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The nature of fire phenomena during the 1927 Crimean earthquakes

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During the Crimean earthquakes of 1927, incomprehensible natural phenomena were observed in the Black Sea — flashes of fire above the water (henceforth referred to as the fire phenomena). It was originally believed that these phenomena were associated with ignition of methane, which had escaped from the seabed due to tectonic disturbances formed during seismic movements.

Analysis of the available geological and geophysical materials, along with the seismicity of the northern Black Sea region, indicates that the fire phenomena that had occurred during the Crimean earthquakes of 1927 were caused by massive gas emissions. These emissions were a result of the powerful mantle gas-fluid flow into the decompaction zones of the crystalline basement along tectonic disturbances of various scales within the Odessa-Sinop and Circum-Black Sea fault zones during this time. In fact, the earthquakes were a trigger for the activation of tectonic disturbances in the bottom sedimentary horizons for the migration of focused deep gas-fluid flows.

To establish a proper interpretation and understanding of the fiery phenomena observed during the Yalta earthquakes of 1927, the conceptual system of the hypotheses of A.L. Gilat and A. Vol [2012] is provided. The main energy source for the Earth's internal processes is considered to be the induced chain of degassing reactions of hydrogen and helium, as the most common and important energy carriers and reservoirs.

This article analyzes the deep structure of focal zones and the nature of the seismic process, and it, and via these analyses it considers the possible nature of the manifestations of the fires phenomena phenomena. Through the methods used in this study, their spatial and temporal directionality of the fire phenomena is established. The main bands of the fire outbreaks over the water spread in two directions. The earlier one, the Sevastopol-Evpatoriya zone, was elongated submeridionally to the west of the coast. It lied was spatially situated to the east of the Nikolaevskiy fault. The later one, the Yalta-Alushta zone of the northeastern extension, was associated with tectonic disturbances within the Circum-Black Sea fault zone. This fault zone remains active at the present time, which is confirmed by its seismicity, the structure of the consolidated crust and sedimentary strata, the forms of the bottom relief, etc.

Key words: gas-fluid flow, gas emissions, fault zones, Black Sea, earthquakes.

Introduction. In the Black Sea during the Crimean earthquakes of 1927, powerful gas emissions were observed, which were accompanied by fire phenomena. The latter were overlooked, and A.A. Nikonov [2002] drew attention to them for the first time. However, already in the 1930s, researchers assumed that the outbreaks of fire above the water were associated with the ignition of methane, which had escaped from the seabed through cracks

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formed during seismic movements. The volumes of gas emissions were significant — millions of cubic meters of methane. This is what prompted us to consider these emissions as a kind of gas plume, and to associate their genesis with the upper mantle and deep fault zones [Shnyukov, Kobolev, 2021].

Interpretation of the fire phenomena to the west of Crimea is a rather complex task. In the thirties of the last century, the structural features of the northwest of the Black Sea were still insufficiently studied. The Black Sea water area to the west and south of the Crimean Peninsula, where fire phenomena were manifested after the Crimean earthquake of 1927, was intensively studied by geological and geophysical methods in the post-war period — from 1946 to the present. The level of geological knowledge has vastly increased during this time. Today, the geological structure of the region, the development of fields of gas seeps, gas hydrates, as well as gas deposits and mud volcanoes, are clearly delineated. Fault tectonics, which plays a special role in the location of gas accumulations, has been studied, helping to identify areas of significant fault activity (Fig. 1). At the same time, the unreliability of the geographical location of events makes many, even most, judgments conjectural.

Classical models of seismology predict that earthquakes occur as a result of tectonic movements of rocks during a critical accumulation of elastic stress. However, the elastic energy of ruptures in the lithosphere cannot cause such a powerful release of energy to ensure the dominant vertical component of the Earth's surface motions. The cycle — foreshocks, main shock, aftershocks — which is observed during catastrophic earthquakes, and most importantly, their energy source [Bürgmann, Dresen, 2008], is also not explained by the classical models.

For the interpretation and understanding of the nature of the fiery phenomena observed during the Yalta earthquakes of 1927, the conceptual system of hypotheses of A.L. Gilat and A. Vol [2005, 2012] is of interest, in which the main source of energy for the Earth's internal processes is considered to be the induced chain of degassing reactions of hydrogen and helium, as the most common and important energy carriers and reservoirs. The essence of the proposed hypothesis: primary hydrogen and helium, the basic elements of the cosmos, accumulated excess energy during the period of Earth's accretion through the formation of solid and liquid solutions, chemical compounds, cluster structures, and Van der Waals compounds. After the end of the accretion process, the process of energy release, degassing, began and continues to this day, i.e., a chain of induced chemical reactions at the boundaries of local changes in RT conditions. These changes cause exothermal decomposition of unstable structures and associated secondary endothermic reactions from the formation of other compounds that are stable under these conditions. The proposed model provides a solution to the problems associated with the lack of a suitable energy source for the main endogenous processes of the Earth. At the same time, it provides a key to explaining the synthesis of inorganic hydrocarbons (mainly methane), which are formed in parallel with intrusive and effusive processes during mutual reactions of elementary decay products of hydrogen and helium compounds. The release of the primary accretion energy stored in hydrogen and helium compounds by means of a series of exothermal reactions and phase transformations is, in our opinion, the fastest and most efficient of all energy transfer processes.

As one of the important sources of energy, the latent energy of primary hydrogen (H) and helium (He), which comes from the Earth's core and causes the degassing processes, is considered. This latent energy is converted into completely different types of chemical, electromagnetic, and thermal energy of active compounds responsible for the main endogenous Earth processes [Gilat, Vol, 2005, 2012].

The main sources of the Earth's internal energy are currently considered to include nuclear reactions of cold fusion, natural fission reactions, radioactive decay of U, Th, and ^{40}K, gravitational differentiation in the Earth's liquid core, and the energy of lunar tides. Unlike the above, chemical energy can be

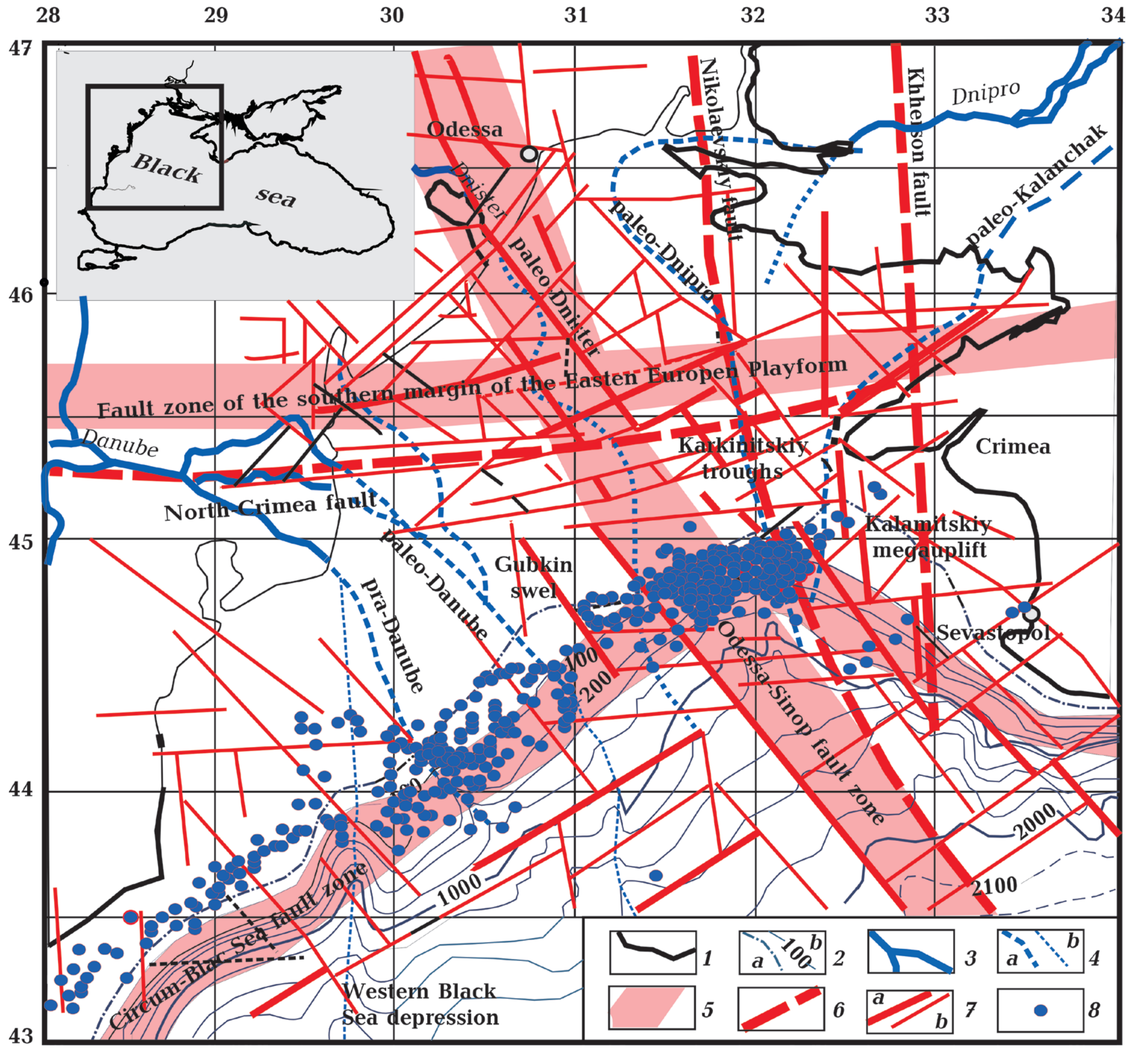

Fig. 1. Main geomorphological and structural-tectonic elements of the Black Sea water area to the west and south of the Crimean Peninsula (after [Shnyukov, Kobolev, 2018]): *1* — coastline, *2* — shelf edge (*a*), water depth isobaths (*b*), *3* — river deltas, *4* — paleo(proto) river deltas: established (*a*), suspected (*b*), *5* — mantle fault zones, *6* — faults of the consolidated foundation, *7* — tectonic disturbances of the first (*a*) and second rank (*b*), *8* — gas seeps/torches.

transported by reactive gases, concentrated and focused in mantle plumes; it can cause powerful earthquakes. The authors quite convincingly consider the earthquake process as a series of chemical explosions caused by physicochemical processes [Gilat et al., 2019].

The present article is an attempt to explain the previously incomprehensible fiery phenomena observed during the Yalta earthquakes of 1927 by taking into account the abovementioned conceptual system of hypotheses by A.L. Gilat and A. Vol [Gilat, Vol, 2005, 2012; Gilat et al., 2019], as well as the previously proposed scenario of the structural-tectonic evolution of the Black Sea megadepression [Kobolev, 2003, 2016, 2017].

General information about the Yalta earthquakes of 1927. Earthquakes in Crimea have been known since ancient times, but the most significant of them in terms of strength and consequences for Eastern Europe in the 20th century occurred in 1927. The first information about them was covered in detail in a collection of articles by V.A. Obruchev, P.M. Nikiforov, P.A. Dvoychenko, P.I. Hollandskiy, A.I. Markevich, E.F. Skvortsov, and

S.V. Shimanovskiy, which was published in 1928 based on the materials of a scientific meeting initiated by the government commission for the elimination of consequences [Black Sea …, 1928]. Unique observations were published by the eyewitnesses — A.V. Voznesenskiy [1927], P.A. Dvoychenko [1928a,b], S.P. Popov [1928], and A.Kh. Polumb [1933].

Many collected archival materials are given in scientific publications that appeared in later years.The materials are not always supported by reliable seismological information and are most often scattered and contradictory. The most meaningful detailed analysis of the macroseismic effect of the Crimean earthquakes of 1927 was performed by the well-known seismologist A.A. Nikonov [1986, 1994, 2000, 2002, 2003, 2007, 2012] and Crimean seismologists V.A. Korolev, V.S. Knyazeva, V.E. Kulchytsky, B.G. Pustovitenko, A.M. Sklyar [Korolev et al., 1995; Kulchytskiy, Pustovitenko, 1995; Knyazeva, 1999; Sklyar et al., 2000]. Let us dwell in more detail on the published facts, namely, the sequence of tremors during the Crimean earthquakes of 1927.

On the morning of June 26, 1927, before the earthquake, the sea remained completely quiet and calm. However, the eyewitnesses said that small ripples formed on the water, and the sea seemed to be boiling. In the bay between Ayu-Dag and Cape Plaka, approximately 40 meters from the shore, a long strip of foam was briefly observed. This may indicate that gas disturbances had already occurred at the bottom and in the water column. The first strong aftershock was recorded at 13:21.The magnitude was approximately 6.0, and the destructive force on the coast was 7 points. The source of the earthquake was located under the seabed, south of the villages of Foros and Mshatka. This earthquake did not cause serious damage or casualties, but panic arose among vacationers. Several people were injured, though there were no deaths. Landslides were observed on the outskirts of Sevastopol; cracks appeared in some houses; the post office building and one of the churches were damaged. On June 29, another weaker aftershock occurred, which did not cause significant damage [Dvoychenko, 1928a].

The earthquakes of June 26 and 29 were a foreshock of the next event on September 11, 1927, which was much stronger and caused a real catastrophe. The first signs of the earthquake began to appear at about 8 pm. The animals were noticeably worried and refused to eat. Horses neighed anxiously and broke free from their harnesses; cows mooed continuously, and dogs and cats huddled close to their owners. Fishermen who had gone out for night fishing heard a rumble on the sea between Alushta and Sudak. An unusual disturbance in the form of a small lump, outwardly similar to the «boiling of the sea» forced even the bravest to return to the shore. At exactly midnight, dogs howled all along the coast, and then a loud roar was heard, which interrupted this howling [Dvoychenko, 1928a].

The intensity and duration of first shock, which occurred on the night of September 11—12 at 0:13, surpassed in all earthquakes in Crimea, at least since the beginning of the 19th century [Markevich, 1928]. Its epicenter was located under the seabed at a depth of 17 km, about 20 km southeast of Yalta, and was elongated along the coast. Its intensity on the coast is estimated at 8 points on the MSK-64 scale, with a magnitude of 6.8. Windows were breaking; plaster was falling off; floors and ceilings were cracking; iron sheets on the roofs were rattling, and floors and ceil chimneys [Dvoychenko, 1928b].

The first shock lasted no more than 10 seconds and was followed by a second. Everyone rushed to flee from the houses, where walls were falling, roofs were cracking, and balconies and cornices were collapsing. Landslides thundered in the mountains, the sea moved away from the shore and again crashed against it in a violent wave. The lights went out. Continuous shocks, the destruction of buildings, the groans of the wounded, mass hysteria, and senseless rumors caused an unusual panic. The maximum destructive force near Big Yalta reached 8 points. In Sevastopol, Simferopol, and Alushta it was 7 points; in Feodosiya and Evpatoriya — 6 points; in

Kerch — 5 points; in Novorossiysk and Rostov — 4 points; in Odesa and Kyiv — 3 points. Significant, but not catastrophic, destruction occurred in areas with a 7—8-point impact [Nikonov, 2003].

Within 11 hours, 27 strong aftershocks occurred. In just a few days, more than 200 aftershocks were registered. Huge columns of smoke and fire appeared at sea near Sevastopol. The Earth seemed to be shaking in a fever. Panic broke out every now and then. Severe destruction was also observed in Simferopol, many villages in the foothills and steppe parts of Crimea were in ruins (Fig. 2). The earthquake lasted for several days, and even on September 15, its aftershocks were still felt. The most powerful ones destroyed buildings on the coast from Alushta to Sevastopol. In Alushta, hotels and the Genoese Tower were damaged, and in Alupka, the Vorontsov Palace and mosque. Collapses formed on the highway near Oreanda, the village of Opovzneve was severely damaged, and landslides occurred on Mount Kishka. In the Yalta area, 70 % of buildings suffered; in the city itself, the Rossiya and Yalta hotels, as well as residential buildings, were damaged [Knyazeva, 1999].

According to S.V. Shimanovskiy [1928], in the period from September 11 to December 31, 1927, 352 aftershocks were recorded in Yalta. The maximum number of aftershocks fell on September 12(41), the greatest force of the shocks was between 8 and 9 points, followed by a gradual decrease in the number of shocks and their strength. All cities within the zone of 7-point shocks on June 26 were affected by an 8-point impact. There is limited and contradictory information about the number of dead and injured.

The Crimean earthquakes of 1927 can be compared with the February catastrophic earthquakes in Turkey and Syria in February 2023 (magnitude 7.7).

The fire phenomena. The earthquake of September 11, 1927, was accompanied by many side effects: tsunami waves of 0.5—0.7 m [Nikonov, 2002] (Fashchuk [2005] reports waves of up to 2—3 m), underwater landslides, the fires [Dvoychenko, 1928b; Nikonov, 2002]. The work [Nikonov, Sergeev, 1996] notes that during the Crimean earthquakes of 1927, surface disturbances also occurred as landslides and rock falls.

Fire phenomena at sea were observed 30 km west of Sevastopol by Professor P.A. Dvoychenko, who, on the evening of September 11, heading to Chersonese, saw the western part of the sky covered with a bright brown—orange light, effectively reflected on the smooth surface of the Quarantine Bay. It was as if a fire was burning, the bright light

Fig. 2. Special issue of the newspaper Krasnyy Krym dedicated to the Yalta earthquake of 12 September 1927.

of which passed through a smoke screen. The reflection from the water surface was so bright that the horse rushed to the side and did not want to walk close to the water [Dvoychenko, 1928b]. He notes that at the moment of the main shock, only from Sevastopol, there was a triple-flash, but a short-lived flash of pale flame was observed near the sea horizon;due to panic, no one noticed it.

During the earthquake of 12 September 1927, fire phenomena were recorded for almost a month and a half— in September and October. A.A. Nikonov [2002] cites the testimony of residents of the village of Nizhny Kermenchik that during the earthquake they observed red fire in the western direction, where there were no storm clouds at that time. Thus, the fire flashes were enormous in size, since they were visible at a distance of up to 60—70 km. A fire flash about 500 m high and about 1.8 km wide was observed on Cape Lukull. These flashes were visible even from Evpatoria. It is also known from the stories of eyewitnesses from Feodosiya that 30 km in the direction of Anapa (i.e., on the other side of the main focus and also at a great distance), in the sea, fire pillars were also seen. Thus, it turns out that outbreaks of fire, including linearly distributed ones, took place in the Sevastopol-Evpatoria, Sudak zones (tentatively), and Feodosiya. In the Sevastopol-Evpatoria zone, they were observed during the main earthquake and aftershocks that occurred on the same night, then in early October, in the Sudak zone — in early November. It should be assumed that outbreaks of fire as stripes and spots above the water are definitely associated with tectonic disturbances due to earthquakes. This conclusion somewhat helps the interpretation of the outbreaks since the main lines of disturbances, fields of gas flares and gas hydrates, are outside the coastal zones. If we take into account data on local tremors in the Sevastopol-Evpatoriya zone, it is obvious that there was a separate focal zone to the west of the coast near Sevastopol, elongated, apparently, submeridionally.

The emissions of large masses of hydrocarbon gases west of Sevastopol were described by G.I. Popov [1969]. He noted that during the earthquake, a huge fiery band was observed from three lighthouses on the western coast of Crimea, 30 miles (55 km) from the coast over a large stretch between Sevastopol and Cape Lucull.

Perhaps the most professional observations were made in the western part of the Black Sea by employees of three lighthouses in the Crimea — Konstantinovskiy ravelin (Sevastopol), Cape Lucull, and Evpatoriya. Lighthouse archives allowed L.I. Mitin to clarify the sequence and number of flashes [Shnyukov et al., 1994]. P.A. Dvoychenko [1928b] emphasizes that after a moment of panic, flashes of fire were recorded from all lighthouses on the western coast. He estimated the duration of the flashes to be 1—1.5 min; their height and width were determined by eye up to 500 m up and up to 2 km wide. The fire was pale, faintly luminous, and some defined it as a luminous cloud.

In total, 16 large-scale fire phenomena were observed to the west of Crimea. Most likely, different phenomena were observed from different lighthouses. In terms of time, only observations from Cape Lukull and from the Konstantinovskiy ravelin (Sevastopol) coincide, which recorded flashes on September 12 at 3:32 a.m. and 3:41 a.m. The distance between the lighthouses is 50—60 km, perhaps the same fire phenomena were noted. In other cases, there are discrepancies in the time of the flashes, which indicates different observation objects.

Unfortunately, the initial information on the fire phenomena is often based on controversial data. This applies, first of all, to the distances from the coast and observation points, number, and duration of the flashes. The latter is largely explained by their location and, accordingly, scale and the possible observation of one phenomenon from different points. Meanwhile, the distances to the emission sites were estimated by random observers, excluding the fire service workers. Hence, there is a large spread in estimates of the remoteness of the fires.

Naturally, the idea arises to use data from other regions for comparison. Explosions and burning gases of mud volcanoes have been repeatedly observed in the Caspian Sea. At the same time, more accurate data on the distance of fiery phenomena from the coast and observation points during the explosions of mud volcanoes of the Baku Archipelago in the Caspian Sea were obtained due to their reliable location. Thus, a column of flame over 500 m high in 1977 on the Garasu volcano was observed in Baku at a distance of about 40—50 km [Aliyev et al., 2015]. The latest case of a large-scale fiery torch above the water was recorded on July 4, 2021 off the coast of Azerbaijan in the Caspian Sea. The probable cause of the giant pillar of fire in the middle of the sea, rising high above the horizon, was the eruption of a mud volcano on Dashly Island, approximately 30 km from the coast (Fig. 3).

Fig. 3. A giant pillar of fire in the Caspian Sea was observed on July 4, 2021, from the coast of Azerbaijan (left) and drilling platforms (right) https://twitter.com/JournalistSahab/status/ 1411863359373266948.

As one can see from the above review, more than 16 powerful gas (fire) emissions were registered to the west of the Crimea. According to P.A. Dvoychenko [1928a], most of them lasted 1—1.5 min. However, the fire phenomenon in October, observed from Evpatoria, lasted more than two hours. To the south and southeast of the Crimea, fire phenomena and gas emissions were longer. Their number is not less than 6. At the same time, many millions of cubic meters of methane were released and burned. The phenomenon was grandiose and had been underestimated before.

According to P.A. Dvoychenko [1928a], it can be assumed that at least 10 fires had dimensions of up to 500 m in height, up to 2000 m in length and at least 100 m in width. The total volume of the flash space is 10,000,000 m^3. According to reference data, the flash of a gas mixture (air and methane) occurs when methane in the air reaches a minimum of at least 16 %, and explosions — most often at 9.5 % methane. Explosions lasted 1—1.5 min. It is obvious that one million cubic meters of methane, which probably formed such a gas accumulation, burned out and dispersed instantly. But the two-hour flame was obviously fed all the time, and in this regard it can be assumed that 80 times more methane burned out — up to 80 million m^3. Thus, only the western part of the fire phenomena absorbed at least 100 million m^3 of gases! Obviously, all these are hypothetical calculations, but the order of the figures is very indicative and demonstrates the scale of the phenomenon. Energy expenditure in the south and southeast of Crimea were no less.

The composition of the gases was estimated at the time of observations. P.A. Dvoychenko [1928a] even tried to decipher the color shades of the fire phenomena. In his opinion, a pale flame appeared as a result of the flash of hydrogen phosphide, and then hydrocarbon gases flashed brightly, as he believed, from the mud of the Black Sea. Sailors of the ships met in the area of the explosion by a special hydrograph boat spoke of the smell of hydrogen sulfide. This smell was also felt on the beach. Therefore, we can conclude that hydrocarbon gases were emitted, mainly methane with impurities of hydrogen sulfide, hydrogen phosphide or fluoride, and simply hydrogen. The role of methane is obvious.

The data on fire phenomena in the Black Sea south of Crimea are rather uncertain. Various sources mention pillars of white steam. For example, on September 14, at 5:23 p.m., 7 km from the coast opposite Kuchukkoy (near Alupka), an unknown observer saw a pillar of white steam approximately 200 m high. After 3—4 s, it dissipated, and another one rose in its place. No tremors were observed in Yalta at that time [Nikonov, 2002].

A.A. Nikonov [2002] notes fire phenomena in the sea on October 2, 3, and 4 opposite the village of Uskut (Pryvitne), 20—25 km southwest of Sudak, but a detailed description of this phenomenon was recorded only on October 4. According to P.A. Dvoychenko [1928a] from the words of eyewitness E. Karpovich: «On the 4th, at 11 p.m., in the middle of the sea, approximately opposite the village of Uskut, a weak whitish strip appeared at first, which gradually acquired an increasingly bright red color. At about 10:40 p.m., its darkening in the form of smoke was noticed from the shore, which moved to the center of the strip and captured the latter by 2/3. The remaining part, at 11:15 p.m., burst into flames in the form of a column of fire measuring 0.75 m^2, from which sparks separated. The bright red fire lasted for about 5 min, and then it sank into the water, leaving a trace that was observed on a large area of the illuminated surface. A few seconds later, the flame quickly flared up again in the same place and over a considerable area in the form of a large glow. Such flashes lasted for more than an hour. They were bright red, and the flashes were repeated very often, simultaneously in several places in the direction of Sudak. In the intervals between the flashes, phenomena resembling shrapnel explosions were observed three times in the air, quite high above the sea. However, the flashes were so strong that the clouds glowed. Tongues of flame were visible in binoculars». As one can see, a fairly detailed description of the phenomenon indicates really constant emissions of large masses of gases over a significant area for an hour. Judging by the description, these were emissions of millions of cubic meters of gas. An implausible detail about the size of one of the flashes — 0.75 m^2 — is an assessment that is hardly possible in the sea on the horizon.

Taking into account the eyewitness accounts of the fiery phenomena during the earthquake of September 12, 1927, we have schematically depicted their approximate location and directions of spread (Fig. 4).

Fire outbreaks, including the linear ones, occurred in the Sevastopol-Evpatoria, Sudak zones (tentatively), and Feodosia. In the Sevastopol-Evpatoria zone, they were observed during the main earthquake and aftershocks on the same night and the first days of October. Thus, the phenomena have both a spatial and a temporal direction. The main bands of fire outbreaks over the water spread in two directions. The earlier one, in the Sevastopol-

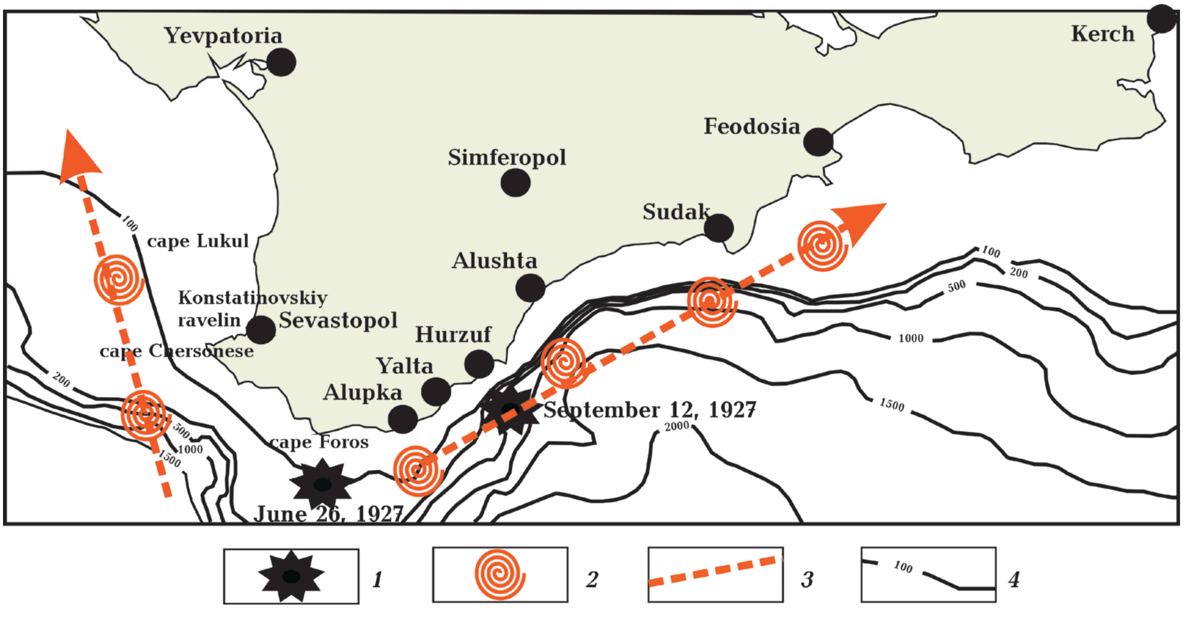

Fig. 4. Location of fire pillars during the Yalta earthquakes of 1927: *1* — epicenters of the earthquakes, *2* — approximate location of fire pillars, *3* — hypothetical directions of the propagation of fire phenomena, *4* — isobaths of the seabed relief.

Evpatoriya zone, is elongated submeridionally to the west of the coast and is situated to the east of the Nikolaevskiy fault. The later one, moving in the northeast direction, is definitely associated with tectonic disturbances within the Circum-Black Sea fault zone.

Today, the submeridional Nikolaevskiy (West Crimean) fault, closest to the western coast of the Crimea, is geophysically well-known and clearly traced (see Fig. 1). However, it is located almost 100 km from Sevastopol and Cape Lukull. It would be very tempting to explain the fire phenomenon migrating from north to south at 3:40 am on September 12, 1927, by the emission of a huge strip of gases along the submeridional fault, its ignition in the northern part, and the movement of the flame from north to south as the methane burned out. However, for such an explanation, the gas emissions must be enormous, illuminating the clouds during combustion so they would be visible so far away. Alternatively, the emissions occurred along a smaller fault, subparallel to the Nikolaevskiy fault but much closer to the shores of Crimea.

One version of a possible explanation for the appearance of the grandiose flash of flame on September 2, 1927 at 3:31 am (and 3:41 am), observed from Cape Lukull and the Konstantinovskiy ravelin of Sevastopol, is the impact of earthquake aftershocks on the gas hydrate field, which has been delineated in this water area [Kobolev, Verpakhovskaya, 2014]. It may well be that shaking the sedimentary layers during the earthquake led to the destruction of gas hydrates and to a powerful emission of gases or release of gas bubbles at the bottom, which produced a huge flame [Rybak et al., 2024].

It is impossible not to pay attention to other flashes, especially in the movement of the flame from north to south — to the east of

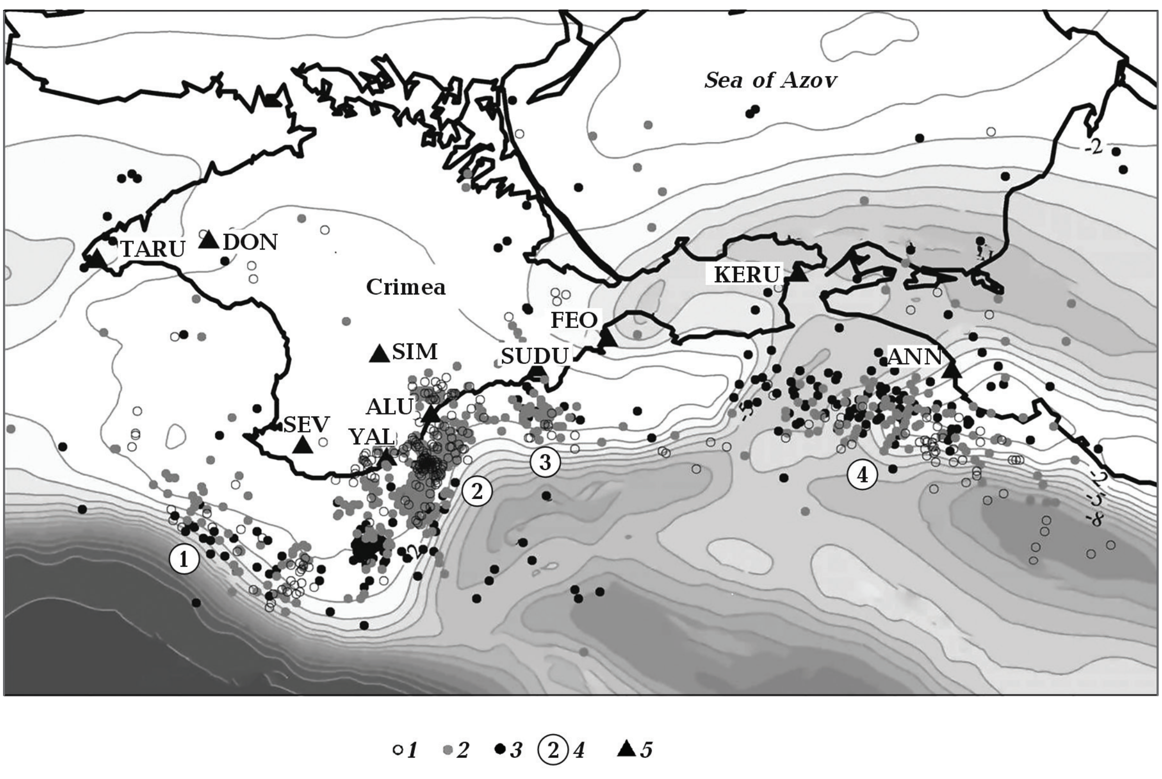

Fig. 5. Spatial distribution of earthquake epicenters and their magnitudes (shown by icons of different shapes) in the South Crimean seismogenic belt: *1—3* — epicenters at depth (*1* — 0—15 km, *2* — 15—30 km, *3* — more than 30 km), *4* — Crimean seismogenic subzones (1 — Sevastopol, 2 — Yuzhnoberezhnaya (or Yalta-Alushta), 3 — Sudak, 4 — Kerch-Taman), *5* — seismic stations (ALU — Alushta, ANN — Anapa, DON — Donuzlav, FEO — Feodosia, KERU — Kerch, SEV — Sevastopol, SIM — Simferopol, SUDU — Sudak, TARU — Tarkhankut, YAL — Yalta (modified after [Gobarenko, Yegorova, 2020]).

the Nikolaevskiy fault. There, several points of flame were traced that continued just as grandiosely in October for two hours to the south of Evpatoria [Dvoychenko, 1928a].

Seismicity analysis of the Crimean region. Unfortunately, instrumental seismological observations in Crimea began only after the devastating earthquakes of 1927 [Pustovitenko et al., 1989]. Fig. 5 shows the distribution of earthquake foci in the South Crimean seismogenic zone [Gobarenko, Yegorova, 2020], which is based on the corrected earthquake parameters in the seismic-tomographic constructions. This zone is characterized by earthquakes with epicenters at depths from 15 to 33 km or >33 km with magnitudes of 3—6.

Within the Crimean-Caucasian seismogenic belt, we are interested in two main zones of grouped earthquake foci, in which the seismic activity and the stress field's orientation are considered to be relatively homogeneous. These are seismically active zones with different earthquake foci locations (see Fig. 5): Kerch-Taman, which dips in the north at an angle of ~30°, and Yalta-Alushta, which is gently inclined to the southeast at an angle of ~18° [Gobarenko, Yegorova, 2020]. The most seismically active should be considered the Yalta-Alushta zone, where the powerful earthquakes of the 20th century occurred in 1927.

It should be noted that the vast majority of earthquake epicenters in the northern part of the Black Sea are recorded in a continuous strip from Sevastopol to Feodosiya. The earthquake epicenters are located mainly of 10—40 km from the coast. They are concentrated in the steep part of the continental slope between the continental shelf and the bottom at depths between 200 and 2000 m. This boundary is the place of contact of areas of the Earth's crust that experience oppositely directed modern vertical movements. They proceed unevenly and are accompanied by earthquakes [Gobarenko, Yegorova, 2020].

Peculiarities of the deep structure of the South Crimean seismogenic zone. The Black Sea region is part of the southern alpine belt, which includes structures of different ages, genesis, and evolution, the restructuring of which in the Cenozoic formed its modern appearance. A characteristic feature of the region is increased seismic activity and high mobility of the lithosphere, manifested in a differentiated anomalous thermal field. The latter indicates deep energy processes associated with increased matter mobility [Kutas et al., 1998]. Vivid evidence of them is anomalous gas manifestations in the form of seeps, torches, and fountains of mud volcanoes. This circumstance can be the basis for searching for general patterns in their distribution in connection with seismic activity. The physical nature of this connection can be explained by tectonic processes that shape the heterogeneous structure of the Earth's crust. This is especially clear within fault zones, which serve as migration channels for gas-fluid flows and are clearly seen in the distribution of anomalous gas manifestations [Shnyukov, Kobolev, 2018; Kutas, 2020].

The shelf and continental slope of the southern coast of Crimea are characterized by the largest dip gradients caused by contrasting neotectonic and modern tectonic movements. The geomorphology of the coastline of the southern coast of Crimea and the seabed relief in its continuation and the degree of horizontal and vertical dismemberment of the underwater relief indicate the differentiation of neotectonic movements. Multidirectional movements occurred throughout the entire neotectonic stage and continue to this day. At the same time, the velocity gradients of the latest dips of the Black Sea megadepression are an order of magnitude higher than the gradients of the raised adjacent land. The zone of the highest gradients of seabed movement velocity is located in the continental slope region. The transition zone from areas experiencing uplift to areas of subduction includes the modern shelf and a narrow strip of the southern coast of Crimea [Shnyukov et al., 2010].

The earthquakes of 1927 were concentrated on the continental slope south of the Crimean Peninsula within the South Crimean seismic zone. The boundary of the continental shelf and the steep slope of the depression coincides with a deep fault. In this area oppositely directed modern vertical movements are concentrated. They proceed unevenly, accompanied by tremors, i.e., earthquakes. Within this fault, modern relative movements of the crust occur: the rise of the Mountainous Crimea and the lowering of the Black Sea bottom. According to V.V. Yudin and Y.G. Yurovskiy [2011], the vertical component is expressed in a 3.6km difference in the modern relief from the highest point of Crimea, the town of Roman-Kosh (1545 m) to the sea bottom at a depth of 2100 m. Given the thickness of the Neogene-Quaternary sediments in the Black Sea, the vertical difference of the neotectonic relief reaches 10 kilometers or more.

A significant role in the dynamics of the lithosphere of the Black Sea region is played by faults of both mantle and crustal origin, which extend far beyond the boundaries of the megadepression and separate large tectonic blocks of the Earth's crust. Deep faults of the Black Sea megadepression have developed over a long time. Many of them have retained their activity at the present time, which is manifested in intense seismic activity.

Based on the increased gradients of the mantle component of the gravitational field, V.I. Starostenko et al. [2010, 2015] distinguish a number of fault zones of the consolidated crust according to the scheme of fault tectonics of the consolidated crust of the Black Sea. These include, first of all, the Odessa-Sinop fault zone, which is traced from the East European Platform to the Pontides parallel to the axis of the Central Black Sea Uplift and intersects with the Latitudinal fault zone which occupies the water area south of Crimea between the deep-sea depression and the continental slope (Fig. 6).

Previously, based on the results of seismic work, this transition zone between the deep-sea depression and the continental slope west of Crimea was interpreted as a flexural fold, not accompanied by large disturbances and relative movements of the crustal blocks [Tugolesov et al., 1985]. Later, a number of researchers [Chekunov, 1987; Banks, Robinson, 1997; Kobolev, 2003] showed that this boundary has a clearly tectonic character and is a deep fault. Behind it, was a significant displacement of the basement and the Moho section, a sharp change in the thickness and structure of the crust, and dislocation of deep-sea sediments. This is evidenced by the results of the reinterpretation of seismic materials along the 25th profile, which showed the existence of a high-amplitude fault south of the Crimean Peninsula, along which the basement on the shelf dips sharply (up to 8 km) [Baranova et al., 2008].

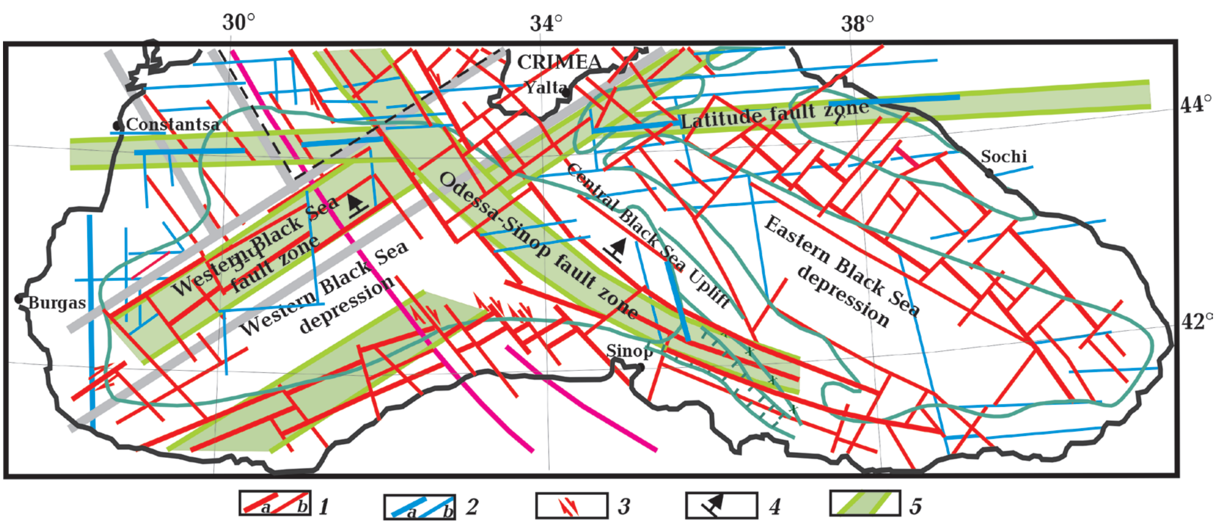

Fig. 6. Fault tectonics of the consolidated crust of the Black Sea megadepression [after [Starostenko et al., 2010] with alteration]: *1* — faults of the diagonal system of the first (*a*) and second (*b*) order, *2* — faults of the orthogonal system of the first (*a*) and second (*b*) order, *3* — directions of shifts, *4* — directions of dip, *5* — zones of elevated gradients of the mantle component of the gravity field.

This conclusion was also confirmed by the results of the regional seismic studies of the Black Sea Geophysical Survey [Graham et al., 2013]. In our opinion, the transition zone from the continental slope to the deep-sea basin along the Crimean Peninsula is a long-lived Circum-Black Sea fault zone, complicated along the perimeter by a depression of variable width. This fault zone remains active, which is confirmed by its seismicity, the structure of the consolidated crust and sedimentary strata, the forms of the bottom relief, etc. This is indirectly evidenced, in particular, by the anomalous concentration of gas jet manifestations within its boundaries.

The application of the ideas of plate tectonics to the geological explanation of the seismicity of the North Black Sea area assumes the presence of oceanic lithosphere and its descent into the subduction zone under the continental lithosphere of Crimea. The subduction zone has earthquakes at its boundary in the slip plane of the oceanic and continental lithosphere. Such a plane is called the seismofocal zone.

The South Crimean seismogenic zone off the coast of the Mountainous Crimea is often perceived as a manifestation of the subduction zone to the north. If the thrusting here really occurred, it was concentrated in the crust, in a local area, which is not at all typical for Benioff zones with their linear extent and depth of earthquake foci. Within the Alpine fold belt, where very active processes are currently taking place, there are essentially no Benioff zones. However, there are separate points or localized areas that can only be compared with these zones after a number of caveats or warnings.

Thus, since there are no signs of a deep-sea trench, back-arc, or inter-arc basins south of Crimea, it should be assumed that a true subduction zone is absent here. However, an accretionary wedge of dislocated sediments lying on the suboceanic-crust negative gravity anomalies and significant small-focus seismicity allowed this type of convergence to be called pseudosubduction or quasisubduction [Yudin, Yurovskiy, 2011]. It should also be noted that many Ukrainian researchers still reject the ideas of the above authors about the structures of powerful tangential compression formed during the Cenozoic convergence in the Crimean-Black Sea region. As an alternative, it is appropriate to distinguish extensional structures in the form of an endogenous Circum-Black Sea fault or a keystone subsidence of the Crimean blocks along steep listric faults and flexures into the Black Sea [Kobolev, 2003].

An important circumstance is the fact that along the northern border of the deep-sea part of the Black Sea, a system of intracrustal bodies of basic and ultrabasic composition has been discovered [Starostenko et al., 2001]. This series of bodies, recorded by seismic-gravity modeling in the upper part of the granite-gneiss complex and the lower part of the sedimentary cover, characterizes areas of crustal failure and horizontal displacement.

The above allows us to argue that the «large-scale» subduction of the «oceanic» Black Sea lithosphere in the northward direction under the continental lithosphere is impossible, at least since the middle of the Cenozoic. The reason for this is the «heated» Black Sea lithosphere, which, due to its physical properties, is unable to «subduct» under a rigid continental plate [Kutas et al., 1998].

Thus, the geological situation in the north of the Black Sea, to some extent, resembles an accretionary prism. Despite all the differences in interpretation among tectonists (subduction, pseudosubduction, quasisubduction), the accretionary wedge that goes under Crimea is traced here. It is here, south of Crimea, that the main swarm of deep-sea mud volcanoes is recorded in the Sorokin trough. Active upward migration of deep-sea gas-fluid flows formed secondary centers with anomalously high gas pressures above the section(the mud diapirs). Through-going deep-sea mud volcanoes are an example of localized flows of deep hydrocarbons that pass through the sedimentary cut and are controlled by deep faults and flexural-thrust zones.

Plume-tectonic nature of the Crimean earthquakes of 1927. Most endogenous regimes are evidence of the enormous role of deep-matter advection as the main source of global and regional tectonics. Advection of gas-fluid flows plays an important role in plume tectonics. Local emissions of deep fluids in the upper mantle are associated with plumes. They are sources of active tectonic transformation of the continental lithosphere and bear signs of pulsating degassing of the Earth.

It was previously thought that heat from the liquid core to the lithosphere is transferred by mantle plumes in narrow ascending columns due to convectional heat transfer. However, the driving forces for their formation from the liquid core to the lower mantle boundary cannot be explained by the hypothetical temperature difference between the uppermost liquid core and the lowermost mantle. Partial melts cannot pass through the colder solid barriers of rocks several kilometers thick without additional energy input. Thus, plumes cannot migrate through the nearly 3000 km thick solid mantle.

According to the hypothesis of A.L. Gilat and A.Vol [2012], it is the latent energy of primary hydrogen (H) and helium (He), unlike the energy of traditional sources, that creates convection in the Earth's outer core and forms liquid magma in the mantle and supplies energy to upward flows. It can be easily transferred from plumes along large faults and their branches, quickly concentrated and realized explosively. It creates very high rates of energy release and all the geophysical and geochemical anomalies typical of earthquakes. It is the concentrations of explosive accumulations that are responsible for the cycle of earthquakes (foreshocks — strong shocks — aftershocks) within their ascending hypocenters [Gilat et al., 2019]. It should be emphasized that the geodynamics of areas with high seismicity and the nature of strong earthquakes are more closely related to mantle plumes rather than plates' movement along individual faults [Kopnichev, Sokolova, 2017].

According to the hypothesis of A.L. Gilat and A. Vol [2012], sublimation of H and He from the solid core and convection in the outer shell with flow melting in the mantle create gas-fluid blowing plumes. The release of H and He is accompanied by an intensive release of their accumulated specific (latent) energy (Table). Their ionization and inclusion in various chemical compounds are accompanied by decomposition due to local and gradual *PT*-changes. Constant compression and decompression (foreshocks — strong shocks — aftershocks) in the upward-moving hypocenter are accompanied by additional energy emissions, which cause the release of elementary H, O, C, S, Cl, F, etc. This process causes explosive or combustible synthesis of H_2O, SO_2, H_2SO_4, CO_2, H_2S, HCL, HF, and other compounds in accordance with local changes in thermodynamic conditions [Gilat et al., 2019].

The idea of a plume as an element of

Specific potential (latent) energy of helium and hydrogen [Gilat, Vol, 2005]

Depth, km	Pressure, Gpa	Temperature, K	Specific energy, J/mol	
			Helium	Hydrogen
0	0	300	12.480	8652
10	0.3	500	20.800	14.420
100	3.4	1800	74.880	51.912
500	18	2000	83.200	57.680
1000	40	2500	104.000	72.100
2000	88	3500	145.600	100.940
3000	160	5500	228.800	158.620
4000	238	5800	241.280	167.272
5000	321	6000	249.600	173.040
6000	358	6200	257.920	178.808

geodynamics arose relatively recently. This was caused, on the one hand, by the failure of plate tectonics, which could not find an explanation for intra-plate volcanism and magmatism, and, on the other hand, by the successes of seismology, in particular, seismic tomography [Nolet, 2017]. In this regard, the seismotomographic constructions of *P*-velocity models directly under the Black Sea megadepression, presented in [Gintov et al., 2016], are of significant interest (Fig. 7). On vertical longitudinal sections of the *P*-velocity model of the mantle directly under the Western Black Sea Depression (Fig. 7, *a*, *b*) at depths from 2500 to 1700 km, a low-velocity heterogeneity ($\Delta V_P \leq 0.175$ km/s) is clearly recorded, which we identify with the relic of the Black Sea plume. At the same time, under the Eastern Black Sea Depression (Fig. 7, *c*), there is no such anomalous zone. These constructions are a significant confirmation of the above considerations about the existence of a mantle multi-intrusion — the Black Sea plume — as a structure of deep energy discharge. The location of the latter to the west of the Central Black Sea Uplift can explain the difference in the mechanisms of formation of the main structural units — the western and eastern depressions of the Black Sea megadepression — as well as the absence of mud volcanoes in the Eastern Black Sea Depression and their rather wide distribution in the Western Black Sea Depression.

The movement of such significant (in the first hundreds of thousands of cubic km) masses of melt into the lithosphere created an equivalent deficit of them at depth. As a result, compensatory collapse occurred, and corresponding dips appeared on the Earth's surface. At present, they are located on the periphery of the Black Sea megadepression in the form of mobile compensatory structures of the Greater Caucasus, Eastern and Western Pontus, the Crimean geosyncline, and the Black Sea trough [Kobolev, 2003].

Conclusions. Earthquakes in Crimea have been known since ancient times, but the most significant of them in terms of power and consequences for Eastern Europe in the 20th century occurred in 1927.

These are spatially concentrated on the continental slope south of the Crimean Peninsula within the South Crimean seismic zone. The boundary of the continental shelf and the steep slope of the depression spatially coincide with the Circum-Black Sea fault zone, in which oppositely directed modern vertical movements are concentrated. They proceed unevenly, accompanied by tremors, i.e., earthquakes.

Analysis of the available geological and geophysical material allows us to assert that

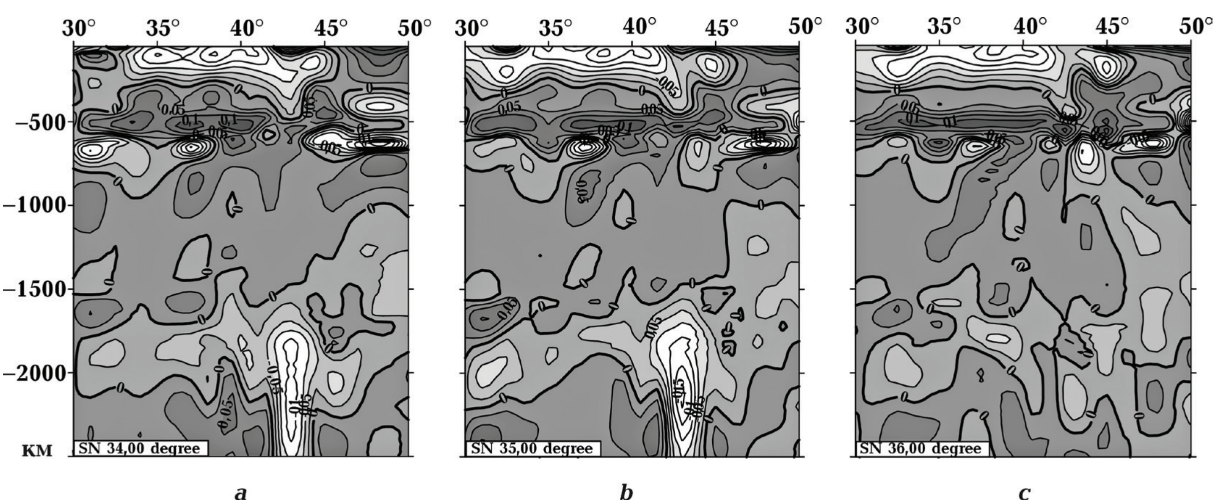

Fig. 7. Vertical longitudinal sections of the *P*-velocity model of the mantle under the Black Sea megadepression [Gintov et al., 2016]: *a* — 34°N, *b* — 35°N, *c* — 36°N. Dark gray and gray colors show relatively high-velocity heterogeneities, and light gray and white — the relatively low-velocity.

subduction of the Black Sea lithosphere in the northern direction is impossible. On the other hand, the geological situation under Crimea, to some extent, resembles an accretionary wedge.

The massive methane emissions resulting from the Crimean earthquakes of 1927 were accompanied by fire phenomena as a result of a powerful mantle gas-fluid flow into the decompacted zones of the crystalline basement along tectonic faults of various scales within the Odessa-Sinop and Circum-Black Sea fault zones. The earthquakes were a trigger for the activation of tectonic faults in the bottom sedimentary horizons and the migration of focused deep gas-fluid flows. The fire phenomena should be attributed to methane, which escaped from the crust and ignited by spark electric discharges during friction and collision of rocks. Part of this gas may be gas hydrate [Rybak et al., 2024] since when the pressure and/or temperature change, the latter can dissociate and be both an additional source and a destabilizing factor for sediments.

The Black Sea is a globally unique phenomenon since no other sea in the world has such active gas release [Shnyukov, Kobolev, 2013]. According to modern ideas, methane can be biogenic or catagenic. In the first case, it is generated directly in the sedimentary layer by the biochemical oxidation of organic matter. In the second, it migrates from great depths. The biogenic hypothesis has certain difficulties explaining the accumulation of such large volumes of gas.

We have every reason to believe that microbial metagenesis in the Cenozoic sediments is not enough to ensure such a powerful gas discharge at the bottom of the Black Sea megadepression [Shnyukov, Kobolev, 2018]. Thus, the grandiose gas-fire phenomena during the Yalta earthquakes of 1927 are difficult to explain satisfactorily without involving the deep component. They have a spatial and temporal direction. The main bands of fire outbreaks over the water spread in two directions. The first one, the Sevastopol-Evpatoriya zone, is elongated submeridionally to the west of the coast and spatially follows the Nikolaevskiy fault. The second one, the Yalta-Alushta zone of the northeastern extension, is associated with tectonic disturbances within the Circum-Black Sea fault zone. This fault zone remains active at present, which is confirmed by its seismicity, the structure of the consolidated crust and sedimentary strata, the forms of the bottom relief, etc. This is indirectly supported, in particular, by the anomalous concentration of gas-mud manifestations within its boundaries.

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Природа вогненних явищ під час Кримських землетрусів 1927 р.

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Під час Кримських землетрусів 1927 р. у Чорному морі спостерігалися незрозумілі природні явища — спалахи вогню над водою. Останні, як тоді вважали, пов'язані з загоранням метану, який виривався з дна моря через утворені при сейсмічних рухах тектонічні порушення.

Аналіз наявних геолого-геофізичних матеріалів, поряд з сейсмічністю півночі Чорноморського регіону, свідчить, що вогняні явища під час Кримських землетрусів 1927 р. зумовлені грандіозними викидами газу в результаті потужного мантійного газофлюїдного потоку в розущільнені зони кристалічного фундаменту вздовж тектонічних порушень різного масштабу в межах Одесько-Синопської та Циркумчорноморської розломних зон. Натомість землетруси були тригером активізації тектонічних порушень у придонних осадових горизонтах для міграції сфокусованих глибинних газофлюїдних потоків.

Для тлумачення і розуміння природи вогненних явищ, що спостерігалися під час Ялтинських землетрусів 1927 р., розглянуто концептуальну систему гіпотез А.Л. Гілата и А. Вола [2012], згідно з якою основним джерелом енергії внутрішніх процесів Землі є індукований ланцюг реакцій дегазації водню та гелію, як найбільш поширених і найважливіших зберігачів та носіїв енергії.

У статті аналізується глибинна будова осередкових зон і характер сейсмічного процесу, розглядається можлива природа проявів вогненних явищ. Встановлено їх просторову і часову направленість. Основні смуги спалахів вогню над водою поширювались у двох напрямках. Перша за часом Севастопольско-Євпаторійська зона, витягнута субмеридіонально на заході від узбережжя, просторово наслідує Миколаївський розлом. Друга за часом, Ялтинсько-Алуштинська зона північно-східного простягання, пов'язана з тектонічними порушеннями у межах Циркумчорноморської зони розломів. Ця розломна зона зберігає активність і нині, що підтверджується її сейсмічністю, будовою консолідованої кори і осадової товщі, формами рельєфу дна та ін.

Ключові слова: газофлюїдний потік, викиди газу, розломні зони, Чорне море, землетруси.