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MURAT KAMALETDINOV AND THE STRUGGLE FOR ACCEPTANCE OF THE THRUST-NAPPE THEORY

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There is nothing more practical than a good theory
Gustav Robert Kirchhoff

ABSTRACT

This article describes the confrontation between fixist and mobilistic ideas in the USSR in the twentieth century. The history of discovery of the Urals thrust-nappe structure and the creation of the thrust-nappe theory are outlined. The fundamentals of the thrust-nappe theory are considered. These fundamentals allow for the explanation of geological processes and phenomena from the standpoint of mobilism. The geologic processes of interest include orogenesis, folding, magmatism, metamorphism and the formation of mineral deposits such as oil, gas, metal ores, coal and others.

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1. INTRODUCTION: THE CONFRONTATION BETWEEN FIXISM AND MOBILISM IN THE USSR

In 1965 J. Tuzo Wilson (1908–1993) published a ground-breaking article in *Nature* entitled “A new class of faults and their bearing on continental drift” that argued for the idea of global mobilistic plate tectonics. In the same year, the Russian journal *Reports of the USSR Academy of Sciences* published an article by Murat Kamaletdinov (1928–2013) entitled “New data on the geology of the southern Urals” that became the basis for the mobilistic thrust-nappe theory. That theory did not become as well-known to the world scientific community. The author of the thrust-nappe theory, Kamaletdinov (Figure 1), was an outstanding scientist and thinker, the discoverer of the nappe structure of the Urals, and the founder of a scientific school focused on geotectonics.

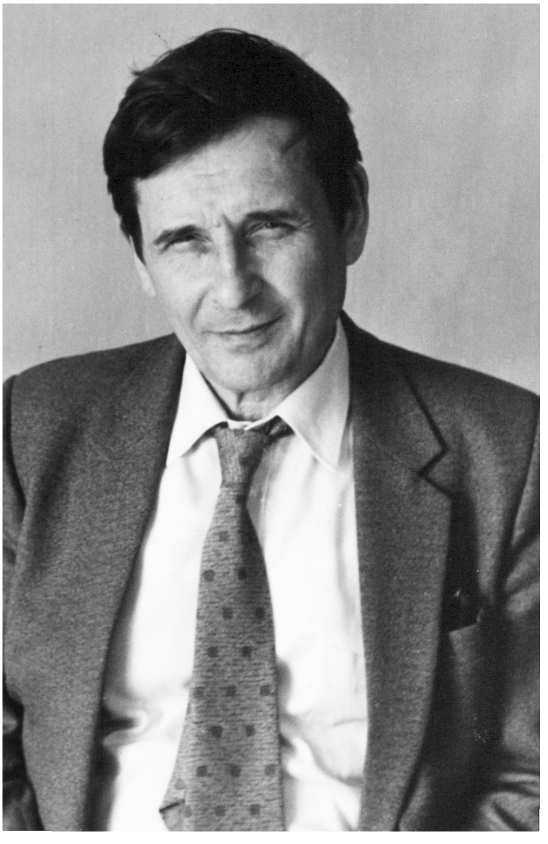

Figure 1. Murat Kamaletdinov in 1983.

After graduating from the geological faculty of the Kazan University in 1953 Kamaletdinov worked in the southern Urals. For sixteen years he held a variety of positions including geological party chief (1954–1956), head of the geological expedition (1956–1964), and chief geologist (1964–1969). Extensive observations on the structure of this region, obtained over many years of industrious work, allowed him to become a leading specialist in the geology of the Ural Mountains.

The start of Kamaletdinov's research work coincided with the so-called 'golden age' of Soviet regional geology. In 1954, the government of the USSR launched a program to map the country at a scale of 1:1,000,000 and 1:200,000. This program of detailed geologic mapping was implemented by the participation of geologic technicians appointed by the state to operate mobile drilling rigs, earth-moving machines and trenching machines, and to perform geophysical surveys.

While mapping the Karatau Ridge in the southern Urals in 1954, Kamaletdinov discovered a large thrust sheet (Figure 2), and this was the first scientific evidence of the nappe structure in the Ural Mountains after a long period of denial. To evaluate the importance of this discovery we will examine the history of nappes.

A nappe, or thrust sheet, is a large sheetlike body of rock that has been moved above a thrust fault from its original position. The term stems from the French word for tablecloth in allusion to a crumpled tablecloth being pushed across a table. Nappes were first recognized at the end of the nineteenth century when horizontal transfers of rocks through tens to hundreds of kilometers were discovered in the Alps by Marcel Bertrand (1847–1907), Maurice Lugeon (1870–1953), Émile Argand (1879–1940) and others. This discovery provoked plenty of discussion. The 6th (Zurich, 1894) and 9th (Vienna, 1903) International Geological Congresses were devoted to the thrust-nappe issue. By that time two major tectonic hypotheses had been established in geology—fixism (the theory of geosynclines) and mobilism. Fixism explained mountain formation by vertical oscillatory movements of the Earth's crust caused by the Earth's internal heat. Mobilism, in contrast, accepted large-scale horizontal displacements of rocks (Wegener 1912). Confrontation between fixism and mobilism was central to the history of geology during the twentieth century (Karaulov 1988).

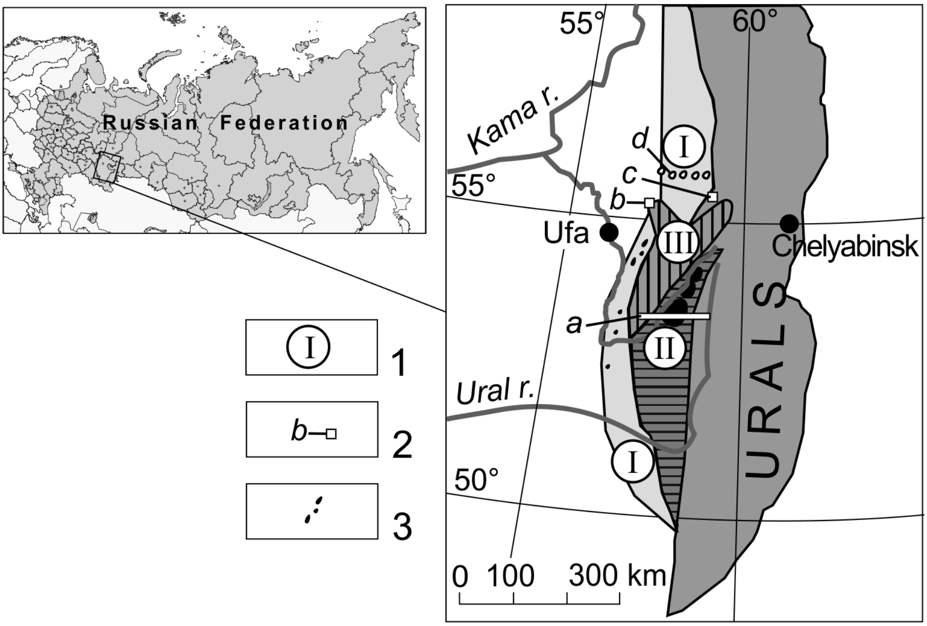

Figure 2. Overview map of the southern Ural Mountains where major structures include: I – Pre-Ural foredeep; II – Zilair synclinorium of the southern Urals; and III –Bashkir meganticlinorium of the Urals. Geological features mentioned in the text include: a – cross-sections through the Kraka ultrabasic massifs (see Figures 3 and 4); b – thrust of the Karatau Ridge; c – the klippes in the Uraim River basin; and d – migration of the reef massifs from the east to the west in the Pre-Ural foredeep; 3 – oil and gas deposits mentioned in the text (from north to south: Arkhangelsk, Bakrak, Tabynsk, Teiruk, Voskresensk, Yermolayev)

Thrust-nappes were officially recognized in 1903 at the 9th International Geological Congress in Vienna. However, they were believed to exist only in young Cenozoic folded regions like the Alps. Allochthonous covers on the platforms and in the oceans were not recognized at all (Hallam 1989; Trümpy 2001).

In 1927 geologist Georgiy Nikolayevich Frederix (1889–1938) was the first to describe a nappe in the Ural Mountains, an ancient mountain range. He found it in the Chusovaya River drainage basin (central Urals) and adjacent areas where Carboniferous and older sedimentary rocks lay on Permian strata in the form of tectonic thrusts and klippes. He put forward the idea of a nappe structure for the region (Frederix 1927). In the 1930s, nappes in other parts of the Ural Mountains were described by a number of geologists. For example, Olga Fedorovna Neyman-Permyakova (1888–1950) identified a series of nappes in the Silurian-Devonian sedimentary strata of the Ufa amphitheatre in 1931 (Neyman-Permyakova 1931). In the same year Olga Lvovna Abakumova described nappe structures in the basins of the Satka and Ai Rivers, Alexander Alexandrovich Chernov (1877–1963) found that the Upper Silurian and Devonian rocks were thrust over Carboniferous limestones (Abakumova 1931; Chernov 1931). In 1932 the academician Andrey Dmitrievich Arkhangelskiy (1879–1940) published an article, proposing a hypothesis for the covering structure of the whole Urals (Arkhangelskiy 1932).

Research efforts that developed the idea of a nappe structure for the Urals, have radically changed common notions about the tectonics of the Ural Mountains. Many geologists distrusted the nappe hypothesis,

> . . . since clearly expressed thrusts had never been observed, and all the more, such grand cover structures, traces of which would certainly have been revealed somewhere, it must be admitted that westward gradual folding decay is more probable. The nappe theory doesn't conform to the well-established facts of the Western Urals tectonics (Ivanov 1928, p. 72).

The fixist paradigm supporters based their arguments against the validity of mobilist ideas on the inaccuracies in geological data interpretation. These inaccuracies were caused by the lack of high-quality geological maps and the paucity of reliable data on the Precambrian and Paleozoic stratigraphy of the region. For example, in one of his maps Frederix wrongly correlated Lower Permian sandstones with Vendian (Ediacarian) sandstones. As a result,

> . . . All authoritative workers of the Ural Geological Administration, as well as many prominent scholars of VSEGEI (All-Russia Geological Bureau), sharply criticized the idea of nappe structures application to understanding the Urals tectonics, basing their opinion on the analysis of the above-mentioned map. Very negative attitude to this idea, at least among Uralian geologists, was so strongly established, that even mentioning it would discredit any serious researcher. I should say that rejection of the nappe structures in the Urals got so deep in the minds of geologists, that some could not get rid of it till the end of their days, despite the fact that irrefutable proofs of such structures were discovered (Smirnov 1992, p. 197).

In the Soviet Union discussions about nappes in the Ural Mountains in the 1930s turned into a tragedy, because a severe campaign against bourgeois ideas in science began at that time. Mobilism was considered to be a hostile trend belonging to the capitalistic camp and the concept of nappes was prohibited due to its bourgeois origin (Legler 1988; Romanovsky 2004; Kamaletdinov 2007). The 'scientific debates' were the muddy water where the security forces such as the NKVD, and then the KGB, could catch fish to any taste, and plans to reveal 'saboteurs' and 'public enemies' were implemented extensively (Romanovskiy 2004, p. 105).

The world scientific community is well aware of how the Soviet government crushed the science of genetics in the Soviet Union in the 1940s. That narrative is commonly associated with the name of Lysenko. The repression of geologists during Stalin's regime is less well known, although geologists were persecuted earlier than geneticists. Frederix was convicted of promoting the concept of nappes and executed in 1938. His conviction stated that he was guilty of a

> . . . deliberate misinterpretation of the geological cross-section in the exploration of Chusovaya Boroughs for oil, as well as involvement in the plot to assassinate the country's leaders and personally Stalin (Orlov 1995, p. 175).

In 1938 geologist Nikolay Alexandrovich Zenchenko (1902–1938), Frederix's co-author of the article on the central Urals nappes, was shot. His conviction read: ". . . carried out sabotage in geological exploration" (Orlov 1995, p. 73). Natalya Vasilyevna Potulova (1895–1963), who displayed a series of tectonic sheets on the western slope of the southern Urals on her geological map, was sent to a labor camp. In February 1938 professor, and prominent geologist, Dmitriy Ivanovich Moushketov (1882–1938), a major supporter of the nappe structure in Central Asia, was executed as a public enemy. Many other scientists were sent to labor camps or into exile, and the rest were morally crushed (Kamaletdinov 2007). Manuscripts of Frederix, Moushketov and other 'public enemies' were withdrawn from the libraries (Khomizuri 2008). Academician Arkhangelskiy, as noted above, who in 1932 expressed the idea of the nappe structure of the Urals, died suddenly on 16 June 1940 in the sanatorium 'Uzkoye' at the age of 61 years. Valeriy Vasilyevich Sinyukov (1931–2007) and Zinaida Ivanovna Sheptunova (born 1930) reported that he met a violent death (Yanshin 2003, p. 290). He was the last of the influential geologists who persisted in believing in the mobilist ideas.

All the geologists affected in the 1930s and 1940s were later rehabilitated for lack of *corpus delicti*. To commemorate those geologists, who deemed scientific truth superior to other concerns, even at the cost of their lives, Kamaletdinov dedicated his 2007 book *Scientists and Times*.

The opposition to the concept of nappes was deeply embedded in Soviet geology at that time. For example, the academician Nikolay Sergeevich Shatsky (1895–1960) argued that the hypothesis for large-scale nappes on the western slope of the Ural Mountains should be discounted (Shatsky 1945). After Stalin's death the ban on mobilism was lifted, but awareness of the concept was limited due to continued aggressive ideological antimobilism propaganda.

The leader of the fixist tectonic school in the Soviet Union was the Corresponding Member of the USSR Academy of Sciences, Vladimir Vladimirovich Belousov (1907–1990)—a strong proponent for the fixist orthodoxy. He harshly refuted many of the tenets of mobilism in his book *Basic Questions of Geotectonics* (Belousov 1962). Likewise, Boris Petrovich Vysotsky made a wide survey of tectonics in the USSR and characterized nappes as a tribute to bourgeois fashion (Vysotsky 1955). He argued against the existence of nappes, even in the Alps, and called the refutation of these structures an important achievement of Soviet geologists.

University education played a major role in securing fixist ideas in the USSR. Students studied with maps where mobilist elements were absent. Thus, a strict fixist model of the USSR geological structure was established as a result of a multi-year effort. It looked so convincing that some foreign scientists speculated that the territory of the USSR was a non-mobilist exception on the Earth (Legler 1988). As a result, the fixist paradigm in Soviet geology was firmly established.

2. THE PROOF OF THE NAPPE STRUCTURE OF THE URALS

The discovery of a nappe at Karatau Ridge in 1954 by Kamaletdinov transformed traditional views that the ridge was a vertical-block structure. Mapping of this nappe ran contrary to official Soviet science policy and required great courage.

> My discovering the nappe on Karatau ridge was immediately reported to the local KGB Party by the secretary of Sterlitamak geological survey office. So, I was dismissed from the position of the 'head of geological party' and was prohibited from using 'top secret' and 'official use only' maps (Kamaletdinov 2011, p. 126).

Such scrupulous attention to the young specialist on the part of security organs was explained by treating him as the son of a 'public enemy'—his father, Abdulhak Iskhakovich Kamaletdinov (1899–1937), a mining engineer, who in 1934 had been invited to work in Moscow in the central administrative board for 'Glavzoloto'. In 1937 the entire engineering corps of 'Glavzoloto' was shot, including the 38 year-old Abdulhak Kamaletdinov. In 1956 he was posthumously rehabilitated.

Thanks to the chief geologists, Fedor Semenovich Koulikov (1906–1964) and Nikolay Ivanovich Meshalkin (1907–1982), who trusted the results of Murat Kamaletdinov's work and agreed with his interpretations, he was reinstated in 1955. Furthermore, the newly discovered Karatau thrust was included in the 1:200,000 geological map of the USSR in 1956.

Geological survey work in the central Ural Mountains in 1960 allowed Kamaletdinov to map previously unknown tectonic klippes composed of Silurian rocks overlying younger Carboniferous strata (see Figure 2) (Kamaletdinov 1962). Standard Soviet geology of that period denied the existence of klippes as well as thrusts and nappes. The term 'klippe' in the USSR geological dictionary (1955) was defined as 'excessive'. According to the prevalent paradigm at the time, all outcrops that contained older rocks associated with younger rocks in the Ural Mountains were associated exclusively with anticlines. Therefore, in order to prove the existence of each nappe and klippe in the Ural Mountains, Kamaletdinov had to engage in detailed geological surveys supplemented by data from extensive mining operations and drilling. Kamaletdinov recalled that the "prejudice of some geologists against the existence of covering structures was so strong that no facts could shake it" (Kamaletdinov 2010, p. 169).

"Prejudice does not have reasonable grounds, so you can not deny them with rational arguments"—said Samuel Johnson (Dushenko 2001, p. 634).

The next major topic of investigation was the nappe structure of the Kraka ultrabasic massifs (now known as the Uralian ophiolites) (see Figure 3). The problem of the origin of the

Ural ophiolites was investigated by many outstanding scientists in the USSR including Alexander Nikolayevich Zavaritsky (1884–1952), Boris Mikhaylovich Romanov (1893–1956), Dmitriy Gersimovich Ozhiganov (1892–1978), and others. The majority of Uralian geologists believed in the intrusive origin of the Kraka massifs, which were typically shown in the form of mushrooms on cross-sections (Ozhiganov 1941) (see Figure 3).

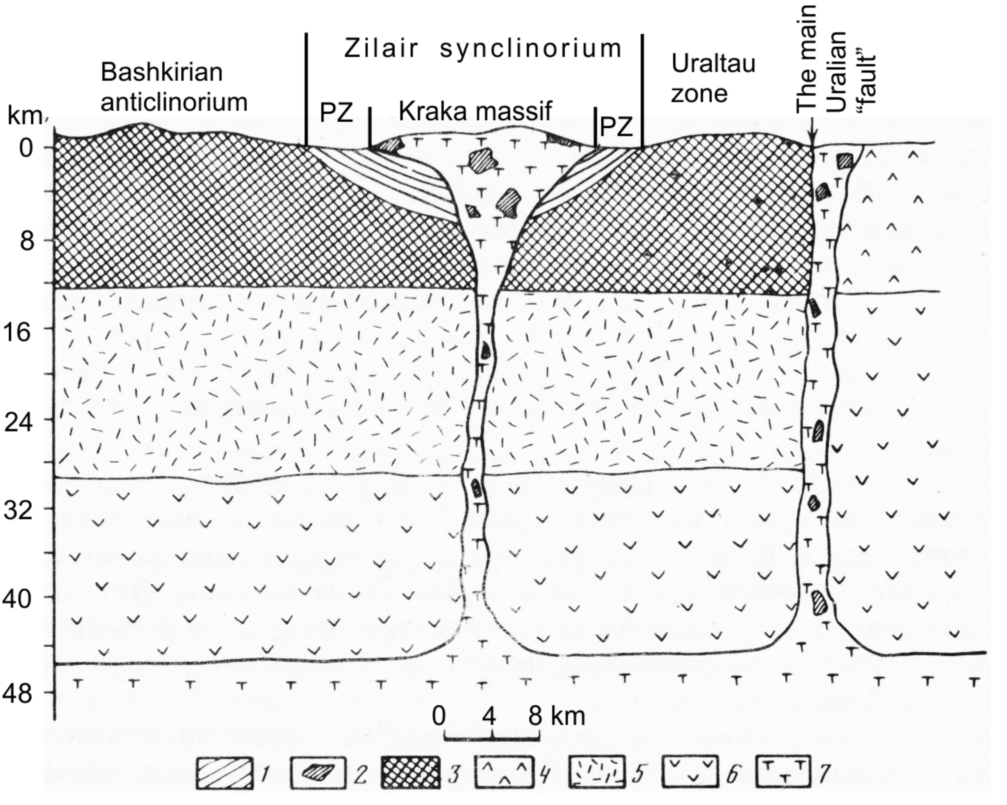

Figure 3. The geological section of the Kraka massif, interpreted according to supporters of an intrusive origin (from the book Allochtonous Ophiolites of the Urals *(Kamaletdinov et al. 1983))*
Legend: 1 – Paleozoic sediments (limestones, sandstones, shale); 2 – xenoliths composed of volcanic-sedimentary formations of Silurian and Devonian age; 3 – Precambrian sediments; 4 – Paleozoic volcanic-sedimentary formations of the eugeosynclinal zone; 5 – granite-gneiss basement; 6 – ‘basaltic’ layer; 7 – ultramafic.

However, thermally altered contacts between ultrabasic and sedimentary rocks were absent, so some geologists interpreted the structural position of the Kraka ultrabasic massifs as a vertically lifted mantle block (Moskaleva 1959). Kamaletdinov was the first to propose the allochtonous origin of the Kraka ophiolites, and this had a considerable body of evidence in support of this interpretation.

The new hypothesis ran counter to many generally accepted ideas and therefore required detailed study to document the supporting evidence. Kamaletdinov for several years organized a series of expeditions to the Kraka arrays to prove their allochthonous occurrence. In 1965 geologists Tamara Timofeevna Kazantseva (born 1934) and Yuri Vasilyevich Kazantsev (1935–2011) arrived in Sterlitamak and came to the geological office chief looking for work, because geological studies in Siberia, where they participated were finished. Kamaletdinov, having an acquaintance with the young specialists, employed them.

In 1967 Kamaletdinov created a thematic geological survey party to study the structure of the Kraka Mountains, and he appointed Kazantseva as the chief. The work resulted in proving for the first time within the territory of the USSR, the allochthonous origin of ophiolites. They did this by applying all available geologic methods including mapping, excavating pits and drilling. This discovery turned out to be a global scientific sensation (Figure 4) (Kazantseva and Kamaletdinov 1969).

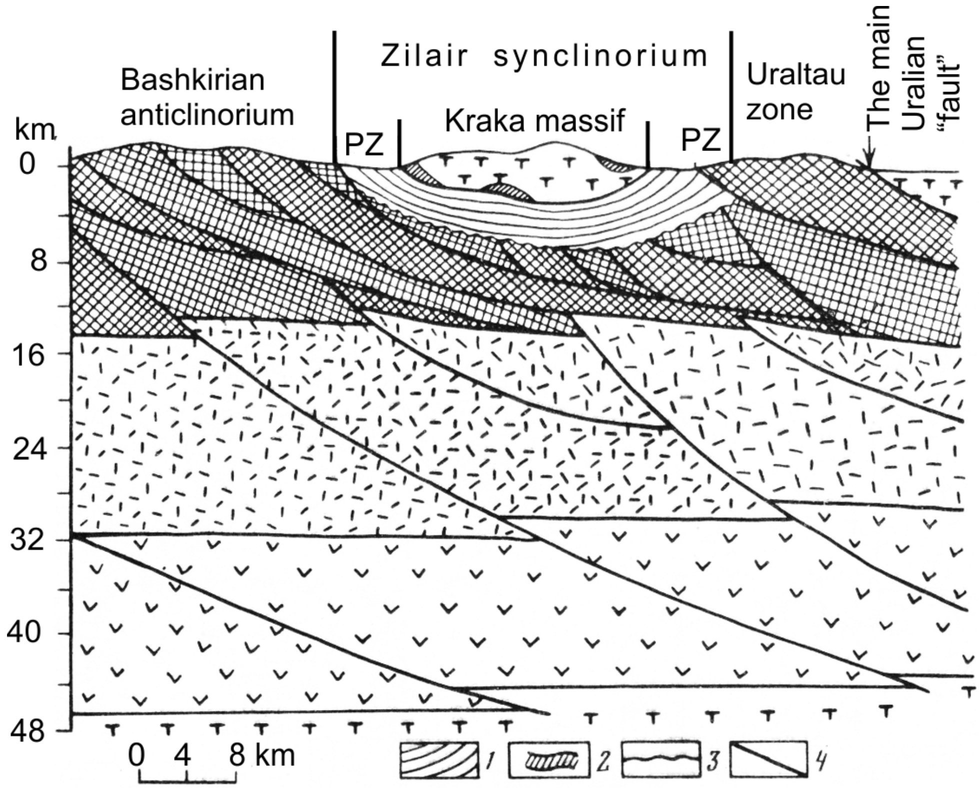

Figure 4. Kraka massif geological section (by Kamaletdinov and Kazantseva 1983)
Legend: 1 – Paleozoic sediments (limestones, sandstones, mudstones, shales); 2 – blocks of Paleozoic volcanic-sedimentary (eugeosynclinal) rocks comprising a melange; 3 – stratigraphical contact with erosion; 4 – contact of thrust-nappe plates. For the rest of the symbols, see Figure 3.

The practical value of a correct understanding of the ultramafic rocks' structural position can be understood by reference to the Ostaninsky chromite-bearing array of the central Urals. This site is about five by seven kilometers in areal extent and it was drilled in a uniform grid of more than 100 wells. The drilling program showed that the thickness of the ultramafic rocks did not exceed 440 meters. One reason for such a large number of drilled wells was the misconception about its intrusive origin and the subsequent attempt to find a feeder conduit with the highest degree of mineralization.

In 1974 Kamaletdinov published a monograph entitled *The Cover Structures of the Urals*, which became a manual for geologists dealing with the tectonics of folded regions in the USSR. In the same year Kamaletdinov was appointed Director of the Institute of Geology of the USSR Academy of Sciences in Ufa. The initiator of this appointment was academician Alexander Voldemarovich Peive (1909–1985), the director of the Geological Institute (Moscow). At that time in the Soviet Union there were only two geological institutes, headed by mobilists—in Moscow and in Ufa. Kamaletdinov retained this position for the next 17 years. Annual International and All-Union conferences conducted in Ufa helped to introduce new data on cover structures to prominent geologists both within the USSR and worldwide. The list of academicians who attended the conferences included Victor Efimovich Khain (1914–2009), Petr Nikolayevich Kropotkin (1910–1996), Evgeniy Evgeniyevich Milanovsky (1923–2012), Vasiliy Dmitriyevich

Nalivkin (1915–2000), Peive, Yury Mikhaylovich Pousharovsky (born 1916), Boris Sergeevich Sokolov (1914–2013), Andrey Alekseevich Trofimuk (1911–1999), Alexander Leonidovich Yanshin (1911–1999), and others (Figure 5). In addition, well known international scientists who attended the conferences included John Rodgers (1914–2004) and Preston Cloud (1912–1991) of the USA, as well as geologists from Canada, Australia, France, Germany, Poland, Czechoslovakia, Iran, Japan and India (Ismagilov *et al.* 2015).

Figure 5. Murat Kamaletdinov (gesturing with his right hand) in 1983 conducts a geological excursion in the southern Urals. Participants in front row (from left to right): Academician Milanovsky (in profile), Corresponding Member Nalivkin (behind front row man wearing glasses), Professor Kinzikeev (first man with hammer), Academician Kropotkin (third man with the hammer), Academician Yanshin (behind front row), Academician Khain (with hand at chin), Kazantsev (with the map), Academician Sokolov (second man to the right of Kamaletdinov), and others.

Investigations during subsequent years covered all the southern Ural Mountains, and as a result tectonic concepts were revised and the essential role of thrust-nappes was established. In 1980 the first mobilistic map of the southern Ural Mountains, edited by Kamaletdinov, was published (*Geological Map of Bashkir Autonomous Soviet Socialist Republic* 1980).

In 1983 a field session of the Department of Geology, Geophysics, Geochemistry and Mining Sciences of the USSR Academy of Sciences was held in the southern Urals (Figure 5). It was attended by eleven academicians and corresponding members of the USSR Academy of Sciences—the most prominent geologists from Moscow, Saint Petersburg, Yekaterinburg, Minsk, Ufa and other cities—comprising more than seventy people. According to the conclusions of the session, the nappe structure of the Urals was at last recognized officially and the Institute of Geology of Ufa, headed by Kamaletdinov, was appointed the USSR leading institute for investigating nappe tectonics.

In 2006 Valentin Innokentyevich Sizykh (1936–2006) wrote about Kamaletdinov's work on the Ural Mountains and said "He critically comprehended all the geology of these mountains which did not fit into the Procrustean bed of the fixism" (Sizykh 2006, p. 21).

From 1978 to 1995 Kamaletdinov conducted lectures on tectonics at the Bashkir State University, so this university became one of the first in the USSR where geology was taught from a mobilistic point of view (Farkhutdinov *et al.* 2016).

In 1995 scientists from Russia, Germany, the USA and Spain carried out the Urals Reflection Seismic Experiment and Integrated Studies Project (URSEIS), an integrated seismic transect 450 kilometer long across the southern Urals. The seismic profile obtained during the project confirmed the nappe structure of the Ural Mountains and the accuracy of the geological cross-sections made by Kamaletdinov.

3. THE THRUST-NAPPE THEORY

The new data allowed Kamaletdinov to construct the thrust-nappe theory, according to which nappes comprise main structural elements of the lithosphere, and their movements have important geological effects, such as orogenesis, folding, accumulation of sedimentary rocks, magmatism, metamorphism, seismicity and the formation of mineral deposits (such as oil, gas and metal ores).

The subject of orogenesis in geology was one of the most complicated facing geologists at that time. For example, there were over forty models for folding. The academician Shatsky noted that “folding is one of the most difficult issues of theoretical tectonics” (Shatsky 1945, p. 58). “The problem of folding formation conditions in the Earth’s crust is one of the oldest unsettled problems of geology” wrote Belousov (1962, p. 3).

It was thought formerly that after a fold forms and “exhausts possibilities of plastic dislocation” the folded rock splits to form a rupture. In this approach, the formation of nappes was associated with giant overturned folds. A detailed study of the origins of folds in mountain districts, and their laboratory modelling under the supervision of Kamaletdinov, showed that the process actually operated in reverse order: first there is thrusting, followed by folding and deformation (Kamaletdinov *et al.* 1978). Investigations showed that folds were not formed without ruptures and that folds only existed as part of a rupture-fold dislocation pair. The offset along a thrust rupture is immeasurably greater than that of a plicate rupture. An allochtonous (nappe) plate, formed by an inclined or horizontal rupture, could be complicated in its frontal part by dozens of anticlinal folds, forming linear swells of considerable extent. Such is the case as seen in the Pre-Ural foredeep. The importance of this discovery also proved that neither a mountain fold structure nor a continental massif can form without nappe breaches. Rather, they both represent nappe packets, tectonically piled up as a result of horizontal movements of the Earth’s crust.

One of the most complicated questions facing geologists at the time was the horizontal transfer of stress over long distances emanating from the site of pressure application. The problem was that folding represented plastic dislocation, which could not extend great distances from the source of the mechanical force. Kamaletdinov and his group solved this problem by proving that folds appeared in thin frontal parts of moving plates where their thicknesses decrease, thereby permitting plastic deformation to occur.

According to earlier conceptions, the migration of the Pre-Ural foredeep was explained by “the extension of Urals arched uplift” (Shatsky 1945, p. 112). In 1971, Kamaletdinov for the first time established a different mechanism, the thrust-nappe theory, for the formation of the Pre-Ural foredeep. He showed that the formation of pre-mountain foredeeps was caused by isostatic plunging of the edge of the continental platform under the weight of folded structures (nappes) moving over them (Kamaletdinov 1971).

The new mechanism explained the process by which barrier reefs over geological time migrated from the east to the west across the Pre-Ural foredeep. In the Late Carboniferous, the contact between the foredeep and the platform, which was marked by an ancient linear reef complex, was situated at the meridian of the Vydrzisky reef. In the Asselian age (299–294 Ma), the reef was situated 7–10 kilometers to the west; in the Sakmarian age (294–284 Ma), it had migrated 15–20 kilometers further west; and finally, in the Artinskian age (284–275 Ma) it had shifted to 20–30 kilometers further west. The total distance of migration of the western margin of the foredeep therefore reached 50–60 kilometers by the Early Permian (see Figure 2). The reef-building organisms likely colonized westward migrating areas of shoaling formed by the thrust-generated anticlinal folds. Additional accommodation space that permitted vertical reef growth was then supplied by the subsidence of the platform margin under the weight of the stacked thrust-nappes of the Urals as the orogen moved westward. The migration of the reef massifs matched the direction and speed of emplacement of the Urals’ allochthons. Thus, based on the migration of the barrier reefs, the rate and distance over which nappes moved in the orogenic fold belt was reconstructed (Ismagilov *et al.* 2014).

Investigations carried out in the 1970s in collaboration with Dmitriy Vasilyevich Postnikov (1921–2013) confirmed that nappe structures formed the foundations of both old and young platforms including those of eastern Europe, western Europe, Siberia, western Siberian, North America and Africa. These platforms were characterized by variation between areas of intense dislocation and discrete areas of construction. In other words, the platforms were not monolithic plates, but rather they consisted of aggregations of plates and blocks which, under compression, shifted relative to each other. This absorbed the energy of compression and directed it to interblock movements. In the 1980s Kamaletdinov together with Kazantsev and Kazantseva made comparative analyses between the tectonics of the Urals and the Crimea, the Caucasus, the Verkhoyansk Range, the Himalayas, the Appalachians, the Rockies and other orogenic zones. An important conclusion was reached: nappe structures were characteristic of the Earth's crust as a whole (Kamaletdinov and Postnikov 1979; Kamaletdinov *et al*. 1981, 1990; Kazantsev 1982). According to the thrust-nappe theory all the continents consisted of multilayered aggregations of numerous, stacked nappes, forming zones of high-capacity tectonic clustering. Owing to such crustal thickening, continental massifs in cross-section have the form of a biconvex lens; their roots extend deep into the Earth's mantle and their surfaces rise above sea level (Kamaletdinov 1974).

The problem of generating significant amounts of extractable oil in the context of the thrust-nappe theory was also considered by Kamaletdinov and his group. The 'weak point' in the established organic theory of hydrocarbon origination was the problem that many source rocks for oil were in low permeability clay-rich strata, which due to their low permeability would not readily release the oil. The thrust-nappe theory suggested that clay-rich source rocks could be mechanically shattered when subjected to horizontal pressure, thereby acquiring higher permeabilities. In addition, these zones were characterized by the necessary thermobaric conditions for oil generation from buried organic substances.

In a laboratory hydrocarbons can be produced in many ways, by both organic and inorganic processes. The question is, do the conditions for such chemical reactions exist in nature? Research into the variety of physical and chemical environments in the Earth's interior provided insights into hydrocarbon synthesis by both organic and inorganic means. These investigations indicated that hydrocarbons occur almost everywhere in the Earth's interior such as near the Earth's surface in the form of marsh gas, in coal mines, in sediments in deep oceanic basins, in folded areas, and in deep wells on platforms. Hydrocarbons have also been found in extraterrestrial objects such as meteorites as well as in the atmospheres of many planets.

According to the nappe theory, geodynamic conditions created by thrust-nappe tectonics were essential to the formation of oil and gas fields. Movements of tectonic plates formed zones of crushed rocks permeable to fluid and gas migration. Mechanical grinding of rocks in the crushing zone contributed to highly active mechano-chemical reactions including hydrocarbon synthesis. Support for this mechanism was provided by the confinement of the majority of oil and gas deposits to the marginal zones of platforms and foredeeps, adjoining the folded regions. According to the nappe theory, anticlines and fractured zones, which could act as collectors of hydrocarbons as well as a means of fluid migration, occurred at the frontal parts of moving allochthonous plates (Kamaletdinov and Kazantsev 1976). According to this conception of oil genesis, large quantities of hydrocarbons could be contained in rocks of broad stratigraphic range and lithological composition (from sandstones and limestones to granites and ultrabasics). What was required were the fractured reservoir rocks found in thrust-nappes, as well as cover-rocks which protected the deposit from erosion.

The established genetic relationship between thrust anticlines and oil deposits allowed Kamaletdinov to develop an efficient method to discover a number of oil and gas deposits in the Pre-Ural foredeep. These oil deposits were found at Tabyn, Teiruk, Shabagin, Yermolaev, Romadan, Bakrak, Arkhangelsk, Voskresensk and elsewhere (see Figure 2). The association of regional folding, formed by horizontal compression, with hydrocarbon traps allowed the use of thrust faults as markers when searching for oil. Because the thrust dislocations were observed for hundred kilometers, they were easier to discover than their associated anticlines. The general-tospecific search principle was applied to oil exploration; that is, a regional thrust fault was first identified and then a series of anticlines along the frontal zone of the nappe was mapped. These anticlines occurred like a series of beads on a string (Kamaletdinov 2001).

The thrust-nappe theory suggested that it was possible to discover large hydrocarbon deposits in sub-thrust zones of the Ural Mountains and in other folded zones around the world (Kamaletdinov 1962; Kamaletdinov *et al*. 1988). In the Ural Mountains, the surface geology comprised intensively dislocated and metamorphosed Precambrian rocks, which were conventionally viewed as having low potential for containing oil and gas. According to the nappe theory, however, these Precambrian rocks comprised allochthonous plates at the surface that covered younger autochthonic platform deposits with a higher potential for containing oil and gas deposits. Under the old paradigm, the eastern portion of the Pre-Ural foredeep was thought to be a barrier, blocking the possible migration of oil and gas from the eastern side of the folded Urals. Instead, investigations undertaken under the new nappe theory paradigm suggested that the Pre-Ural foredeep represented a monocline, plunging to the east due to crustal loading by the folded and thrusted Ural Mountains. Thus, the argument for discounting a possible connection between the frontal foredeep and the adjacent orogen was eliminated.

Extensive analysis has confirmed a genetic link between thrusts and the generation and accumulation of other mineral resources. For example, the association of coal deposits with thrust-nappes has been studied in western Canada (Smith 1988). According to that study, the main coal-bearing regions of western Canada were confined to the thrust belt of the Rocky Mountains. The intensity of nappe dislocations was reflected in the grade of coal where anthracites were associated with the most dislocated zones. Thus, the coal quality and its mining characteristics in the Canadian Rocky Mountains thrust belt and foredeep were determined by the cleavage and the doubling of coal layer thicknesses associated with tectonic deformations (Smith 1988; Kamaletdinov 2001).

Many deposits of copper, pyrite, gold, iron, manganese and other ores, occur in zones of crumpled or crushed rocks (i.e. mylonites), associated with thrust and nappes. In addition, hydrothermal sources occur in the places where volcanism is absent. According to the thrust-nappe theory such hydrothermal springs could be associated with thrust faults separating the nappes (Nigmatulin *et al.* 1998).

Alexander Sergeevich Bobokhov (1936–1999) and other investigators documented a relationship between the distribution of paleotemperatures in the Ural Mountains with the thrust-nappe structure (Bobokhov 1997). The results showed that due to the application of shear stresses at high pressures of about 500,000 kg/cm^2 many metal oxides lose oxygen thereby forming native metals such as silver, copper and mercury. In nature these conditions occur in thrust zones.

The thrust-nappe theory was incorporated into innovative mobilistic research projects, carried out by many Russian geologists including Arif Tadjaddinovich Rasoulov (1945–2010), Sergey Vasilyevich Rouzhentsev (1935–2012), Andrey Stepanovich Perfiliev (born 1932), Vadim Borisovich Sokolov (born 1939), Sizykh, Tofik Abbasovich Gasanov (1932–2001) and others in various regions of the Urals, eastern Siberia, Central Asia, the Carpats and the eastern European platform (Gasanov 1985; Rouzhentsev *et al.* 2004; Sizykh 2006).

The utility of the thrust-nappe theory in explaining the geology of those various regions was highly appreciated by many of the leading geologists in the USSR, and in 1990 it was nominated for the Russian State Prize. In a support letter to the Russian Committee on State Prizes, Academician Viktor Efimovich Khain wrote:

> Over the last twenty years there has been a revision of our conception about construction of folded systems in our country, including platform foundations. The basis of these changes is the recognition of thrust nappe structure of these systems. For the first time this model was worked out on the example of the Urals by a group of investigators headed by Kamaletdinov. Furthermore they developed general theory of nappe structures formation, which highlights their leading role in the construction and development of mobile zones of the Earth's crust (Kazantseva 2003, p. 99).

Unfortunately, the fates of the scientist and his theory have developed in a different ways. In 1987, on the initiative of the Party Committee, the Urals branch of the USSR Academy of Sciences was established, and the Institute of Geology headed by Kamaletdinov was subordinated to Sverdlovsk (nowadays known as Yekaterinburg). In Sverdlovsk 'nappes' were not recognized, and the Presidium of the Ural branch of the Academy of Sciences demanded that Kamaletdinov 'renounce' his mobilistic ideas. Kamaletdinov vigorously refused, comparing that style of leadership with the persecution of geneticists. As a result, the 'obstinate' scientist was dismissed from the post of Director of the Institute of Geology. Also, Kamaletdinov's candidacy for election to the USSR Academy of Sciences became impossible, and the State Prize, previously approved at all stages of the nomination process, was suddenly declined. The leading geologists of the country—14 academicians and corresponding members of the Academy of Science—sent a letter to Guriy Ivanovich Martchouk (1925–2013), the President of the USSR Academy of Sciences, protesting the unlawful dismissal of Kamaletdinov. The protest was left unanswered.

In contrast to the fate of the scientist, the thrust-nappe theory has received additional confirmation over the years. For example, during the 2000s Kamaletdinov and his disciples studied both the Pre-Ural foredeep and the folded Ural Mountains, and identified prospective zones for sub-thrust hydrocarbon deposits (Ismagilov 2006, 2012; Ismagilov and Farkhutdinov, 2007; Ismagilov and Kamaletdinov 2011; Farkhutdinov 2012, 2013). In particular, prospects for oil and gas in the Chelyabinsk graben of the eastern slope of the Ural Mountains were estimated. Also, large anticlines were discovered and areas for drilling wells were suggested (Kamaletdinov *et al*. 2009). In 2012 Kamaletdinov published an article where he provided information about the connection between tectonic activity in the geological history of the Earth with gravitational forces of our Galaxy (Kamaletdinov 2012).

Academician Yuriy Alexandrovich Kosygin (1911–1994) wrote about the thrust-nappe theory:

> This work is of great theoretical and practical importance, it lays the foundation of our modern ideas about the nature and mechanism of the Earth's crust horizontal movements, and it is also the basis for oil exploration in the vast territories with thrust-nappe structure (Timergazin, Timergazina 1992, p. 10).

4. EPILOGUE

The creation of a scientific theory is the peak of a scientist's work. Over the history of geological science only a few global theories have been created. For example, in the late eighteenth century, neptunism attempted to explain the origin of rocks as precipitates from a world ocean. That theory was replaced in the early nineteenth century by the theory of plutonism which explained the origin of igneous rocks as a product of the inherent 'heat' of the Earth. Later in the 19th century, two competing theories arose to explain the origin of mountains. A contracting Earth theory explained folding as the product of a cooling and shrinking Earth where the crust became wrinkled. The geosyncline theory explained the folding observed in mountains by the vertical movements of the Earth crust. The subsequent development of geology can be thought of in terms of the opposition between supporters of fixism and mobilism.

In the 1960s J. Tuzo Wilson, W. Jason Morgan (born 1935), Xavier Le Pichon (born 1937), Jack Oliver (1923–2011), Brian Isacks (born1936), and Lynn Sykes (born 1937) founded a new global tectonic or plate tectonic theory, which had its antecedents in the hypothesis of continental drift proposed by Alfred Wegener (1880–1930) (Wegener 1912). The new global tectonic theory examined large-scale segments of the Earth's lithosphere, their movement and interaction, and the world ocean structure based in part on data from geophysical investigations and deep-water drilling. The thrust-nappe theory investigated the tectonics of continental crust, as supported by the data from geological mapping along with geophysical and drilling data. The thrust-nappe theory, created by the Russian scientist and thinker Murat Kamaletdinov, is a parallel to the new global tectonic theory. It too explained geological processes from a mobilistic position. Processes explained by the thrust-nappe theory included orogenesis, folding, magmatism, metamorphism and the formation of mineral deposits (such as oil, gas and metal ores). Both theories complement each other within the general context of mobilism. Thanks to this research, many years of struggle between mobilistic and fixist ideas in the USSR ended with a general acceptance of mobilism.

As is commonly known, important scientific discoveries are often rejected at first and then, after some time, they are generally accepted as well-known truths (Kuhn 1970). Also, it is common that former opponents assign to themselves the pioneers' discoveries. This was the case with discovery of nappes in the Ural Mountains. From the 1970s more and more geologists have begun considering this theme. These structures are now universally recognized, and former opponents claim to be the discoverers (Ivanov 2014). Kamaletdinov throughout his life vigorously protected justice and devoted much of his work to the problem of morality. Murat Kamaletdinov died in 2013. He loved the Urals and held that nature reveals its secrets to kind people.

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