PECULIARITIES OF THE FORMATION OF THE ZHAILMA VOLCANO-TECTONIC DEEP

Introduction. The issues of the Zhailma trough genesis, which is unique in terms of ore saturation developed in the middle of the last century, are the subject of constant discussions. In most scientific publications, the structure is considered as “the western flank of the latitudinal Uspensky rift zone, the Karakengir-Uspensky riftogenic trough”. In the paper, the authors consider the Zhailma trough alternatively as a volcanic depression, whose initiation and development is associated with intense manifestations of the rhyolitic Middle Devonian volcanism that later on, under conditions of gradual subsidence, was filled with volcanic products of the Middle-Late Devonian, the final stage of magmatism, and then carbonate and carbonate-terrigenous sediments of the Famennian-Early Carboniferous transgressive series.

The main reserves of complex ferromanganese, barite-polymeritic and barite ores of Central Kazakhstan are concentrated in the Atasu ore district. The main ore-controlling structure covering almost the entire territory of the Atasu ore district, is the Zhailma graben-syncline. The results of this work are covered in numerous publications. Most of them that deal with the issues of the trough genesis and consider it as a “riftogenic depression” confined to the extended linear graben-like riftogenic Karakengir-Uspensky trough [1]; to the Uspensky paleorift (Shcherba G. N., 1964, 1970), and others.

In works [2, 3], the Uspenskaya zone is considered as an integral part of the larger Tekturmas polycyclic geotectonic-genic; trough structure (paleorift), and the Zhailma depression as the western flank of the Uspenskaya zone formed by the Early Hercynian rifiting processes. However, Borsuk B. I., et al., 1972, while characterizing the Uspensky part of the Atasu-Uspensky synclinorium, notes that it is a highly compressed linear structure complicated by a system of small, sometimes calm folds with slope of wings 40–500, often steeper and thrown back to the north. It is broken by numerous longitudinal ruptures that caused the thrusting of the older rocks on the young ones [4].

According to seismic exploration (Sherubay-Nurinsky DDS profile) [5], the Moho surface within the Uspenskaya zone (Popov A. A., 1967) forms a trough with an amplitude of up to 5 km. According to the results of DDS, MTS and interpretation of gravimagnetic anomalies, the Uspensky profile and its western continuation in the Zhailma graben-syncline at depths of 6–7 km corresponds to a trough-like depression that expands to the west and narrows to the east. In the Moho surface, against the background of general regional sagging, it corresponds to a depression, where the depth of the Moho surface reaches 52–53 km, both structures have increased thickness of the earth’s crust.

According to geophysical data, the thickness of the crust under the continental rifts decreases and a corresponding rise of the Moho surface takes place. The thickness of the crust under the Baikal rift decreases to 30–35 km, under the Rhine rift to 22–25 km, under the Kenyan rift to 20 km, and to the
north, along the Afar valley, it reaches 13 km, and then under the axial part of the valley there appears the oceanic crust [6]. If we consider similar parameters of the Moho surface troughs in the Central Kazakhstan “paleorift system”, Agadzhy-Vishnevsky 50 km and Kenkuduk-Karaagay 47.5 km, then the thickness of the crust under the rift is significantly greater than in modern rifts. In the mantle ledge under the rift, the rocks are usually decompacted (the velocities of longitudinal waves vary in the range of 7.2–7.8 km/s (Kenyan), and the central Kazakhstan paleorift is characterized by the longitudinal waves velocity that is equal to 8.2 km/s [7].

One of the undoubted achievements in the geology of the past and the beginning of the 21st century is the development of ideas of the rifting processes (Milanovsky E. E. 1976, 1987, 1988; Sengor, Burke, 1978; Sengor, 1995, etc.), which allows giving an objective assessment of the validity of classifying the Zhailma trough and the Uspenskaya shear zone as “riftogenic” crises.

In the modern sense, rifts are extended, fault-limited, elongated grabens, troughs. The term characterizes the process of rupture (stretching) of the previously continuous medium [8]. Under the rifts, the entire thickness of the lithosphere is reduced due to stretching that occurs during the formation of these structures (Sengor, Burke, 1978; Sengor, 1995).

According to a number of scientists, the Central Kazakhstan paleorift is active, the rifting of which is caused by the mantle diapir rise. However, in such settings, rifts form as a result of crustal extension (stretching of the outer arc of the concentric fold, i.e., on the stretching side of the neutral surface) caused by the dome formation (Cloos, 1939).

Rifts form in almost all the tectonic settings (including those over mantle plumes) and at all the stages of the Wilson cycle of ocean opening and closing (Burke, 1978). Sedimentary basins in rift zones retain a record of the tectonic settings of their origin and (or) development much better than orogenic belt basins, although the range of tectonic settings that form in them is limited. The range of rock types in rift zones is poorer than in orogenic areas [9]. Metamorphism of rocks in rifts is much less pronounced compared to the metamorphism that accompanies orogenic processes (Burchfiel, et al., 1992; Davis, et al., 1996). The term “graben” is applicable only to those structures that do not extend to the entire surface of the lithosphere. These are depressions, or troughs in horizontal layers, which are much longer than their width. This concept is purely descriptive (Rosenfeld and Schicker, 1969). This term is applicable to those structures that do not pass through the lithosphere.

Morphological features of continental rifting are the result of deep processes. All the continental rifts tend to have similar geological characteristics. Dome structures and depressions separating them are clearly expressed in the relief [10]. The planned location of rift basins has certain regularities: an asymmetric transverse profile of zones, which is maintained at considerable distances, frequent asymmetry of the rift valley and the constancy of the width of rift basins, which is the most important common feature of continental rifts [11].

Thus, the Uspenskaya and Zhailma “riftogenic structures” are antipodes of rifts, and the ideas of the “riftogenic” genesis of the Zhailma depression developed more than 30–60 years ago and based on the ideas that existed at that time of the rifting processes (stretching of the outer arc of the concentric fold), i.e., on the stretching side of the neutral surface caused by the dome formation (Cloos, 1939).

The Zhailma graben-syncline is located in the junction zone of the volcanic structures of the Sarysu-Teniz segment of the DVGP with the complexly dissected Caledonian structures of the Atasu anticlinorum [12]. Thus, from the east, the Famennian-Carboniferous sedimentary formations that fill the graben-syncline directly overlap the Caledonides of the Atasu anticlinorum; from the south, north and west they overlap the Devonian volcanics.

The Atasu anticlinorum is mainly composed of siliceous-terrigenous formations of the Karashechskaya suite (E-O, kr) and terrigenous–siliceous formations of the Karatas (O1, kr), which make up a single intensively deformed siliceous-volcanogenic-terrigenous formation occurring in the form of allochthonous plates of microquartzites, jasper, siliceous-carbonaceous shales. They are unconformably overlain by a complex of rocks of the flysch formation of the Kogalinskaya suite (O2, kg). In the Sarysu-Teniz segment, Devonian volcanism developed on the active margin of the Caledonian paleocontinent [13].


Stages of magmatism development. The development of magmatism was characterized by the succession of differentially basalt–andesite–dacitic formations (Early Devonian), predominantly thysacite–rhyolite of the middle stage (Early–Middle Devonian), and, finally, contrasting basalt–rhyodite or single–rock formations of increased alkalinity of the late stage of development (Middle Devonian, Late Devonian, Zhaksyksynskaya Series). In general, igneous formations of volcanic belts [14, 15] belong to two groups: sialic and mafic formations. In both groups, the formations of rocks of the normal calc–alkaline and elevated subalkaline series are developed, while the total alkalinity and potassium content increase from early to late formations and from the rear parts of the belts to the frontal ones.

Based on the existing ideas of the stratigraphic section of the region, four stages can be distinguished in the development of magmatism, whose manifestations strictly correspond to certain phases of tectogenesis, in the Atasu region, three of which are associated with magmatism.

The Early Devonian stage is characterized by local outpourings of basalts. Judging by their limited distribution, they originated from small slags and fissure–type volcanoes. Their outcrops are known in individual fragments of the Ustanynzhal block, in the core of the Karazhal brachiatricline, and in the southern edge of the Zhailma syncline. The Lower Devonian granodiorites and quartz diorites of the Karamenda intrusive complex are spatially and genetically related to it.

The lithological composition of this period formations indicates the absence of major tectonic rearrangements in the region.

The Early–Middle Devonian stage of magmatism is associated with emissions of huge volumes of acidic pyroclastics (crystal-clastic tuffs, ignimbrites, clastolaves, fluidal lavas). At the final stage of volcanism, rhyolitic extrusive domes and dikes form (the Zheltymas and Uguztam formations). Volcanics of the second stage make up the core and wings of the Bekta anticline, their small outcrops are known to the north of the Zhairemskoy deposit and at the northern end of the Syyrtysu syncline. In work [1], the authors suggested that the volcanic rocks developed in the Bekta anticline and north of the Syyrtysu syncline are close to the “centers of the Middle Devonian magmatism”. The occurrence in the form of a crescent bordering the tectonic block of the Early Paleozoic rocks from the north–west, the variegated petrochemical composition of the rocks of the suite — from anesites, trachydacites and trachyhydrolites, wide development of crystalline tuffs, the
presence of subvolcanic bodies, the radial-concentric location of faults make it possible to consider the north-western closure of the Alka-Adyr brachianticline as a part of a large volcano-tectonic edifice preserved from erosion. The inclination angles of the seams in the north are 20–45°, in the south-west direction they dip at the angles of 35–50°. In the southern frame of the Zhairem syncline (near the city of Karashoky) there is a sharp increase in the angle of incidence up to 40–50°. Another center of distribution of the Middle Devonian effusive magmatism is assumed in the mountains of the S. Kedeytau, where it is apparently fixed by the dome-shaped extrusive body of lified zones (SFZ) of Famennian sedimentation are distinguished in the Middle Devonian, effusive magmatism is associated with deep-water clays, siliceous-carbonate deposits extending from the northeast to the west of the structure and for the most part coinciding with the strike of the Zhairem trough. In the Northern and Southern SFZ, the fames is represented by shallow-water organogenic and organogenic-detrital limestones. Such zoning persisted during the Famennian, Tournaigian and Visean times. Thus, the Zhairem SFZ is an extended “arc-shaped” trough, maximally sag in the central part, which existed for a long time against the background of the general weak subsidence and accumulation of shallow-water sediments along the periphery. The gradual compensatory nature of the accumulation of carbonate and carbonate-terrestrial sediments is evidenced throughout the depression by the presence of stepped normal faults along its sides and the absence of blocky, coarse-grained facies.

Ancient volcanic apparatuses of Central Kazakhstan. For the first time, the presence of a large number of ancient volcanoes developed on the sides of the Zhairem depression was noted by G. N. Shcherba (1964). In work [2], the author cites the data of intense volcanism of the Lower Devonian, and then the Givetian-Franian time, which determined the location of the main volcanic centers at the intersection of faults along the main northeastern and northwestern large faults. These were dynamic effusive-explosive processes accompanied by ejections of first basic, and then medium and acidic lavas and their products, the rapid growth of volcanic cones (the Taszhargan, Kedeytau, Mur-zhalasy, S. Zhairem, Ushkul volcanoes). Later, the activity of volcanism clearly weakened.

Some of these volcanoes are clearly observed in the form of fragments of ring structures bordered along the periphery by dike belts. Volcanogenic structures are most clearly shown on the geological map compiled by V. I. Schibrik (1989). On this map, the authors highlighted dikes of basalts, diabases and rhyolites, trachyandesites, and fragments of radial and ring faults (Fig. 1).

This made it possible to establish with a high degree of reliability and clarity the presence of two large volcanoes on the northern side of the caldera structure: North Zhairem and Ustanynzhal. To the south, in the central part of the Zhairem depression, the buried volcano Zhairem stands out in a practically closed ring, with the caldera diameter of 20–22 km, which probably corresponds to the later (Givetian-Franian) stage of volcanism. At the same time, the entire Zhairem syncline is completely limited by an arcuate fault, which coincides well with the outer boundary of the arcuate trough (Yu. A. Vasyukov, et al., 1991), with the radius of about 40 km developed parallel to the boundaries of the Ustanynzhal caldera. This makes it possible to consider the basin as a fragment of the main northeastern and northwestern large faults. These were dynamic effusive-explosive processes accompanied by ejections of first basic, and then medium and acidic lavas and their products, the rapid growth of volcanic cones (the Taszhargan, Kedeytau, Mur-zhalasy, S. Zhairem, Ushkul volcanoes). Later, the activity of volcanism clearly weakened.

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a deep volcanic chamber, or not at all coinciding with the centers of individual chambers, was named “external” by E. E. Milianovsky. They can be contrasted with internal depressions: calderas.

The proposed sequence of the volcanism development in the Zhailma trough is in good agreement with the scheme (Fig. 2).

The burial of the ancient relief expressed by peculiar primary “ingressive” volcanic unconformities, testifies to the rapid filling of low spaces with volcanic mass, its great fluidity and spreading over a large area. Descriptions of such geological phenomena in paleovolcanic regions are available in a number of works.

Internal structure, shape and patterns of the volcanic structures location. These factors depend on faults of different scale and genesis that controlled the rise of magma. This leading position of volcanology finds confirmation and substantiation in many works dealing with geology of Central Kazakhstan.

The greatest attention is attracted by large volcano-tectonic structures, depressions and subsidence calderas developed above volcanoes due to the removal of huge masses of the volcanic material to the surface (Tikhomirov V. G., 1973).

According to the mid-frequency seismic data [5], the Zhailma graben-syncline cross section is a “backer-shaped” trough, with the depth of 5 to 8 km with the ledge-shaped structure of the wings formed on the Caledonian (Early Paleozoic) base. The base surface is represented by a reflecting horizon, sharply discordant with the overlying subhorizontal boundaries; below the section is uniform. At the depth of 8 km, shear movements in the northeast direction are recorded, indicating the thrusting of the folded complexes of the Aktau-Mointinsky uplift onto the board of the Zhailma trough.

In the geoelectric field [7], along the profile that crossed the Zhailma graben-syncline and the Atasu uplift in the northeast direction, two horizons are reflected: the first one with rock resistivity of 2–10 Ohmm and the thickness of up to 70 m corresponding to the Mesozoic Cenozoic deposits, and the second one with resistivity of up to 100–200 Ohmm, the thickness of 800–3000 m characterizing the upper sedimentary part of the structure section.

The northeastern side of the graben in the deep section starting from the depth of 4 km, is sharply limited by a steeply dipping southwest zone of convergent field gradients, although on its surface its boundary with the Atasu uplift is shifted far to the northeast. To the north-east of the gradient zone characterized by resistivity of 100–200 Ohmm, below 3.5–4.0 km, the sedimentary complexes of the graben-syncline are underlain by high-resistivity (300–1500 Ohmm) rocks, similar in electrical resistance values to those neighboring the Atasu uplift. This pattern is typical for thrust deformations.

Thus, the results of seismic and electrical exploration do not contradict the authors’ ideas of the volcanogenic origin of the Zhailma graben-syncline and contribute to the deciphering of the structure of the northeastern wing of the trough, which turned out to be elevated relative to its central part, due to thrusting (“underthrusting”) under the Fammennian–Early Carboniferous (plastic) carbonate formations, in the form of tectonic plates and wedges of hard (siliceous-terrigenous) rocks of the early Paleozoic. One of these plates is exposed on the daylight surface in the vent part of the Ustanyzhalsky paleovolcano, cut through by the Devonian granitoid intrusion.
According to Shcherba G. N., the Taszhargan brachiactinidiane is also a volcanic apparatus, whose vent part is made by exursion of trachyryholites.

The formation of the Zhailma depression is caused by the development of intense volcanic processes, a system of plicative and disjunctive dislocations developed along deep basement faults.

Within its limits, a series of brachifolds has been established, less often linear with dips on the wings from 30 to 90°, complicated by flexures, faults, strike-slip, thrusts, interformational failures, brecciation zones [17]. A complex combination of tectonic processes led to the development of the dissected topography at the base of the Famennian sediments (Fig. 3). This is very important for the processes of formation and accumulation of "metal-bearing" solutions.

Faults in the Zhailma structure are divided into tectonic blocks, whose boundaries are marked by zones of high gradients of the gravimetric field. The time of laying belongs to the Devonian period characterized by tectonomagmatic activation, manifestation of intense volcanism and blocky deformations of the Caledonian base, as well as the formation of consedimentary horst anticlines and graben synclines [18].

Volcano-tectonic structures of subsidence in the latitudinal branch of the Devonian volcanic belt, are described by Fedorov T. O. Various volcano-tectonic depressions are developed, according to M. K. Bakhiteyeva, A. E. Mikhailova, and others, V. G. Trifonova, M. N. Shcherbakova, in the southern part of the Tokraus and North-Balkhash depressions. In ancient volcanoes, as well as in modern ones, one can firstly distinguish a surface structure (superstructure) formed by lavas and ashes of successive eruptions along with intrusions penetrating them; secondly, deep substructure covering the area of the earth’s crust between the roots of the volcano and the earth’s surface, and thirdly, the volcanic heath (focus), due to which volcanic eruptions are fed. All these parts are successively exposed by erosion (Tyrell G., 1931) (Fig. 3).

The upper part of the volcanic edifice (Oberbau) has a caldera and a central cone, bedded, conical and radial veins, with a crater and a vent. The deep part (Unterbau) has conical and ring veins (partially continuing the ring caldera).

The translational movement of the melt is associated with modern concepts of segregation: the process that plays a particularly important role in the formation of banded textures of volcanic rocks, and determines the lava fluidity. The distribution of roots feeding volcanic activity is strictly subordinated to the structural setting and is controlled in a number of cases by a system of tension cracks in the domes.

The typical structural features of the deep root zones of ancient volcanoes do not differ in morphology from modern ones. Different sections can expose either supracyrystal or deep roots of ancient volcanoes, heterogeneous in structural features at different depths. The root zones of the upper intercrys-tal stage are characterized by intrusions under volcanoes or subvolcanoes combined with volcanogenic formations, which represent structural elements of the ancient supercrystal apparatus preserved from erosion and destruction. Intrusive, outflowing and pyroclastic rocks are typical for the upper tier (Luchitsky I. V., 1971).

Thus, the Ustanyzhalsky and Northern Zhairem paleovolcanoes correspond to the zone of the upper intercrystal layer of ancient volcanoes.

The presence of large Devonian volcanic structures is also characteristic of the Munglu-Uguztau horst anticline, the southern flank of the Zhailma trough.

The data given by the authors basically coincide and partially supplement the conclusions of Patalaha G. N. and Shuzhanov V. M. that the “Atasu metallogeny”, in fact, completes the process of formation of the Devonian volcano-plutonic belt in the Carboniferous, i.e. is Caledonian at the Hercynian stage characterized, however, by a very specific structural localization; it is confined only to the outer peripheral structures of this belt, such as grabens with basaltic magmatism, which experienced a steady deflection throughout the entire history of the belt evolution. It is this main specific feature of the structures of the Zhailma type that provides a real key to understanding why the search for deposits of the Atasu type carried out over many decades in Kazakhstan, has been so unsuccessful.

Conclusions.

1. The initiation and development of the Zhailma graben-syncline is closely related to the processes of tectonomagmatic evolution of the Devonian volcanic-plutonic belt.

2. The development of magmatism was characterized by the change in differentiated basalt-andesite-dacitic formations (Early Devonian), the predominant rhyodacite-rhyolite of the middle stage (Early-Middle Devonian) and finally contrasting basalt-rhyolite or single-rock formations of increased alkalinity of the late stage of development (Middle-Late Devonian, Zhaksykonian series).

3. The formation of the Zhailma volcanic depression, surrounding the Ustanyzhhal caldera in the form of a ring, is associated with Early-Middle Devonian volcanism associated with powerful eruptions of large volumes of rhyodacite-rhyolite volcanic rocks from large stratovolcanoes (Northern Zhairem and Ustanyzhhal), accompanied by subsidence surfaces above the foci of emptying magmatic chambers.

4. At the final stage of Devonian magmatism, a parasitic crater (Zhairem) arose in the Zhailma depression probably composed of loose volcaniclastic formations, which were later completely eroded and only trachyryholites and trachybasals of dike and extrusive facies were preserved, which created an extremely complex, rugged nature of the sediment bed of the transgressive series.

5. Thus, the most powerful Devonian tectonic restructuring of the region was associated with intense manifestations of rhyolitic volcanism. The first and the final periods were marked by relatively weak manifestations of tectonic activity.

6. The final (taphrogenic) stage was marked by the period of the Late Frasnian-Famennian-Early Carboniferous transgression with the accumulation of thick carbonate and carbonate-terrigenous sediments, including ore-bearing ones.

7. Thus, predictive metallogenic and accordingly prospecting work is recommended to be carried out within the graben-synclines of the Sarysu-Teniz segment of the Devonian volcanic belt, where such deposits of ferromanganese ores as Tur, Bogach and Karadayr of the Atasu type are already being developed in the Aydagarla graben-syncline.

References.

Особливості формування Жаїльмінської вулкано-тектонічної западини

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Мета. Виявлення особливостей формування Жаїльмінської вулкано-тектонічної западини, а також принципів і факторів, що впливають на рудоутворення цієї структури.

Методика. Аналіз результатів ізотопного датування гірських порід, критичний аналіз літературних і фондо-нових матеріалів, аналіз генезис та специфіки орудення Жаїльмінської структури, особливостей формування вулкано-тектонічної депресії.

Результати. Формування Жаїльмінської грабен-синкліналь пов’язане із підйомом після викидів значних мас кислого магматичного матеріалу стратовулканів, сконцентрованих на Жаїльмінській структурі. Закладення й розвиток грабен-синкліналі тісно пов’язані із процесами тектономагматичної еволюції девонського вулкано-плутонічного поясу.

Наукова новизна. Переглянута пошукова модель для стратифікованих родовищ Атасуєвського типу з урахуванням оригінальної теорії вулкано-тектонічного походження структури, сформованої на завершальних етапах становлення й розвитку девонського вулкано-плутонічного поясу. Генезис родовищ Атасуєвського типу сприймається як осадово-гідротермальний, пов’язаний із процесами діагенезу й катагенезу, що відбуваються всередині осадових басейнів. Обґрунтована наявність на північному борту структури кальдери двох великих вулканів: Північний і Устанинжал.

Практична значимість. Рекомендовано проведення геохімічних та ізотопних аналізів для визначення і вивчення геотермальних зон.

Ключові слова: вулкано-тектонічна, ізотопний аналіз, грабен-синкліналь, осадово-гідротермальний."