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Dynamics of Fluids in the South Caspian Basin

I. S. Guliyev and D. A. Huseynov

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Irregular degassing of the Earth is a fundamental feature of its evolution reflected in tectonic and sedimentation cycles, sea-level fluctuations, accumulation of mineral resources, and other phenomena. This peculiarity of E global-scale Earth degassing is related to cosmic and endogenic rhythms or cycles. Such cycles are hundreds and tens of thousands to millions of years long. There are, however, also shorter cycles that are registered on a real time scale. One of the most interesting and important, both in fundamental and applied terms, is the problem of rhythmic hydrocarbon gassing. This scientific problem is of significance for understanding the evolution of the atmosphere, ocean, and climate (greenhouse effect). The important applied task is to reveal regularities in migration of hydrocarbon and other fluids and their impact on oil and gas production. The second practical aspect of the problem is ecological consequences related to hydrocarbon fluxes to the land and sea surface.

Rhythms in hydrocarbon gassing are most obviously manifested in the periodicity of eruptions and activity of mud volcanoes that are accompanied by the release of hundreds of millions of cubic meters of methane, oil, and groundwater. The periodicity in eruptions established for a sufficiently long time interval indicates a stable dependence of mud volcanism on solar activity, fluctuations of the Caspian Sea level, and seismicity (Fig. 1).

The figure demonstrates that activation of mud volcanism and seismicity in the region corresponds to phases of Caspian Sea level falls. At the same time, measurements in geodetic test areas and GPS measurements show almost meridional waves of rise and subsidence of block structures in the Caspian region that were responsible for alternating periods of compression and tension in the Caspian Sea depression. The extension phases correspond to sea-level falls. It is remarkable that the rhythms in these vertical movements correlates with phases of seismic and mud volcanism activity, variations in oil and gas production, and sea-level fluctuations [2, 5].

The high-rank rhythms influence hydrocarbon production and ecology. Recently, reliable and informative data on the periodicity in dynamics of fluid processes were obtained using advanced technologies for monitoring natural objects, such as multichannel satellite-based survey (MSS) of the land and ocean surface. The digital technology used for the processing of the MSS data formed the basis for elaboration of spectral analysis algorithms, which allow high-precision diagnostics of minerals and rocks, as well as fluid-saturated, aqueous, and vegetation objects, based on their reflection and absorption spectra. Using this technology for observation of mud volcanoes on the subaerial western South Caspian Basin slope, we established that even the inactive mud-volcanic system is characterized by intense fluidal emission, although on-land observations do not reveal any changes in volcanic fluid-dynamic parameters, such as the appearance of mudflows, formation of salses, gryphons, gas and water discharges, and others. Fluid-saturated elements of mud-volcanoic structures are characterized by high absorption of electromagnetic waves, making it possible to reliably outline conduits. Figure 2 demonstrates the Landsat 7-ETM+ image of the Ayazakhtarma mud volcano, where the fluid conduit is clearly recognized in the central part of the inactive crater. Solid products of different eruptions are also distinctly differentiated. The earlier products are clearly distinguished by their bright light color.

The spectral analysis of the TERRA-ASTER satellite image of the Caspian Sea surface revealed the active fluidal dynamics in underwater mud volcanoes and fault zones (Figs. 3a–3c). The images clearly show the mass release of hydrocarbons registered as hydrocarbon films on the sea surface and changes in water transparency. This cataclysm is related to the seismic, mud-volcanic, and solar activation at the end of 2000–beginning of 2001. The South Caspian region experienced several strong earthquakes (*M* up to 6.8) and a record-breaking number (15) of mud-volcanoic eruptions at that time. The decrease in the seismic and fluid intensity was synchronous, which is reflected in a self-cleaning of the Caspian Sea water column. This

Institute of Geology, National Academy of Sciences of Azerbaijan, pr. Dzhavida 29A, Baku,1143 Azerbaijan; e-mail: iguliev@azeurotel.com

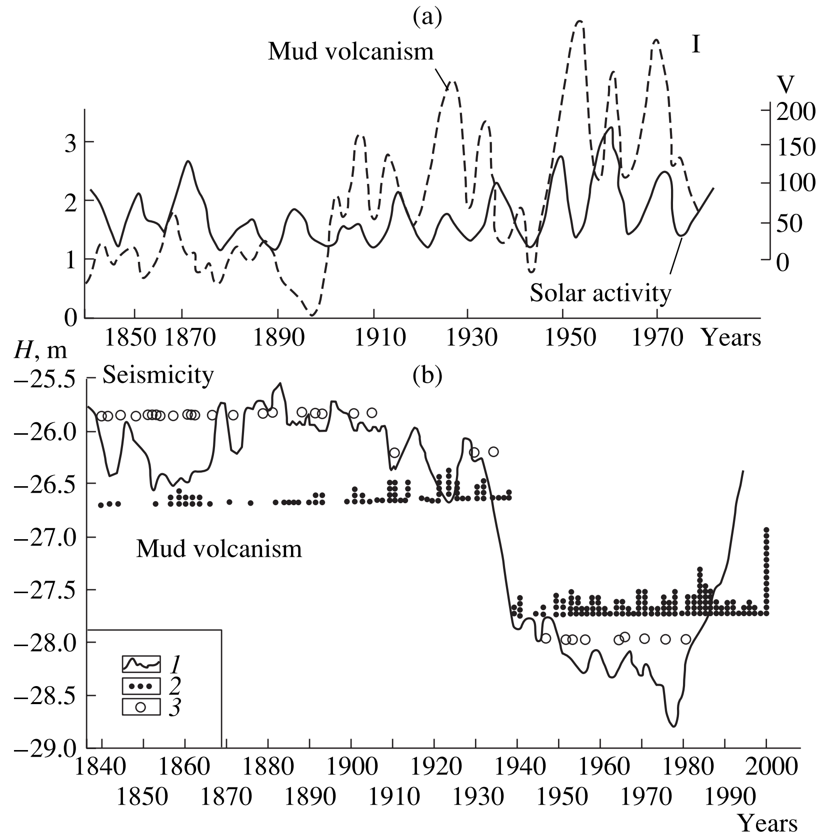

Fig. 1. Relationships between periodical natural processes in the South Caspian Basin. (a) Solar activity and mud volcanism, (V) Vulf number [7]; (b) Caspian Sea level fluctuations (*1*), seismicity (*2*), and mud volcanism (*3*) (modified after [2, 5]).

resulted in degradation of the hydrocarbon film in a few months (Figs. 3d–3f).

The influx of hydrocarbon and water fluids from mud volcanoes during their inactive stage into the water column of the Caspian Sea was always considered to be a very important factor responsible for the basin bioproductivity. The submarine discharge of water from mud volcanoes and relevant influx of different elements are decisive for the salt balance in the sea and interstitial waters. The geochemical aspect of the submarine fluid discharge is scrutinized in [13]. Discharge sites are marked by high heat flows; saturation of bottom sediments and interstitial solutions with liquid and gas hydrocarbons, carbon dioxide, nitrogen, silicic acid, and sulfates; and a sharp increase in organic matter bituminization (12–13% against the general syngenetic background of 3%). All these processes are responsible for the formation of the nutrient medium favorable for the vital activity of microorganisms, benthic fauna, and flora. The studies carried out during different seasons in the Shakh-Gum submarine mud-volcanic and Lenkaran–Astara volcano-free marine areas demonstrated the impact of the mud-volcanic activity on the state of benthic communities. The benthos biomass and population density in the mud-volcanic area are substantially higher (221.6–259.7 g/m^2) relative to the volcano-free areas 82.17–115.5 g/m^2) [9, 13]. Nevertheless, periods of submarine paroxysms are catastrophic for sea dwellers. The explosive blowout of hydrocarbons during the seismic and fluid activation in 2000–2001 resulted in their mass death [14].

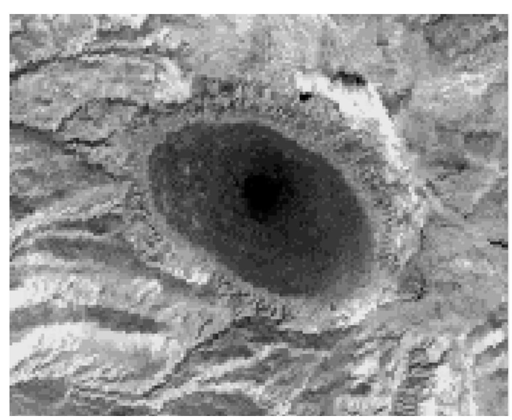

Fig. 2. The Landsat 7ETM+ image of the Ayazakhtarma mud volcano. A fluid-saturated channel is seen in the central part of the crater. Products of earlier eruptions are scattered along the crater periphery. The image visualized from channels 1, 3, and 6 is transformed into black and white.

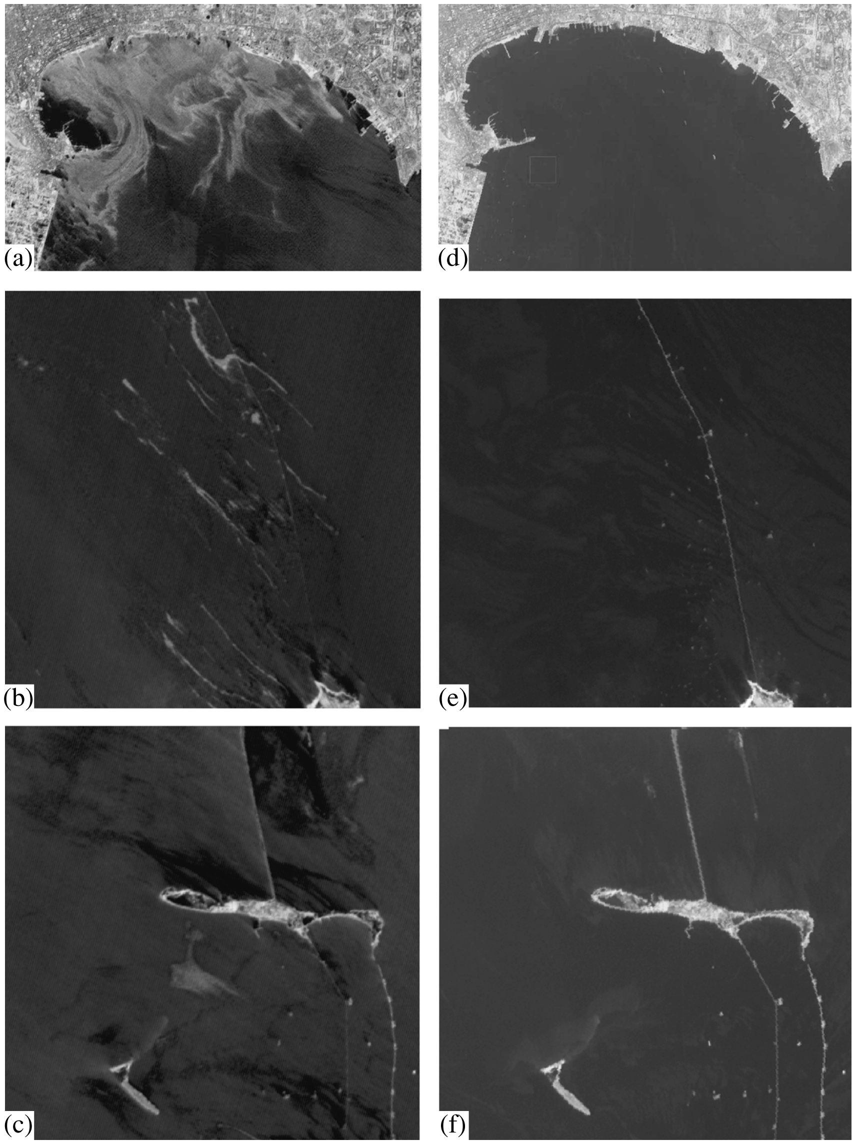

Fig. 3. The ASTER image of three different areas of the Caspian Sea obtained on July 23, 2000 (four months prior to the earthquake on November 25, 2000). Oil spots at the sea surface: (a) Baku Bay; oil tail related to fluid emission from the buried Bibi-Éibat Volcano; (b) northwestern part of Pirallakhi Island (northeast of the Apsheron Peninsula); (c) area between the Gum and Vulf islands (southeast Baku); (d–f) the same marine areas photographed on August 10, 2001 (eight months after the November earthquake). The sea surface is barren of oil. The image visualized from channels 1–3 is transformed into black and white.

The study of recent fluid dynamics in the Caspian Sea mud volcanoes provides an insight into the nature of past unique geological phenomena, e.g., absence of marine macrofauna and scarcity of microfauna in the Early Pliocene basin. Based on drilling, seismoacoustic, and deep seismic profiling data, the mud volcanism in the South Caspian Basin commenced in the Early Miocene and became most intense at the Miocene–Pliocene boundary (Fig. 4). This was accompanied by a catastrophic sea level drop by more than 600 m (locally, up to 1500 m) in the Early Pliocene [15] due to the paleo-Caspian sea isolation from the Eastern Paratethys [1, 8] as a result of the intense collision of the Arabian and Eurasian plates and the consequent rise of orogens surrounding the basin. The great extent of mud volcanism and fluid-dynamic events at the considered stage of the Caspian region development is confirmed by reconstructions, geochemical studies, and basin modeling. According to these data, the active fluid generation zone (oil–gas window) of the terminal Miocene–Early Pliocene included Jurassic–Cretaceous rocks that were characterized by a higher gas-generation potential than the Paleogene–Miocene rocks that host recent volcanoes [12]. The avalanche sedimentation rate reached 3.0–3.5 km/10^6 yr (occasionally, >4 km/10^6 yr) in the Early Pliocene basin. This indicates extremely high subsidence rates, which are undoubtedly possible under conditions of intense faulting in deep-seated zones.

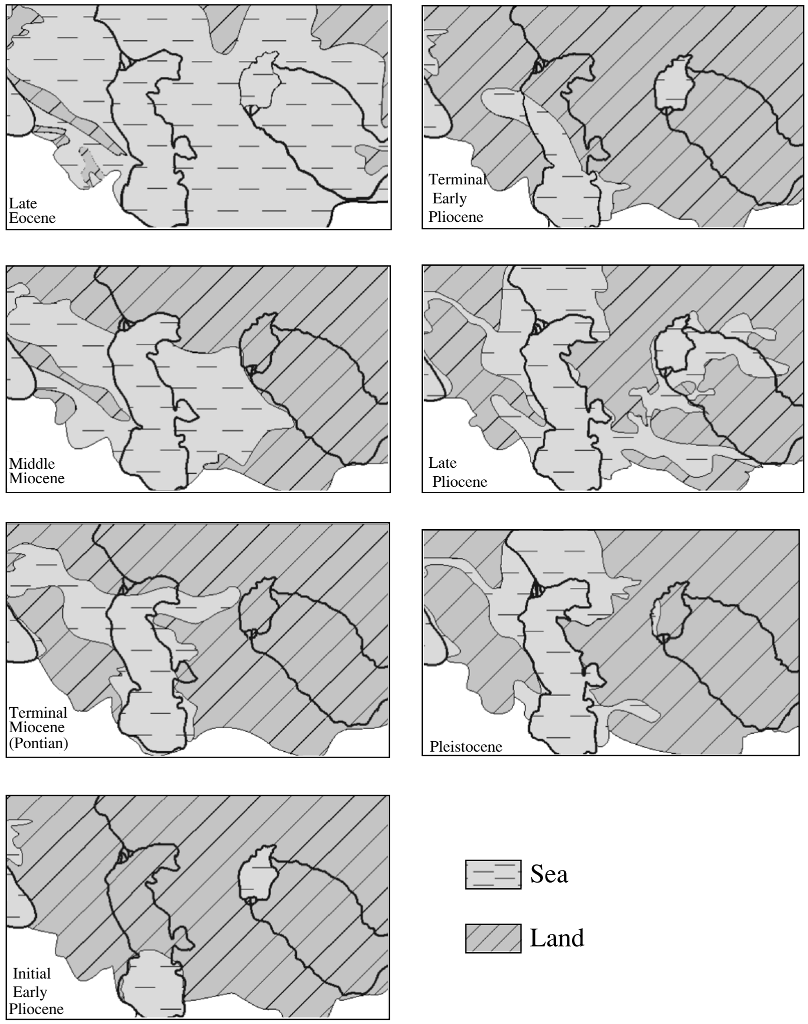

Fig. 4. Paleogeography of the Eastern Paratethys in the Cenozoic (modified after [1, 8]).

These faults were responsible for the mud-volcanic fluid dynamics and redistribution of material within the sedimentary cover of the South Caspian Basin. They also served as conduits for abyssal fluids. This is evident from the detection of large buried (apparently root-free) columns (3–4 to 10 km across and 8–10 to 20 km high) in seismic records with time scanning of 12, 16, and 20 s. They penetrate the entire sedimentary cover up to the crystalline basement and are confined to contact zones of deep-seated faults that divide the South Caspian bBasin into large blocks [3, 6]. The inflow of abyssal fluids to the Early Pliocene basin should undoubtedly have accompanied the subduction of the South Caspian oceanic crust under the Middle Caspian continental plate that commenced 5.5 Ma ago (at the Pontian–Pliocene boundary) [10].

At the beginning of the Early Pliocene, the dimension and volume of the paleo-Caspian basin reduced by several tens of times down to those of the present-day South Caspian Basin (Fig. 4). At the same time, mud volcanism and abyssal fluid dynamics became more active, particularly in the central part of the basin, resulting in oversaturation and intoxication of the desalinated basin by methane and the consequent mass death of sea dwellers. This situation is probably responsible for the absence of macrofossils in the 6–7-km-thick Lower Pliocene sequence that accumulated over 2.0–2.5 Ma.

In the Late Pliocene (Akchagylian), mud volcanism was active in a vast semimarine basin intermittently connected with the Euxinian and Mediterranean basins (Fig. 4). As in the present-day Caspian Sea, differently oriented currents stimulated rapid mixing of gas-saturated waters and reduction of background concentrations of hydrocarbon gases. This resulted in the formation of conditions favorable for development of life in the present-day basin.

It is probable that high-rank rhythms in hydrocarbon degassing in the South Caspian Basin is a result of its significant nonequilibrium state [4]. Basins related to the Alpine tectogenesis are characterized by avalanche sedimentation, contrasting environments, and fast vertical and horizontal movements [5, 11, 12]. The fluid dynamics of the basin are caused by its significant mechanical and phase instability reflected in pulsating degassing patterns.

The satellite-based monitoring of the land and sea surface, particularly mud volcanoes, makes it possible to reveal trends of hydrocarbon degassing in the South Caspian Basin in a real time scale.

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