *Osnovnye voprosy tektonofiziki i tektonika Baidzhansaiskogo antiklinoriya* (Basic Aspects of Tectonophysics and the Tectonics of the Baidzhansai Anticlinorium; 1963), which, in addition to the topics mentioned above, covered prospects for using tectonophysics in solving various problems in regional tectonics, exploration geology, mineral exploration, and research on deep geological and geophysical processes. This book was the result of 14 years of his work in the Karatau region, which formed the basis for his doctoral dissertation that he defended in 1962. This treatise marked the conclusion of the first stage in the development of tectonophysics.

ESTABLISHMENT OF THE LABORATORY AND SOLUTION OF SPECIAL PROBLEMS IN TECTONOPHYSICS

The next stage involved extensive development and intensification of tectonophysical research, in particular, on special problems in tectonophysics. Gzovskii managed to organize an interdisciplinary research team consisting of experimenters (engineers and physicists), specialists in mechanics, and geologists. The experimental group modeled tectonic processes and studied properties of rocks and equivalent materials; the mechanical–mathematical group worked on theoretical solutions to tectonophysical problems; and the geological group conducted field observations of the crustal structure and movements and gathered seismotectonic data for assessing seismic hazard. In 1964, Gzovskii celebrated his 45th birthday and was at the peak of his potential. The subsequent seven years were spent to elaborate the strategy for developing tectonophysics and to conduct research along three directions: the intensification of studies aimed at creating the physical basis of tectonophysics, developing the physical theory of tectonic processes, and solving some special problems of tectonophysics, i.e., determining tectonophysical regularities that are essential in solving applied problems in exploration geology, seismic hazard assessment, etc. In his paper of 1970, entitled "Development of New Lines of Tectonophysical Research," Gzovskii formulated the following tasks: "Tectonophysics should provide a physical description and explanation of tectonic processes. To do this, we must learn to express tectonic data in terms of physical quantities and to develop methods for obtaining objective quantitative characteristics of physical quantities such as strains, stresses, and energy, which correspond to various manifestations of tectonic processes: movements, folds, fractures, large faults, and earthquakes. Tectonophysics should determine regularities in quantitative relations between various physical characteristics, as well as between geological manifestations of tectonic processes on various scales at the surface and in the interior."

This new and last period of his studies was characterized by the joint development of all lines of research, which were connected by mutual requirements and expectations.

1. Model Study of Deformation Mechanisms, Development of Quantitative Analysis, and Research on Properties of Equivalent Materials

During this period, model studies of mechanisms were concerned with the development of a new quantitative approach: general schemes reflecting the stress (strain) state and kinematics of structures to be reconstructed on the basis of general considerations gave way to a new method of marking models and calculating all required parameters, making it possible to reliably determine the strain values, their increments during the formation of a structure, the distribution of viscous properties, energy losses at various formation stages of the structure, etc. The transition to quantitative studies using models required a more careful selection of equivalent materials. In view of this, detailed research was conducted on the rheological properties of bentonite clay pastes, from which models were prepared, and the viscosity of the pastes and its dependence on clay humidity and shear stresses were determined; as a result, it was possible to describe the properties of models in terms of fields of strain, viscosity, velocities, etc., and subsequently, in collaboration with theoreticians, to develop a combined research procedure. Simultaneously, a theoretical solution was provided to the problem of longitudinal compression of a layer in the same scenario as the experiment but for a linearly viscous medium. Model data and field investigations were used to publish, in 1971, the first classification of the main types of crustal deformation mechanisms, the groundwork for which had been laid in the preceding period.

The theoretical group embarked on the elaboration in 1970 of a mathematical theory of tectonic processes. On Gzovskii's initiative, A.S. Grigor'ev and V.P. Ionkin analyzed and critically reviewed papers dealing with the solution of tectonophysical problems by the methods of mechanics of deformable solids. Their review revealed the status of the mathematical theory of tectonic processes (in the late 1960s), making it possible to outline the directions for its further development, which involved the use of more complex physical and geometric models that were more adequate to the crustal (lithospheric) conditions; this was essential for the solution of specific tectonophysical problems, most notably, problems of the stress state and deformations of lithospheric regions involving different deformation mechanisms. Solutions were obtained to such problems as thrusting, bending of the sedimentary cover due to basement-block subsidence or uplift, and the stress state and deformation of the lithosphere consistent with the hypothesis that the base of the lithosphere is influenced by convective flows.

2. Study of Tectonic Stress Fields

Research on tectonic stress fields was still at the center of attention.

(a) Construction of stress and energy-consumption maps: all of the then available *in situ* data on principal stress axis orientation were generalized, relative tangential stresses $T_{\max}$ in the crust were estimated from seismic data (from the spatial earthquake distribution density), absolute maximum tangential stresses were estimated from data on tectonic movements over the last 30 Myr and on seismicity over the last 50 years within the Soviet Union, and the energy consumption in tectonic deformation was estimated. These data were presented on special maps; zones differing in values of these characteristics were delineated and were compared with zones of different tectonic activity.

(b) Improvement of the method of reconstructing tectonic stresses: work was continued on the basis of the old approach to the reconstruction of the stress field in various regions, but, at the same time, efforts were made to improve and formalize it (O.I. Gushchenko).

(c) Modeling of tectonic stress fields: in collaboration with D.N. Osokina, experiments on photoelastic materials were continued, the equipment and methods for studying stresses in faulted models were improved, and the groundwork for two new lines of these investigations was laid. (1) Physical regularities in the structure of the stress field near isolated or complexly structured faults of the most typical types were investigated; a large amount of work was done to describe the stress fields $T_{\max}$ for faults of various configurations, variously orientated relative to the external field axes. (2) Stress fields were studied in models simulating the fault structure in concrete earthquake-prone regions. The first experiments of this type were conducted, and the model stress fields were compared with the seismicity of a specific region.

3. Rheology of Rock Masses and Rock Pressure Control

In addition to investigating the rheological properties of equivalent materials, Gzovskii and coworkers performed a series of studies to assess the rheological properties of rock masses and crustal areas. The first steps were made to develop an indirect method of estimating the viscosity of rock masses on the basis of correlations between elastic-wave attenuation characteristics and viscous properties of solids and rocks. The results made it possible to compile a scheme predicting the depth variation of the maximum and minimum viscosities in the main crustal layers. These studies, as well as reconstructions of tectonic stresses, attracted a great deal of attention from miners in the context of rock pressure control and led to new contacts with both organizations (the Kola Branch of the USSR Academy of Sciences) and individual specialists in this field (Turchyaninov, Markov, Kazikaev, etc.). In May 1971, the All-Union Conference on Tectonic Stresses in the Crust was held with the aim of elaborating a well-founded unified procedure for determining stresses in mine workings by the discharge method. The conference discussed both measurement procedures and the first results of applying data on tectonic stresses to rock pressure control. Gzovskii was the organizer and one of the main speakers at the conference.

4. In situ Study of Tectonic Movements, Structures, and Deep Processes

Gzovskii always gave much attention to research on tectonic movements, both in the context of deformation mechanisms and when identifying tectonic zones of different activity. In the last few years of his life, he conducted these studies together with A.A. Nikonov, who worked in his laboratory. Among the problems investigated were the geophysical interpretation of data on neotectonic and contemporary tectonic movements and interpretation of the relationship between the vertical and horizontal velocity components of deep tectonic movements. Contributing to a subject that was widely debated at that time, Gzovskii discussed two schemes of crustal deformation and showed that the realization of either of them depends on the relative values of the vertical and horizontal components of tectonic movements.

Much work was done to determine the relationship between the velocity gradient of deep movements and the stress state in the crust and upper part of the subcrustal layer. It was believed at that time that the solution of this problem would provide an effective method for estimating tectonic stresses. To identify areas differing in their tectonic activity, the quantitative characteristics of contemporary and recent tectonic movements in areas with various tectonic regimes were studied; as a result, a map showing velocity gradients of the neotectonic vertical movements within the territory of the Soviet Union was constructed. The general principles of constructing maps of deep structural zoning in the crust were developed, and the domain of applicability of these maps was defined.

In the early 1970s, an attempt was made to introduce the concept of contemporary tectonic activity of large geostructural regions, namely, platforms and orogenic zones (not necessarily geosynclines). Contemporary tectonic activity and crustal movements were examined for present-day time periods of 10^{-2}–10^{2} years. It was planned to measure the activity from three independent groups of data: contemporary surface movements, stress state measurements in mine workings, and the energy and recurrence interval of earthquakes in the crust (Gzovskii and Nikonov, 1973). These proposals were not significantly developed. At the same time, it should be noted that the ensuing decades have made no essential contribution to both the understanding of the tectonic activity of large geostructural units (let alone individual faults) and measurement methods.

5. Tectonophysics and Seismicity

These two areas of study in the Earth sciences are closely related and need one another. Tectonophysics uses seismological data to reconstruct contemporary tectonic stress fields and to estimate the stresses and energy consumption of tectonic processes. Also, seismic data might provide constraints on rheological properties of rock masses. Tectonophysics makes its own contribution to the solution of some problems of seismicity. Together with coworkers (G.I. Reisner, N.N. Leonov, Yu.G. Leonov, and others), Gzovskii closely examined the possibility of providing tectonophysical substantiation of geological criteria of seismicity and assessing the intensity and recurrence of earthquakes. Particular attention was given to theoretical and practical issues of seismic zoning. In a case study of Central Asia, new approaches to seismic zoning were realized (jointly with V.I. Bune and N.A. Vvedenskaya).

Such is an incomplete list of the tectonophysical problems that were handled or solved during the last seven years of his life.

IV. ORGANIZATIONAL ACTIVITIES AND MONOGRAPHS

M.V. Gzovskii was an extremely active organizer of scientific activities. He took part in many All-Union and international conferences, congresses, and meetings; his papers appeared in many foreign publications, in particular in the United States, Great Britain, Canada, France, Japan, and China. In 1957, Belousov and Gzovskii organized the First All-Union Tectonic Conference, which brought together geologists, physicists, specialists in mechanics, physical chemists, and specialists in the strength and properties of rocks and equivalent materials. The proceedings of this conference were published in 1960 under the title *Problemy tektonofiziki* (Problems of Tectonophysics). In 1961, Gzovskii was actively involved in the All-Union Conference on recent crustal movements (Moscow). In May 1971, Gzovskii organized the All-Union Conference on Tectonic Stresses in the Crust with the participation of mining scientists. In 1960–1963, he published the aforementioned two-volume treatise *Osnovnye voprosy tektonofiziki i tektonika Baidzhansaiskogo antiklinoriya* (Basic Aspects of Tectonophysics and the Tectonics of the Baidzhansai Anticlinorium). In 1964, Gzovskii and Belousov published their monograph *Eksperimental'naya tektonika* (Experimental Tectonics), which was later translated into English. In 1969, Gzovskii completed the monograph *Matematika v geotektonike* (Mathematics in Geotectonics; 1971), devoted to mathematical methods and theories that should be introduced into geotectonics to make it an exact science. He regarded this book as a prologue to his future monograph on tectonophysics. That same year saw the publication of the collection of papers entitled *Tektonofizika i mekhanicheskie svoistva gornykh porod* (Tectonophysics and Mechanical Properties of Rocks) edited by Gzovskii and M.P. Volyarovich. This book opened with a large paper written by Gzovskii and entitled "Present-Day Opportunities for Assessing Tectonic Stresses in the Crust." In the last few months of his life, Gzovskii was actively preparing four papers to the 15th General Assembly of the International Union of Geodesy and Geophysics. He worked until the last day and last hour of his life. These papers were read at the General Assembly and were published in two languages, but this was done by Gzovskii's students.

The last of Gzovskii's publications is the monograph *Osnovy tectonofiziki* (Principles of Tectonophysics; 1975), which is a collection of his most important works, including unpublished papers. This book is frequently cited in modern publications, as are other fundamental publications written by this scientist. His research results are widely used in the Earth sciences. He created not only a scientific discipline but also a scientific school. He was visited by researchers from all parts of the country (Apatity, Yerevan, Kemerovo, Lvov, Tashkent, etc.) and from many foreign countries (Great Britain, Japan, Germany, China, Yugoslavia, Czechoslovakia, and Bulgaria). They came to him for advice or for training. He displayed a lively interest to every study, discussed it, and tried to help. Many geologists consider him to be their teacher: both those who worked under his supervision and those who interacted with him only on a professional level. Some of his students have become prominent researchers in the fields of tectonophysics, in particular, P.N. Nikolaev; O.I. Gushchenko; V.D. Parfenov; A.V. Mikhailov; and Ma-Tzing, his postgraduate student from China who has become a leading tectonophysicist of the People's Republic of China, professor of tectonophysics.

SIGNIFICANCE OF GZOVSKII'S STUDIES

The significance of Gzovskii's work can hardly be overestimated. First of all, he provided an entirely new approach to the study object in geology: assessment of the tectonic environment with due regard for the laws of mechanics, investigation of tectonic deformations in a rock mass in terms of tensor calculus, the need to study the mechanical properties of the rock mass and natural stress fields, and quantitative study of both natural objects and their models.

The creation of a new science at the interface between geology and physics led to the development of a new methodology. Geologists with an intuitive mode of thinking, which rests on the colossal observational experience gained by themselves and previous generations, should now master a deterministic approach to natural phenomena with rigorous cause-and-effect relationships, which are derived from numerical modeling and are not always apparent. Now we outline distinctive features of the methodology of the new discipline as it was, in our opinion, seen by the creator of tectonophysics and as we see it ourselves:

(a) All studies should rest on field data acquired by the researcher himself and/or reflected in geological publications.

(b) It is essential to use quantitative analysis for discovering regular features in geological phenomena and determining their characteristics.

(c) It is necessary to use equivalent modeling (in a broad sense) to study long-lasting tectonic processes on relevant time and space scales.

(d) The available archive data should be revised in the context of new lines of research (application of seismic data to the study of *in situ* rock properties, application of seismological data to the reconstruction of recent stress fields, etc.)

(e) In view of the extraordinary complexity of the study object, one should compare the results obtained by a variety of methods: compare stress field reconstructions with data derived from *in situ* measurements, fractures, and seismic evidence; to study the characteristics of movements, one should use geodetic, geophysical, geomorphological, and geological methods; to study the mechanisms responsible for the formation of structures, one should synthesize results of field investigations, experiments, and numerical modeling.

In scientific and industrial research, the following contributions of Gzovskii have found the widest application:

(1) The theory of tectonic stress fields, including the procedure for reconstructing natural stress fields, based on Coulomb's theory, and methods for studying stress fields disturbed by tectonic faults. Both lines of research are actively developing, and more advanced

and formalized procedures are being created on the basis of other models. New studies concerning the effect of faults on the stress field are used to reconstruct stress fields and to predict secondary tectonic deformations and tectonic settings in particular regions.

(2) In both geotectonics and engineering geology, the theory of equivalent modeling developed for geological structures is widely used. It is applied to structures of various scales—local, regional and global—both in our country and abroad. Although this approach has a number of serious limitations (the impossibility, at the current level of research, of meeting the similarity condition for gravity, poor fit to similarity conditions, inadequate accuracy of determining kinematic and deformational characteristics, etc.), they are, however, bypassed by some researchers through a combination of theoretical and experimental procedures.

(3) There is also an intense interest in the reconstruction of mechanisms responsible for natural tectonic structures (for which, in fact, the entire system of tectonophysical research was created), and this line of research is pursued by scientists both in Russia and elsewhere.