AZERBAIJAN NATIONAL ACADEMY OF SCIENCES
GEOLOGY INSTITUTE

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PETROLEUM SYSTEM IN DIS-EQUILIBRIUM BASINS (IN CASE OF SOUTH CASPIAN BASIN)

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SUMMARY

History of geologic evolution and recent geologic position of the South Caspian (SCB) resulted in the formation of a unique oil and gas basin. Its peculiar features are intensive processes of transformation-redistribution of matter which are still going on. Ubiquitous active fluid dynamics, convective movements and phase transitions result in a high phase and mechanical instability of the composing sedimentary formations and fluids and in the intensive dynamic processes. Basins like the SCB may be classified as non-equilibrium, a metastable basin.

Formation of hydrocarbon systems (HC) in non-equilibrium basins differs from traditional ones. Very important factors for generation, migration and accumulation of HC in the non-equilibrium basins are different kinds of mass-exchange, namely convection (thermal, chemical, etc.), emersion (heaving) of huge masses of deconsolidated, plastic clayey bodies, deformation of the sedimentary cover structure and formation of subvertical faults and crushing zones, high-speed cross flows of matter during eruptions of mud volcanoes etc. Formation of HC systems in this case should be considered as a component of complex processes of mass-exchange and phase transitions in the sedimentary cover resulting in the formation of specific mechanisms and canals of their migration as well as in the mosaic distribution of their accumulation.

Proceeding from the above mentioned it is necessary to apply new approaches to the simulation and in the exploration of HC in the non-equilibrium basins.

Preface

There exist no common notions of "non-equilibrium oil and gas basins" up to now. To a certain extent all basins are non-equilibrium as the change of geologic environment takes place during the whole course of their evolution and parameters of the state of composing rocks and fluids constantly strive for equilibrium. At the same time in some basins, especially in the young ones which are located within mobile belts these processes take place faster and they are characterized by intensive dynamics: volcanism, seismicity, active migration of fluids, diapirism, mud volcanism etc. A part of these processes takes place in recent time and can be registered by up-to-date monitoring facilities (Guliyev I., 1999). Conventionally these basins may be related to non-equilibrium. The SCB may be related to the basins with the most distinct peculiarities of non-equilibrium. Within the basin there were determined rich multi-layered oil and gas condensate fields. According to some geological, geophysical and geochemical parameters the SCB is a unique basin. These parameters are as follows:

-very high velocities of subsidence and sedimentation (up to 3,5 km/my) for a very short period of geological time (Pliocene-Quaternary);

-formation of a sedimentary cover of a huge thickness (according to the latest data it is up to 30 km);

-mainly clayey composition of rocks composing the Cenozoic section;

abnormally high porous and formation pressures (close to geostatic);

abnormally low temperature gradients (1.5-1.8^{0}C/100 m) and thermal flows (25-50 mWt/m^2);

-widespread diapirism and mud volcanism;

inversions of hydrogeochemical parameters which are reflections of active fluid dynamics;

-mosaic character of the spread of HC fluids.

New data have been obtained recently as a result of intensive research efforts, especially in the marine part of the basin.

DATABASE

Intensive dynamic processes. High velocities and contrast regime of recent vertical and horizontal movements, very intensive mud volcanism, small-focus seismicity, fluctuations of the Caspian Sea level, ground and underwater land-slides (Guliyev and Ivanov, 2001) are typical for the SCB. Sources of mud volcano eruptions and small-focus earthquakes are located in the sedimentary cover at depth 10-20 km and coincide with sources of HC generation. Paragenesis of mud volcano eruptions and some earthquakes as well as certain synchronicity of their manifestation with exogenic and endogenic factors were determined (Guliev and Feyzullayev, 1997; Aliev at al.,1999).

Peculiarities of the sedimentary cover structure. In the sedimentary cover of the SCB there were determined specific structures in the form of subhorizontal and subvertical bodies of a different morphology and sizes – extended regional and local zones of deconsolidation – under-consolidation, clayey diapirs and mud volcanoes, sandy diapirs and dykes, clinoforms, collapse calderas, land-slides etc. These structures are spread at all levels of the section – from the surface to as deep as the base (Guliyev, 1999, Mamedov, 1991) Fig. 1,2,3. Subhorizontal regional zones of under-consolidation –deconsolidation and subvertical clayey diapirs often are united in the extended ridges (like the Saline) and form a peculiar mosaic structure of the sedimentary cover. Within some blocks structures, of the folding, orientation of the folds axes, direction of fault dislocations may be individual. Peculiar features of the SCB tectonics in the flanks are charriers and thrusts. Mosaic structure and autonomous characters of the structures are confirmed by local character of vertical and horizontal movements and by the absence of a distinct regularity in the distribution and activation of mud volcanoes and natural HC seepage.

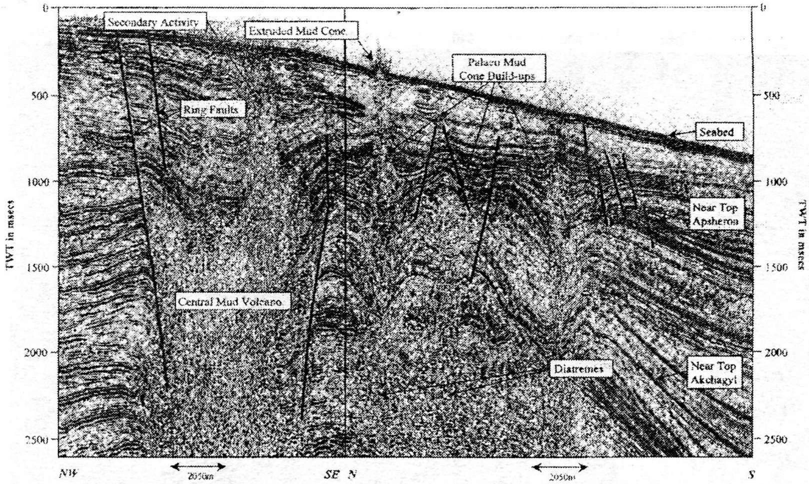

Fig. 1. South Caspian Basin. TWT sedimentary section image (Fowler S.R. et al., 2000).

Character of HC migration. A very important factor in the understanding of peculiarities of HC systems formation in the SCB is migration of HC together with the deconsolidated mass, abundant oil and gas seepage onshore and especially in the sea floor. The scale of subvertical migration of HC in the SCB is very high. It occurs periodically and its velocities are very high (geologically instant). Scale of recent migraton of gases is determined empirically, and paleomigration is determined by the amount of breccia in the deposits of different age (Dadashev and Guliyev 1984; Guliyev and Kadirov, 2000). High velocities and impulse character of fluid migration and processes which determine them may be classified as rapidlygoccuvry going ones (Guliyev, 1999).

Geochemical characteristics of fluids. Chemical and isotope composition of gases, stratal waters and oils are characterized by a very rather wide range of values which proves a considerable range of temperatures and pressures of HC generation and migration (Bailey, 1996; Guliyev et al. 1991; Guliyev and Feyzullayev, 1996; Guliev et al., 2001b;). Studies of the carbon isotope composition of methane and its homologues demonstrate that they consist of mixtures of biochemical and thermogenic gases. A peculiar feature of the gases and oils in the SCB is their relatively young age (Abrams and Narimanov, 1997; Guliev et al.,2001a; Wavrek et al., 1996). A widespread inversion of chemical composition of the formation waters helps to understand the peculiarities of HC migration.

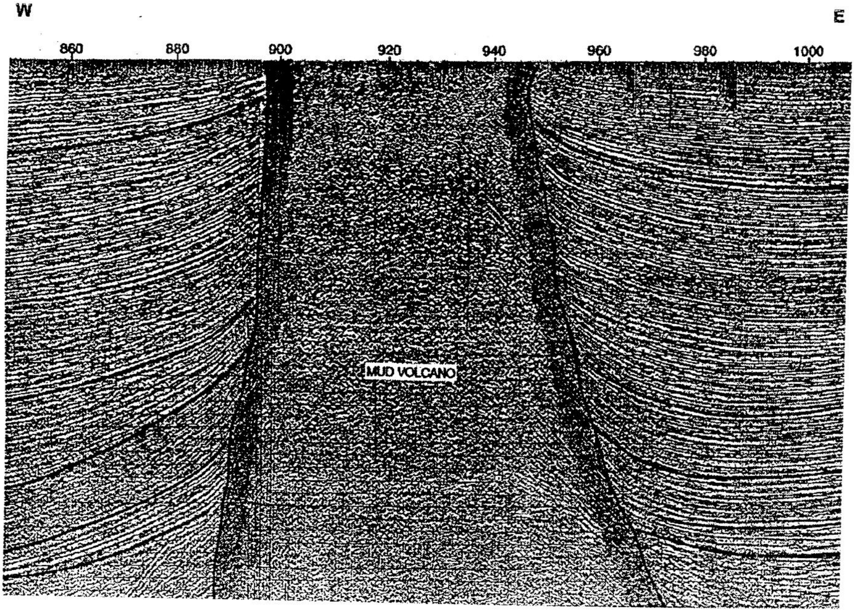

Fig. 2. Lower Kura depression.
Mud volcano image on the TWT section.

PHYSICAL-CHEMICAL PROCESSES IN THE SEDIMENTARY COVER

Underlying physical-chemical models of processes that take place in the sedimentary cover, lie the notions about change of structure, and properties of rocks and fluids.

Main reasons of the formation of a non-equilibrium state of the SCB are as follows:

Process of under-consolidation of rocks determined by competition between sedimentation velocities and velocities of fluid release, namely – a considerable predominance of the first over the second. This competition is very intensive in massive clayey series characterized by low permeability. The porous sediments at the sea bottom accumulate a huge amount of marine water. At high velocities of burial most of the water, being not released, subsides together with the rock. According to data (Le Pichon et al, 1989) amount of such water may reach up to 80 % and more (up to 90 %) of the total amount of the sediments. A part of this water, buried together with the sediment, counteracts normal compaction of rocks, which is typical for basins with low and moderate sedimentation velocities. In other words, the mineral framework of the sediment starts actively resist to the further decrease of porosity and its own destruction. According to simulation results of the compaction process of water-saturated clayey sediments (without participation of any catagenetically formed fluids), formation of increased pore pressures to account for the under-consolidated clays was justified in basins of high velocities of sedimentation.

Proceeding from the classic regularity of the consolidation of rocks with the growth of depth, the upper sill of intensive manifestation of the process in the clays is expected at depths 3-5 km. In the SCB this sill may occur deeper.

Decompaction of the rocks is stipulated by the start of intensive process of hydrocarbon formation. According to vitrinite reflectance data change at depth as well as calculation of that parameter by biomarkers of oils and isotope composition of ethane carbon of fields and mud volcanoes in the South Caspian basin, peak for oil formation is located approximately at depth 6-7 km and for gases 10-12 km (fig. 3).

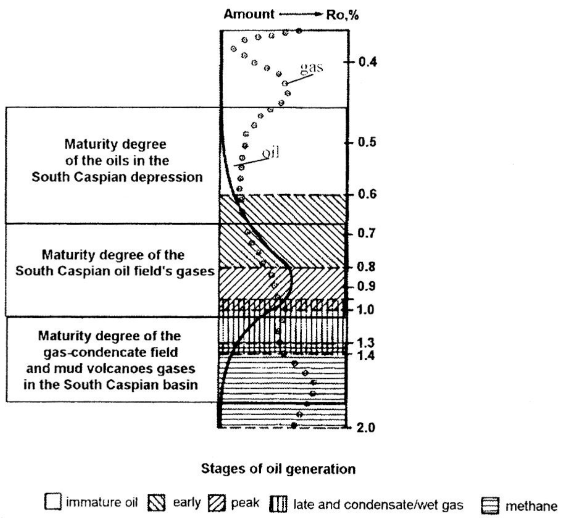

Fig. 3. Schematic plot of maturity (in R_o) against intensity of hydrocarbon generation showing vertical zonality of hydrocarbon formation in the SCB.

Transformation of smectite into illite during the subsidence of sediments to appropriate depths, which is accompanied by emanation of a great amount of water. According to recent studies, this process is stipulated by a kinetic reaction, depending on temperature and time. The beginning of the transformation reaction of smectite into illite occurs in the interval of temperatures 70-96^{0}C; at gradient 1.5^{0}C/100m, typical for most of the South Caspian, corresponding to a depth 4700-6400 m. However, mineralogical studies of rock ejecta of mud volcanoes demonstrate the existence of smectite deeper.

It was determined that a complete dehydration of smectite produces 35 % of water of the initial amount. Amount of water, which is released as a result of this process, leads to the abnormally high porous (AHPP) and formation (AHFP) pressures. It should be mentioned that clayey rocks in most of the SCB are represented by smectite (up to 50 % and more) (fig.4) (Kerimov et al, 2001).

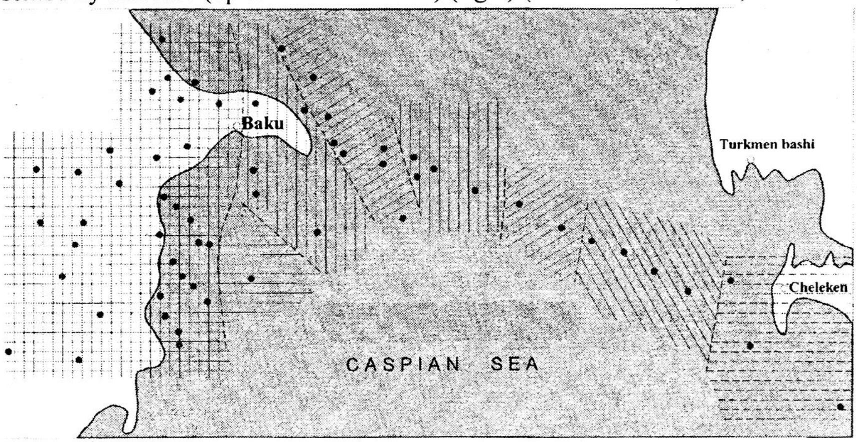

Fig. 4. Smectite content in clay fraction <1mkm in upper division of PS: 1 - >50; 2 - 40-50; 3 - 30-40; 4 - 20-30; 5 - 10-20; 6 - <10%; 7 - studied fields

Thus, each of the 3 above-mentioned processes leads to the increase of pore pressure in the clays, which affects the pressure in the reservoir. These processes form abnormally high (abnormal coefficient. up to 1.8) pressures in the interval 4-7 and more km (fig.5). Such intervals are reflected in geophysical fields in the form of regional zones of abnormally low velocities of waves stipulated by the existence of regional decompaction zones (Guliev et al,, 1988), (fig.6). Essentially, in this case we deal with a closed system. Removal of products, formed as a result of thermo-chemical reactions and physical-dynamic processes, from such systems is very difficult. As is well known from physical chemistry, this leads to retardation of velocity of the reactions. From this point of view thermal cracking of the organic matter (OM) as a result of the growth of temperature, stipulated by the subsidence of the basin will lead to a constant increase of amount of HC formed in the massive clayey series and, finally, this will lead to the retardation of the OM cracking process. Velocity of this reaction may grow dramatically again, if by force some factors (tectonic, thermal and chemical convection etc.) the products will be removed out of the system (for instance, during eruption of mud volcano). It was determined that, during an eruption of mud volcano, amount of the emanated gas products may be nearly 500x10^6 m^3 (Dadashev, 1963). The zones of AHPP are very well correleated in space with the change of a clayey fraction content in the rock section there occurs an increase in the ratio of the abnormally pressure (fig.7). In other words, in the same direction, owing to decrease of effective pressure, there occurs an crease of rock porosity (fig.8).

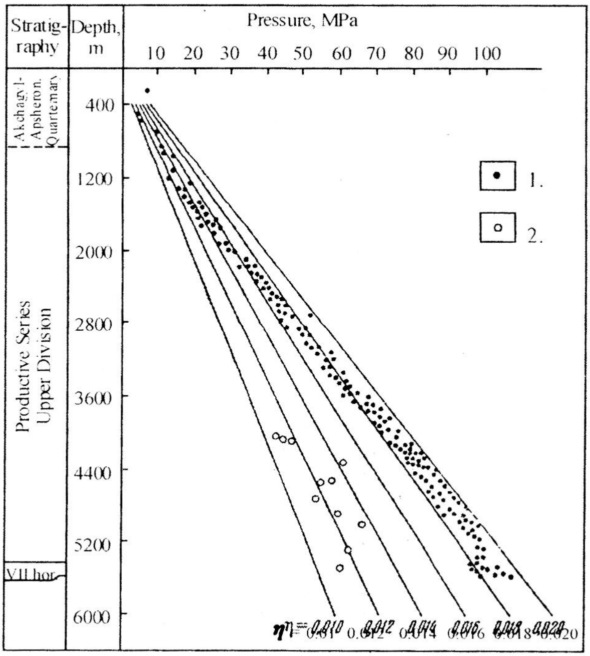

Fig. 5. Changing of the porous pressure (P) in the clays (1) and formation pressure in the reservoir sands (2) with depth in the Baku archipelago oil fields (η - pressure gradient, MPa/m).

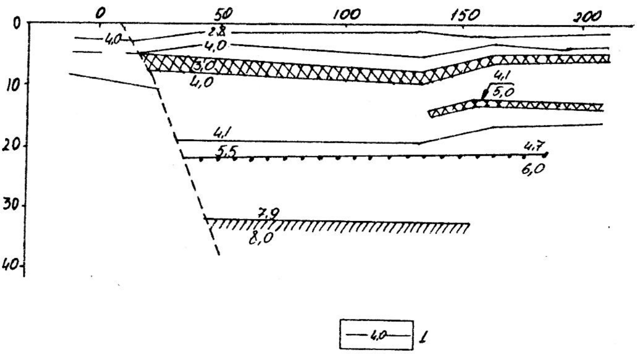

Fig. 6. Velocity 2D model on DSS-9 profile

Existence of 3 processes overlapping each other accompanying the formation in the section of dramatically "excited" clayey layers, which striving to position of thestable equilibrium, start to move in different directions and create peculiar structural forms (diapers, disharmonic folds etc.) (Kityk,1979; Guliev, 1999)(fig.9). This process is promoted by the migrating from below, water and gas by the faults (which saturate the unconsolidated) rocks transforming them into gas-liquid mass) and by the constant-interrupted seismic activation of the earth interior. Annually in the territory of the SCB there occur hundreds of earthquakes. Most of their focuses are located in the sedimentary series (at depths 15-25 km) These shallow-focused earthquakes, causing periodical beds vibration, stipulate a striving to movement of clayey masses from an unstable to a stable position (i.e. they play a role of "mechanic catalyst" of these processes).

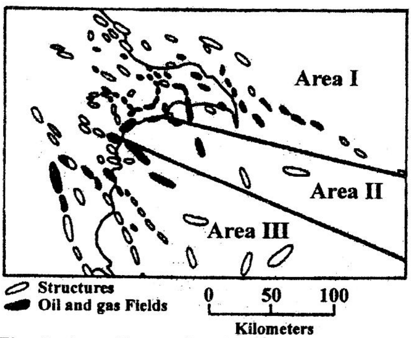

Fig. 7. Area I - predominate sand content;
Area II - predominate silt content; Area III - predominate clay content

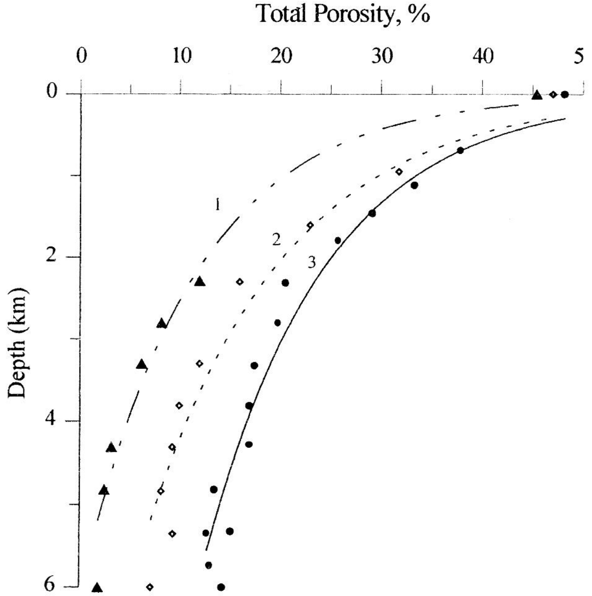

Fig. 8. SCB. Porosity of clays vs. depth. 1 - for zone with normal pore pressure; 2 - for zones with intensive pressure; 3 - for zone with maximal pressure.

These data are very well correlated with notions of the phase and mechanical instability appearing in the sedimentary cover of oil and gas basins at the initial stages of their evolution due to intensive generation and migration of HC, defluidization of rocks and gradual stabilization of these processes with the increase of age of the deposits (Ivanov et al., 1991; Guliyev, 1999). According to this notions evolution of the sedimentary basin is an uninterrupted process of transformation – redistribution of the matter (lithogenesis, HC generation, consolidation of rocks, defluidization during mineral formation etc.) accompanied by the change of its properties and structure. These processes are especially intensive during the first ten million years when the energetic potential of basins is very high. At this stage of evolution (we propose to call it "the youth of the basin") sedimentary series are characterized by the unstabilities of a different kind. They manifest themselves in the convective processes. Thermal, chemical, sedimentation and other kinds of convective movements are quite possible. As a result of them ascending and descending flows of the matter are initiated there.

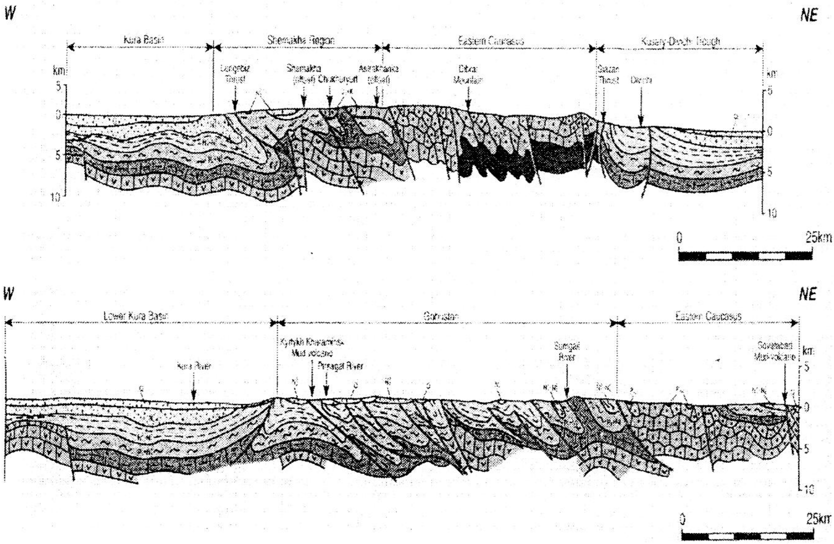

Fig.9. Examples of disharmonic folds, formed in sedimentary cover of SCB.

The presence of two superimposing into each other processes following by a sharp pressure increase in the system, lead to the formation in the section of sharply "excited" clayey layers which striving to the condition of stable balance start to move in various directions creating peculiar structural forms (diapirs, mud volcanoes, disharmonic folds etc).

Gas and water migrating along the fault, (which saturating the crushed rocks and transform them into gas-liquid mass) as well as continuous-intermittent seismic activation of interior of the earth promote to this process. Annually in the territory of the South Caspian Basin there occurs thousands of earthquakes of different magnitude, main peculiarity of which is the correspondence of their most focuses to the sedimentary series with a depth 15-25 km (Fig 10).

These non-deep focused earthquakes causing periodical beds vibration stipulate a striving to movement (displacement) of clayey mass from instable to the stable condition (i.e. play a role of "mechanic catalyst" of these process).

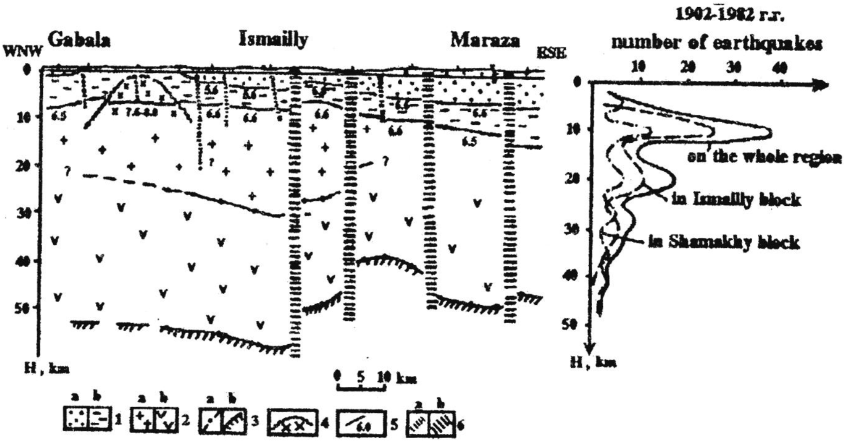

Fig. 108. Cross section of the Earth crust in the Shemakha-Ismailly region, Azerbaijan, and distribution of the earthquakes hipocentres. 1- the sedimentary complexes: a) Jurassic; b) Lower Cretaceous - Anthropogen; 2 - basement: granite; b) basalt; 3 - discontinuities: a) Conrad; b) Moho; 4 - outlines of the intrusive massif; 5 - boundary velocities; 6 - deep faults: a) in basement; b) traced down to Conrad and Moho discontinuities

Given below are some possible mechanisms of formation gravitational unstability of rocks:

Consider the model of the sedimentary cover, which consists of three series of a different dislocation and composition and mechanical properties. The upper series is composed of relatively solid rocks that, during tectonic movements undergo bends accompanied by faults and without a considerable change of initial thickness. The middle series is composed mainly of relatively plastic rocks and underwent plastic deformation of a different intensity in the form one areas and delivery them into the other area and delivery other areas. As a result, the initial thickness of the series as well as intensive deformation of the composing rocks are changed. These plastic rocks often intrude into the upper deposits as well. The lower series is composed of relatively solid rocks too. During tectonic movements it only underwent fold and fault deformations. In the interstitial layer there occurs a transition from the folding typical for the lower solid series to the folding existing in the upper solid series.

Sedimentary layers in the oil and gas regions in Azerbaijan, East Georgia, South-West Turkmenian, West Kuban, Kerch, Gulf of Oman etc., may serve as examples of such geological environments.

Geodynamic processes taking place in such sedimentary basins are mainly associated with the interstitial less viscous layer. This layer is a source of processes of gravitational instabilities also influencing HC migration. Spatial and time correlation between the folds in different boundaries of the sedimentary covers may be explained by three possible mechanisms(Kityk 1979, Kadirov and Kadyrov, 1990; Kadirov, 1997; Kadirov, 2002; Polyanskiy, 1988; Tribitsin et. al. 1998; Guliev and Kadirov, 2000): 1. Convection movements (Rayleigh-Bernard type of the gravitational unstability); 2. Diapiric emersion (Rayleigh -Taylor type of the gravitation unstability); 3. Horizontal flow-gravitational sliding, gravitational sedimentation and yielding (Kelvin-Helmholtz type of the gravitational unstability).

Rayleigh -Bernard type of gravitational instability of the sedimentary layers.

Consider a three-layer model of the deep structure of the Alpine complex of deposits in the region. This complex from below upward is composed of the following layers:

the **lower layer** – geosynclinals; composed of terrigenous – carbonaceous rocks;

the middle layer – lower molassic is composed of plastic clayey series saturated with HC;

the upper layer – upper molassic is composed of sandy – clayey formations.

Paleogene-Miocene deposits spread in the depression zones of the SCB may serve as an example of the interstitial high-plastic series. Thickness of the interstitial layer is 4-5 km on average, but sometimes reach up to 7-8 km. It has maximal values in zones of intensive mud volcanism activity. Results of the exploration drilling demonstrate that clays and clayey rocks in the SCB are from 50 to 95 % of the section. Viscosity of such layers varies from 10^6 Pa/c to 10^{12} Pa/c. Viscosity of the overlapping and underlying rocks is 10^5-10^6 orders higher. Density of sedimentary layers depends upon composition and varies as follows: 1) for clays – 2.3-2.6 g/cm^3; 2) for sandstones – 2.5-2.6 g/cm^3; 3) for limestone – 2.6-2.9 g/cm^3. In the zones of regional deconsolidation the clayey series is least dense – up to 0.2 g/cm^3.

The less viscous Paleogene-Miocene series of the sedimentary complex has the following parameters:

-Temperature coefficient of enlargement $\alpha = 10^{-5} K^{-1}$;

-Coefficient of thermal diffusivity $\chi = 5 \cdot 10^{-7}$ m^2/c;

-Coefficient of thermal conductivity k =2Wt/(m·K).

Coefficients of thermal conductivity of sandstones and limestones are 5.17 Wt/(m·K) respective. For this reason the Paleogene-Miocene deposits are heat insulators and, no doubt, they play an important role in the formation of a thermal field in the upper layers.

Letus now analyze the possibility of gravitational instability process of Rayleigh -Bernard type in the intermediate less viscous layer of the sedimentary complex.

The Rayleigh number for the viscous interstitial layer of the complex is calculated by the formula:

$$R = \frac{\alpha g q d^4 \rho}{\chi k \eta} \tag{1}$$

where:

α - temperature coefficient of a volumetric enlargement;

g – acceleration of the gravitation;

q – thermal flow;

d – thickness of layer;

ρ – density of the intermediate weakly consolidated and highly plastic layer;

χ – coefficient of thermal diffusivity;

k – coefficient of heat conductivity;

η - dynamic viscosity.

According to the linear theory of stability, it the Rayleigh number is higher than the critical R_c, there appears convection movement. Rayleigh critical number for the horizontal layer with "sticky" boundaries R_c=1295. Rayleigh number for the Paleocene-Miocene layer with thickness d=5 km shows that

$$R = \frac{3 \cdot 10^{-5} \cdot 10 \cdot 60 \cdot \left(5 \cdot 10^{3}\right)^{4} \cdot 2{,}3 \cdot 10^{3}}{5 \cdot 10^{-2} \cdot 2 \cdot 10^{12}} \approx 10^{4}$$

As for the Paleogene-Miocene Layer R_c=1,2·103, i.e. one order lower than the typical one, then in this layer the convection movement having a character of 2D cells should take place. Typical time of temperature equilibrium of a liquid layer is determined by:

$$\tau = \frac{d^2}{N\chi} \tag{2}$$

where N – Nusselt number, which characterizes the efficiency of the convectional heat transfer and shows how much max intense the complete thermal flow is, compared the conductive flow.

For the viscous interstitial layer, the convection time is much less than the age of the Paleogene-Miocene complex. Hence, convection in this layer is stationary. After the establishment of convection the value of the temperature in the boundaries of the Paleogene-Miocene layer becomes stable as well. Length of the disturbance wave which characterizes distance between two close ascending flows at fixed temperatures in the boundary of the Paleogene-Miocene series is calculated by the formula **λ=2.016d.** In case when the course of the series exceeds its thickness several times, some convective cells are formed. If the tensions created by the flow exceed the limit of soundness of the upper rocks, then uplifts may be formed above the ascending flows (Trubizin et. al., 1998).

Process of the Rayleigh-Bernard type of gravitational instability reflects one of the possible models of HC migration in the series of the Paleogene-Miocene deposits in the SCB (Kadirov, 1992; Guliev and Kadirov, 2000).

Evaluation of HC diffusion in an environment of high plasticity impossibility of this migration model. The filtration model of HC migration in the massive, impermeable clayey series is excluded as well. Calculations of the time of the HC particles rise to the surface at the expense of the gravitational force of emersion indicates the impossibility of this migration model as well. Transportation of HC upward, together with the enclosed clayey plastic mass of the intermediate layer at the expense of convective processes, is probably a real mechanism of migration and accumulation in the upper parts of the same series, with the further breakthrough the overlapping permeable series. As the clay is elevated upward, the lithostatic pressure becomes lower. As a result, phase transitions will occur and HC will be emanated into a free phase.

It is quite possible that the above-mentioned interstitial layer is the main generator of the most of centres of mud volcanoes in Azerbaijan as well (Guliev and Kadirov, 2000). Fig. 11. demonstrates a scheme of activation of mud volcanoes in a three-layer model of the sedimentary complex with the application of convection.

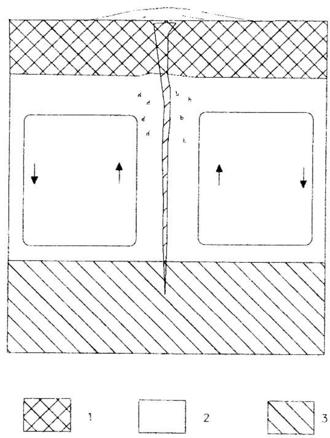

Fig. 11. Model of activation of mud volcano (gravitational instability such as the Rayleigh - Benar) 1 - sandy-argillaceous deposits; 2 - strata of plastic clay material; 3 - terrigenous-carbonate deposits

This model may explain a good correlation of real distances between volcanoes with the change of thickness of the convection (in this case Paleogene-Miocene) layer.

Fig. 12 is a scheme of the change of length of the wave characterizing frequencies of the convective structure in the horizontal direction from the change of the middle layer thickness. Depending on the change of the middle layer thickness the size of a convective cell changes as well. As a result there occurs a change of distance between the ascending flows as well (mud volcanoes).

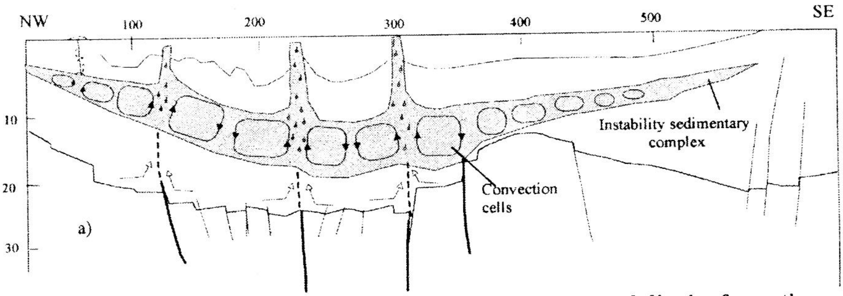

Fig. 12. South Caspian Basin. Model of the mud volcanoes and diapirs formation, based on the Rayleigh-Benar gravity instability type.

Rayleigh-Taylor type of the gravitational instability in the two-layer model of the sedimentary complex and formation of diapers.

Let us assume, that in this model under the first layer with thickness h, density ρ_1 and dynamic viscosity η_1 there occurs the second layer with thickness H, density $\rho_2 < \rho_1$ and dynamic viscosity η_2. Geometry of the task is illustrated by fig. 13. Materials filling these layers are assumed to be high-viscosity and non-mixed liquids.

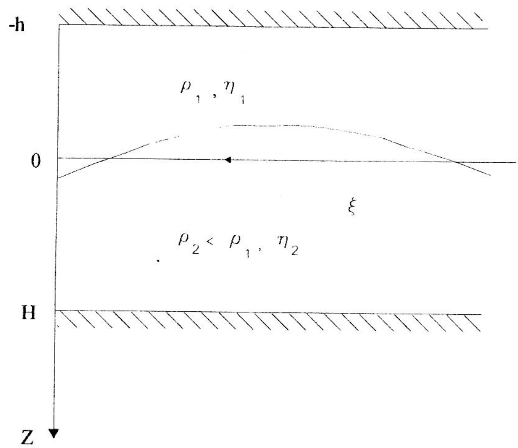

Fig. 13. Geometry of a problem of instability of the Rayleigh-Taylor type.

In the regime of small Reynolds' numbers, equations of motions of the liquid motions are as follows:

$$-\frac{\partial P_n}{\partial x} + \eta_n \left(\frac{\partial^2 V_{xn}}{\partial x^2} + \frac{\partial^2 V_{xn}}{\partial z^2} \right) = 0 \tag{3}$$

$$-\frac{\partial P_n}{\partial z} + \eta_n \left(\frac{\partial V_{zn}}{\partial x^2} + \frac{\partial^2 V_{zn}}{\partial z^2} \right) - P_m g = 0 \tag{4}$$

$$\frac{\partial V_{xn}}{\partial x} + \frac{\partial V_{zn}}{\partial z} = 0 \tag{5}$$

where n=1,2 – numbers of the upper and the lower layers, V_{x1}, V_{z1} and V_{x2}, V_{z2} - components of velocities of the first and the second layers; P_1 and P_2-pressures in the first and the second layers; P_1 and P_2-pressures in the first and the second layers; g-acceleration of a free fall.

Due to inversion of density ($\rho_1 > \rho_2$) the layered system is gravitationally unstable. For this reason in the boundary of the layers division there appear wave disturbances. Assuming that thickness (h) of the overlapping series h are 1-3 km and differences between densities ($\Delta\rho$) are 0.1 and 0.2g/cm^3, the length of the wave of disturbance may vary from 2.964 to 8.892 km and time of emergence may vary from 3.36 my to 20.16 my.

Kelvin-Helmholtz type of the gravitational unstability in sedimentary layers and folding

Vertical uplifts and subsidence of the basement provoke the flowing of the overlapping layers under the influence of a horizontal component of gravitation. Due to its decreased viscosity the interstitial layer undergoes the most intensive influence of the horizontal component of gravitation. Due to the existence of the density difference between the layers and the flows velocities on the division boundary on the free surface, according to Helmholtz principle, there appears a wave disturbances, participating in the formation of fields. This phenomenon together with the other tectonic processes may explain some deformations of rocks (Kadirov, 2002).

Suppose that under the first layer (thickness h_1, density ρ_1 and dynamic viscosity η_1) there occur the second layer (thickness h_2, density $\rho_2(>\rho_1)$ and dynamic viscosity $\eta_2(<\eta_1)$ limited by immobile plane from below, dipping at an angle α to the horizon. To facilitate mathematic simulation suppose that the area of the gravitation flow is not limited. Geometry of the problem is illustrated in fig. 14.

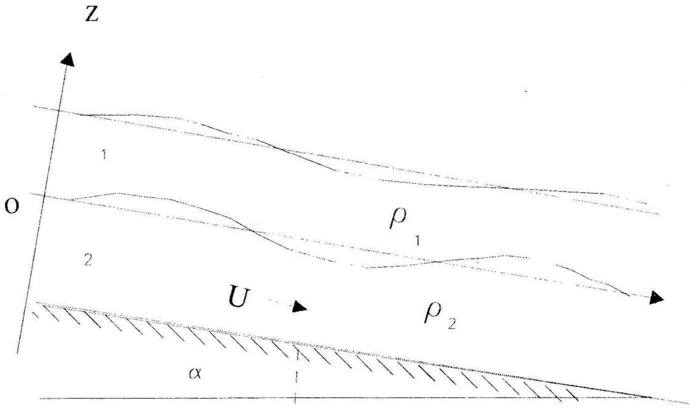

Fig.14.Geometry of the Kelvin-Helmholts instability problem.

Disturbances on the free surface and in the boundary of the division generated by gravitational flows will be in the form:

$$\xi = \xi_{0j} e^{\omega t} \sin kx \qquad (6)$$

Where $k = \dfrac{2\pi}{\lambda}$ - wave number, $\omega < 0$. Here j=1 corresponds to the disturbance in the free surface, j=2 – in the boundary of the division system of equations of Navies-Stokes is as follows:

$$-\frac{\partial \mathrm{P}_n}{\partial x}+\eta_n\left(\frac{\partial^2 V_{xn}}{\partial x^2}+\frac{\partial^2 V_{xn}}{\partial x^2}\right)+\mathrm{P}_n g\sin\alpha=0 \tag{7}$$

$$-\frac{\partial \mathrm{P}_n}{\partial z}+\eta_n\left(\frac{\partial^2 V_{zn}}{\partial x^2}+\frac{\partial^2 V_{zn}}{\partial z^2}\right)+\mathrm{P}_n g\cos\alpha=0 \tag{8}$$

$$\frac{\partial V_{xn}}{\partial x}+\frac{\partial V_{zn}}{\partial z}=0 \tag{9}$$

where n=1,2-numbers of the upper and the lower layers;

V_{x1}, V_{z1} and V_{x2}, V_{z2} - components of motion velocities of the first and the second layers;

P_1 and P_2-pressures in the first and second layer's;

g-acceleration of gravity.

Let's take the following values fro the parameters of sedimentary layers:

$h_1=h_2=$ 1-5km; $\rho_1=2.5$ g/cm^3, $\rho_2=2.6$ g/cm^3; $\eta_1=10^{18}$ Pa**·c**;

$\eta_2=10^{16}$ Pa·c; $\xi_{02}=500m, \alpha=5^\circ$.

Sizes of the folds generated by gravitational flows vary from 5 to 15 km. Period of generation 2·104-4·104 years. These values conform very well to observed values.

Aspiration of sedimentary rocks for equilibrium through the convective processes takes a long geological time. However, this may take less time by means of phase transitions. During the phase transitions dramatic changes occur in the thermodynamic environment, physical properties of rocks and fluids accompanied by strong dynamic effects. We proposed to call unstable (metastable) series "excited systems" (Guliyev, 1999). Relatively low-amplitude occurrences (formation of faults of different genetic origin, effects of local and strong remote earthquakes, impulses of negative pressure etc.) may be triggers to excite the system. They result in considerable change of physical and geochemical properties of the environment.

Within the sedimentary complexes one can observe phase transitions of different types. The widest spread is the transition of "liquid-gas" type, which occurs throughout the section of the sedimentary cover. Conditions of metastability of the system "HC-frmation waters" are given in some papers (Ivanov at al., 1991; Ivanov and Guliyev, 1986).

Another variety of the phase transition of "solid body-gas" type occurs during the decomposition of gas hydrates. Low geothermal gradient in the SCB together with high pressures allow one to suppose, that they lower boundary of gas hydrate spread may subside that the relatively deep. Phase transitions of "solid body-liquid" type may occur during the transition of minerals from one modification into another. Accumulation of HC (proceeding from the above) should be considered as consequence of series processes including convective transfer of the matter, emersion of decompacted clayey bodies, phase transitions and linked with the generation, migration and accumulation of HC.

Based on the above theme can make a conclusion that in the SCB, thermal decomposition of the OM will be, most probably, a regional-mosaic nature, i.e. processes of thermal decomposition of the OM will be most intensive near zones of the discharge of HC (close to channels of active mud volcanoes or, so called subvertical zones of heightened instable zones), formed in massive clayey series. In accordance with the above-mentioned, migration and accumulation of HC in reservoirs will be also unbalanced in space and time i.e. the traps, to which extended the channels of HC discharge (so called, subvertical zones of the impulse discharge of matter.

The formation and migration of HC in the non-equilibrium basins suggests that the formation of every field is controlled by its own local system of oil and gas formation and impulse migration of HC through subvertical zones of the increased instability of rocks (or subvertical zones of impulse discharge of the matter). The above mentioned rapidly occuming processes are accompanied by dramatic changes of thermodynamic, geophysical and geochemical fields and may be fixed (eruptions of mud volcanoes, small-focus earthquakes, hydro fractures) by up-to-date means of geophysical, geodetic and geochemical monitoring.

Slowly varying processes of transformation-redistribution of the matter are very well fixed in the structure and anomalies of geophysical and geochemical fields in particular, in the structures of fields of HC concentrations, helium, argon, tritium and in a number of hydrogeochemical parameters (Ivanov and Guliyev, 1988).

This, high level of discontinuity in the space and time of the environment properties in the non-equilibrium basins is showed by specific mechanisms of the mass transfer, accompanied by phase transitions, require revision of theoretical basis of classical basin model.

Some principles of geological model construction of non-equilibrium basins.

It is quite obvious that development of a new geological model for the non-equilibrium basin is a difficult task. At this stage we only could formulate some common provisions:

Equally with global geodynamic factors, which determine main features of the structure and properties of the non-equilibrium basins, very essential dynamic factors are convective movements and phase transition, stipulated by the instability of a different type. The redistribution of the matter occurs intensively, with high velocities (in a geological scale) and significantly changes the structure of separate blocks, character of the folding and fault tectonics. Taking into consideration the convective processes in the formation of the basin structure and the appropriate folding is extremely necessary.

Phase transitions of a different type are one of the basic mechanisms of the decompaction of the sedimentary rocks, that, together with the processes that produced them, provide impulses of pressure, stipulate a high-velocity displacement of considerable amount of solid, liquid and gaseous matter.

Migration of the decompacted matter forms in the sedimentary cover subvertical channels of variety forms and specific structures. Permeability of such subvertical channels for HC is much higher than in the matrix of the sedimentary rocks and probably in the faults. Periodical cross flows of fluid are very important components of the HC system formation in the non-equilibrium basins.

In the light of the processes taking place in the non-equilibrium basins, the formation and migration of HC will be of a regional-mosaic (discrete) character. Processes of thermal decomposition of the OM will be most intensive near the zone of HC discharge (near eruptive channels of active mud volcanoes or, so called subvertical zones of increased instability), formed in massive clayey series.

Improving technology of HC exploration in the SCB

In the light of the above-mentioned, the study problem of instability of geophysical fields in time is very urgently needed. Especially as the change of the seismic waves parameters (Nevskiy, et al., 1985), gravitation (Okhawa & Yokojama, 1976; Gadjiev et.al 1984, 1988; Kadirov and Nabiev, 1991) and magnetic properties of rocks (Shapiro et al, 1982,) in time is a well-known fact. This is a serious obstacle for the objective interpretation of geophysical data and may result in a significant decrease of the efficiency of HC exploration in the non-equilibrium basins and, in particular, in the SCB. For this reason it is necessary to improve the technology of HC exploration in such basins.

A traditional paradigm of HC exploration in the SCB is oriented to the study of the structure and properties of the sedimentary cover in framework static. New approaches propose to direct the whole arsenal of up-to-date methods to the study of the structure and properties of rocks and fluids in dynamics. The main task is the differentiation of the sedimentary basin according to the level of phase and mechanical stability (Guliyev and Ivanov, 2001). The solution of the problem includes:

-division of the ground waters into zones of convective and diffusion exchange and reconstruction of the velocity field of the convective zones;

-contouring of zones of HC formation and assessment of the abundance of their sources;

-identification of sub-zones (zones of recent and paleo-accumulation), where the velocity of production exceeds the velocity of the withdrawal;

-differentiation of the zones according to the distribution of accumulation velocity, ratio of metastability and excess pressure.

Technologic chain promoting implementation of the above mentioned points includes the following regional exploration tasks:

-mapping of high-gradient zones by means of the study of the spatial variability of different components concentration fields (first of all helium and tritium) aimed at the reconstruction of the underground water-exchange;

-the study of HC fields for the localization of their zones of production, migration and accumulation.

Tasks of the local exploration are as follows:

-mapping of paleo and recent "excitement" sources, their capacity and productivity.

As was mentioned above, the phase transitions in HC systems occur in zones of extreme saturation of formation waters by HC. In seismic profiles such zones are identified in the form of inversion of velocities of seismic waves, which are interpreted as under-compaction and decompaction zones. Mapping and such zones, the study of their nature, assessment of thermodynamic parameters, physical properties of rocks and geochemical peculiarities of fluids all urgent tasks. Such areas are potential zones where the phase transitions are quite possible. The process of the phase transitions ("excitement" of system) occurs periodically. Coordinates of the zones of excitement may be mapped more precisely by methods of seismic monitoring as the "excitement" is accompanied by a dramatic change of pressure and temperature, density, permeability, viscosity of rocks and fluids and appropriate mechanic effects. Mapping of sources of mud volcanoes eruption and small-focus earthquakes which logically may be connected with process of the 'excitement" of the sedimentaru rocks. In this case, it is possible to fix not only coordinates of the "excitement" source and to determine its volume, faciec pecularities, stratigraphic localization, quality of source rocks and their possible productivity.

-Mapping of migration channels. It is supposed that the widest migration of HC occurs during the "excitement" of the system when permeability of the environment (especially in the migration channels) increases considerably as a result of the decompaction of the matter. The migration channels may be of a different morphology. Impulse subvertical discharge of energy accompanied by the intrusion of the matter (clay saturated with gas, oil and water) under high pressure into the upper layers of the sedimentary series creates a complex system of the destructive zones. As a rule it resembles the crown of a high tree and it may be characterized as "migration tree". Typical configuration and consistency of such zones is identified by seismic methods and their projection on the surface occurs in the form of natural oil and gas seepage, and geochemical anomalies.

-Mapping of HC bodies. Theoretically HC bodies may be fixed in any sedimentary basin, where is carried out conditions of mechanical stability of the gaseous bodies in the porous space, i.e. not obligatorily in traditional traps.

Non-traditional traps of a complex configuration (hydrodynamic, in particular), were determined in all oil and gas basins. From this point of view of a special interest are giant subvertical bodies-diapirs and mud volcanos which are zones of HC drainage from the surrounding sedimentary rocks (Lerch et al., 1997). Methods of mapping of such bodies and evaluation of their HC saturation have not been developed yet, although there are interesting ways of interpretation of the geophysical data for such cases. It here ask instances known of the determination of HC accumulations, mapping as zones of inversion of the seismic wave velocities, or zones of pore pressure anomalies.

"Excitement" centers, migration channels and zones of HC stabilization in bodies of different configuration are united in the individual HC systems, autonomous in their evolution. The study of such individual HC systems is very difficult.

The most common regularities of the change of dynamic parameters of the environment, depending on the intensity of HC migration may be studied based on the example of the study of mud volcano's, which are associated spatially and genetically through their complex monitoring. The obtained regularities may be applied during the modeling of paleo -HC system.

The above-mentioned ideas may serve as a basis for the improvement of technology of HC field exploration. This technology may supplement the traditional one with new information about centers of mud volcanoes eruptions, about hypocenters of earthquakes in the sedimentary cover, natural gas-water seepage in wells, elasticity and concentration of HC in ground waters, and about chemical and isotope composition of ground waters and gases. These indices usually are not used sufficiently in the assessment of oil and gas potential. The upgraded technology in the search for HC will increase the efficiency of exploration and HC finding probabilities in the complex SCB.

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