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# Occurrence and nature of overpressure in the sedimentary section of the South Caspian Basin, Azerbaijan

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## Abstract

Two basic factors are identified that contribute to overpressure in different sedimentary basins of the world, including the South Caspian Basin (SCB): tectonic stress and subsurface temperature. Two overpressure zones are identified in the SCB: 1. An upper zone (depth interval 600-1200 m), conditioned by disequilibrium rock compaction (undercompaction) and 2. A lower zone (zone of decompaction) conditioned by hydrocarbon generation (depth below 5 km). The lower overpressure zone is the most intense and depends on the thickness of the shale sequence, the content and type of organic matter, and the temperature conditions of kerogen transformation to hydrocarbons. In this zone the greatest risk is associated with gas generation at depths greater than 9 km, due to both more intense thermal breakdown of kerogen and the cracking of liquid hydrocarbons generated earlier. Overpressure is a major cause of diapirism and mud volcanism in SCB.

**Keywords:** Overpressure, Kerogen, Gas generation, South Caspian Basin, Azerbaijan

## 1. INTRODUCTION

One of the critical physical factors that control many processes below the Earth's surface is fluid pressure. The mechanisms, structure and level of development of pressure in a rock-fluid system vary significantly, depending on the basin history, its geological structure, the thickness and rock composition of the sedimentary section and activity of the geodynamic processes.

Basins subjected to long-term steady downwarping (with high rate of sedimentation and the formation of a more than 10km sedimentary column in which impermeable plastic rocks predominate) are characterized by excessive pore pressure which contributes to diapirism and mud volcanism. Excessive pore pressures are also reflected in reservoir pressures associated with fluidized source rocks. Overpressured sediments have porosities much higher than normal (Smith, 1971).

Evidence of abnormal high pore / reservoir pressures (hereinafter "overpressures") has been encountered in many basins of the world (Dickinson, 1953; Berry, 1973; Bigelow, 1994; Chiarelli and Duffaud, 1980; Chapman, 1994; Bradley and Powley, 1994; Ward, 1995; Audet, 1996; Belonin and Slavin, 1998; Kan *et al*., 1999; Snijder *et al*., 2001; Sun and Püttmann, 2001) and, in certain cases, the pore pressure gradient reaches the lithostatic pressure. Such greatly complicates drilling and has often caused accidents and the abandoning of wells. Consequently, a study of the mechanism (or mechanisms) leading to overpressure and the development patterns in sediments is of importance.

In this connection, it is important to study the history, geology, and petroleum system of a particular basin and, on the basis of theoretical and empirical developments, identify the dominant mechanism for the overpressure formation and predicted depth.

This article is devoted to solving this task for the South Caspian Basin in light of the results of past studies in other basins.

## 2. RESEARCH RESULTS

### 2.1. Roles of various factors in the formation of overpressure

The scientific literature contains descriptions of various dynamic mechanisms that cause overpressures in sedimentary basins (Burst, 1969; Hansom and Lee, 2005; Luo and Vasseur, 1996; Sharp, 1983; Shi and Wang, 1986; Sun and Jin, 2000; Wolf *et al*., 2005; Sun *et al*., 2009).

Based on systematization and summarization of the results of these studies, two basic factors can be identified that contribute to overpressures in sedimentary basins: tectonic stress and the progressive increase in rock temperature with depth.

*The tectonic stresses* that contribute to overpressure formation can be associated with both vertical (downwarping and inversion uplifting of deposits) and horizontal movements.

Vertical movements affect the sedimentation process by creating positive conditions (downward movements) or negative conditions (inversion uplifting and erosion of sediments deposited earlier - upward movements).

Excess pressures associated with inversion uplifting of rocks that, in the past, experienced downward movement can be attributed to the preservation of pore/reservoir pressures in rocks that developed before the inversion. The mechanism underlying overpressure in steadily downwarping of a basin is different.

The porous sediment accrued in the process of sedimentation at the sea floor, accumulates sea water. Existing estimates (Le Pichon *et al*., 1990) suggest that the amount of water at sediment deposition can be up to 80 % by volume of the sediments.

At high rates of steady downwarping of a basin and high rates of sedimentation of low permeability shales, most sediment water is not removed and subsides with the sediments to great depths. Such upsets the normal compaction of rocks typical for basins with low to moderate rates of sedimentation. The mineral matrix of the sediments exhibits active resistance to a further decrease in porosity, thus leading to undercompaction (Terzaghi, 1943; Dickinson, 1953; Smith, 1971; Magara, 1975). This process is especially evident in low-permeable massive shale strata, where the overpressure of sealed sediment waters originates.

Depending on the histories of development and geological structures of individual basins the process of sediment compaction varies over a wide range (Fig. 1)

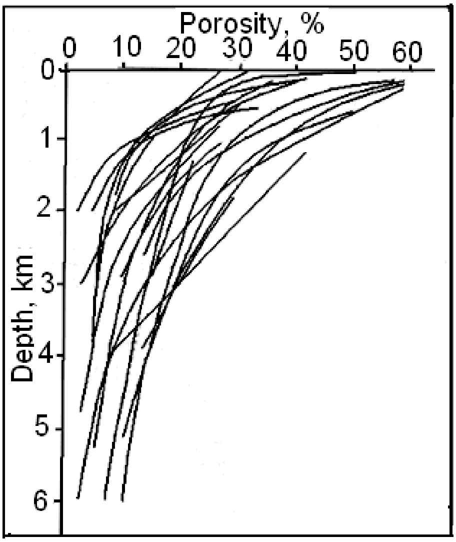

Figure 1. Porosity of clays vs. depth for various basins of the world (Poelchau and Mann, 1989).

The especially large range of porosity variation during rock compaction in various basins of the world is observed to a depth of about 2 km, thereafter the variation is less, being minimized at depths of 5-6 km. As a whole, the process of stabilization for both normal and non-equilibrium compaction of rocks begins at depth of around 3-4 km.

The formation of excess fluid pressure due to non-equilibrium compaction is expected to start somewhat shallower than about 4 km sediment depth. The formation of such mechanism of abnormal high pressure at an early stage of sedimentation history and at relatively shallow depths has been noted by others (Ward, 1995). This factor creates moderate overpressures (Ward, 1995).

The horizontal movements associate with the plate tectonics theory, according to which plates are subjected to horizontal displacements. The resultant lateral tectonic stress results in excess pressure at the plate boundaries (due to compressive strains) in thick fluidized shale strata, regardless of their depth (Darby and Funnell, 2001). The role of this factor in the formation of overpressure has not been adequately studied (Grauls, 1999).

So, for example, in the Nankai trough (Japan) several hundred meters of deposits are subjected to subduction under the frontal part of an accretion prism. These deposits, plunging to depth with high rates, are characterized by excess pressure near the deformation front. The pore pressure values increase downwards on-dip from 60% of geostatic pressure at onset of a zone of deformation (6 km), up to 77% in a zone of subduction for deposits at depth 15 km (Tobin and Saffer, 2003). In this basin 7 mud volcanoes are currently known (Nakamura *et al.*, 2005).

In basins located within an orogenic thrust belt horizontal stresses can exceed geostatic pressure, creating excess pore pressure (Yassir and Bell, 1994; Addis *et al.*, 1996; Yassir, 1999). The fluid pressure is then better correlated with a level of horizontal rather than vertical stress. In association with the horizontal shear stress there arises abnormal-high pressure at the base of thrust as occurs for example within the Gum petroleum field in Iran (Hillier, 1991) and also the coast of California (Berry, 1973).

Other examples are the Sacramento Basin (McPherson and Garven, 1999) and the East Coast Basin (ECB) (Bannister 1986). ECB, located within the limits of the seismoactive territory of New Zealand, is now subject to compression and here the active deformation at the border of the thrusting plates is clear. The lateral tectonic stress was recognized by the observed excess pressure (Berry, 1973; Darby and Funnell, 2001). The relative rate of movement of a plate (about 37-45 mm/year) is subject to convergence on an inclined plane with a rate about 10 mm/year (Cashman *et al.,* 1992). Thus, in a zone of convergence the rate of horizontal movement decreases almost in 3-4 times (Darby and Funnell, 2001). Such an intensity of deformation produces excess pressure comparable to the intensity produced by other mechanisms of fluid pressure formation (Neuzil, 1995).

In the ECB high gradients of fluid pressure varied within the limits of 19-22 MPa/km, 90-100 % of the geostatic gradient of pressure, and moderate (14-19 MPa/km) to normal (about 9.9 MPa/km) values. The excess pressures are revealed on the edge of the Hikurangi plate and are explained by lateral tectonic processes of compression. As a rule, these excess pressures are poorly correlated with depth (Darby and Funnell, 2001). Indeed, even at the shallow depth of 600 m the measured pressure is 12.8 MPa, about 90 % of geostatic pressure. These shallow excess pressures are the reason for formation of a series of mud volcanoes in the region (Ridd, 1970) and also for complex diapiric structures (Mazengarb, 1998).

*Temperature* is a key factor that controls the development of overpressures in sediments by increasing the volume of fluids in the pores of impermeable plastic rocks (shales) as a result of a combination of processes. Such is confirmed by the relationship between the temperature gradient and the depth of overpressure development. For example, in the Mahakam Delta Basin of Indonesia, with a temperature gradient of 35 to 40°C/km, a fluidized zone of decompaction has been detected at depths of approximately 2400 m, while on the continental shelf of the Nova Scotia Basin (Venture Field, Canada), where the temperature gradient is less than 25°C/km, pore pressure increases dramatically from a depth of 4500 m (Ward, 1995).

The temperature factor controls the basic processes responsible for overpressures listed below:

- Thermal transformation of organic matter (OM) into hydrocarbons (HC)
- Transformation of smectite into illite, accompanied by the release of interstratal water
- Aquathermal expansion of water

All processes lead to an increase in the volume of pore fluids and the formation of rock decompaction zones in sediments.

The role of hydrocarbon generation in the formation of excess pressures has been considered by many authors (Momper, 1980; Barker, 1990; Forbes *et al.*, 1992; Luo and Vasseur, 1996; Xie *et al.*, 2001; Hansom and Lee, 2005). Based on the results of quantitative estimation and using numerical modeling, the authors listed have shown an essential influence of petroleum generation on the spatial-temporal distribution of abnormal high pressure in sedimentary basins. Including only compaction or compaction with the generation of oil, the maximal size of excess pressure lies between 300 atm and 425 atm. Taking into account the generation $CO_2$ and $CH_4$ modeling has shown a sharper increase in fluid pressure: up to 475 atm and 750 atm, respectively. The different levels of excess pressure at the formation of oil, $CO_2$ and $CH_4$ are explained by the differences in density and, as a consequence, different degrees of volumetric increase as a result of cracking of kerogen and of cracking of oil to gas (Hillier, 1991; Bredehoeft *et al.*, 1994; Spenser C.W., 1994; Sweeney *et al.*, 1995; Burrus *et al.*, 1996; Lee and Williams, 2000; Hansom and Lee, 2005).

Thus, the generation of oil, all other factors being equal, plays a relatively smaller role in the formation of abnormal high pressure in comparison with gas. By current estimation (Meissner, 1978; Price and Clayton, 1992), the volume of gas makes about 150 % change from the volume of related kerogen. According to results of modeling on an example of the Delaware basin, the level of excess pressure during the formation of oil reached 40% of the pressure that is produced by compaction of rocks, but at formation of gas the pressure reached 110% (Hansom and Lee, 2005).

Dependence of the level of excess pressure formed at hydrocarbon generation is related to the type of organic matter (OM) (Xie *et al.*, 2001). There are more favorable conditions for formation of overpressure in thick clayey rocks containing gas-prone OM (types III and III-II of OM).

The generation of gas as the essential factor of formation overpressure is predicted for many basins (Hillier, 1991; Osborne and Swarbrick, 1997; Burrus *et al.*, 1993; Holm, 1998; Francu *et al.*, 2004), assuming that at the late stages of development of a sedimentary basin no other factors prevail (Xie *et al.*, 2001). The excess pressure from generation of gas is usually correlated with depth, where the temperature conditions are appropriate for such development (Swarbrick and Osborne, 1998; Holm, 1998). In deeply situated petroleum reservoirs, owing to cracking of oil to gas, the pore pressure can reach and even exceed geostatic pressure (Chaney, 1950; Barker, 1990; Luo and Vasseur, 1996).

In general, the formation of excess pressure in a sedimentary section is well coordinated with vertical zoning of oil and gas generation (Vassoevich, 1974; Tissot and Welte, 1984).

Thus the depth interval of oil and gas generation (and accordingly formation of zones of overpressures) depends on the rate of sedimentation: the depth range is shallow in old basins with low rates of sedimentation (and accordingly with relatively high temperature gradients) and is considerably deeper in young basins with high rates of sedimentation (with relatively low temperature gradients). So, for example, in the Dongying depression, located in the Bohaiwan basin (China), where the average geothermal gradient is high at about 3.6°C /100 m (Zhou, 1981), the mature zone for OM is predicted to be at depths of about depth 2200-3000 m, and overmature OM is expected to occur in an interval of 3000-3800 m. In complete conformity with this estimation, excess pressure with gradients of 13-14 MPa/km already occurs here from a depth 2200 m, increasing up to 16 MPa/km below 3000 m (Xie *et al*., 2001).

In SCB with a geotemperature gradient < 2.0°C/100 m, the zone of oil and gas generation and abnormal high pressure occur at great depths, as will be shown below.

According to modern concepts, the process of transformation of smectite (montmorillonite) to illite (hydromica), accompanied by a discharge of water, is caused by kinetic reactions that are temperature and time dependent.

The complete dehydration of smectite produce 25 - 35 % of water from its initial volume (Kholodov, 2001), provides for the occurrence of excess pressures (Fergusson, 1985.).

A threshold temperature, which is necessary for the onset of dehydration of smectite, depends on the geological conditions of each basin and can change within the limits of 75-150°C (Bruce, 1984). So, for the Mississippi river basin this temperature is about 71°C, for the Niger River delta it is about 140°C (Bruce, 1984).

According to Pauers and Berst (see Fertl, 1976) the critical temperature for the onset of the diagenetic transformation of smectite to illite varies within the limits of 86-110°C. The process of dehydration of clays depends on the type of smectite (K or Na smectites react faster than Ca or Mg smectites).

Thermal expansion of water (aquathermal expansion), which practically everywhere saturates the pore space of rocks, as one of the mechanisms of formation of excess pressure in sedimentary basins and was stated originally by Barker (1972) and later was investigated by others (Daines, 1982; Swarbrick and Osborne, 1998).

A modern prevalent opinion is that aquathermal expansion (as well as dehydration of clays in sedimentary basins) provides insignificant values of excess geofluid pressures compared with other mechanisms (Daines, 1982; Bethke, 1986; Shi and Wang, 1986; Osborne and Swarbrick, 1997). For instance, according to estimations of Daines (1982), the relative volume of water during rise of temperature from 54.4°C up to 93.3°C increases only by 1.65%. This statement is supported by experimental data too. So in heating water from 1-10°C up to 90-100°C at constant pressure the volume increase due to thermal expansion is approximately 2%. In a closed system this expansion can result in increase of pressure. Tests on heated water in closed vessels from 15°C up to 85°C have resulted in an increase of pressure (due to thermal expansion of water) to 2.5 atm, and on heating up to 110° C - to 3.5-4.5 atm. These values are insignificant.

The above short state-of-the-art review of an extensive literature has formed the basis for development of the classification scheme reflecting all basic mechanisms of overpressures formation (Fig. 2).

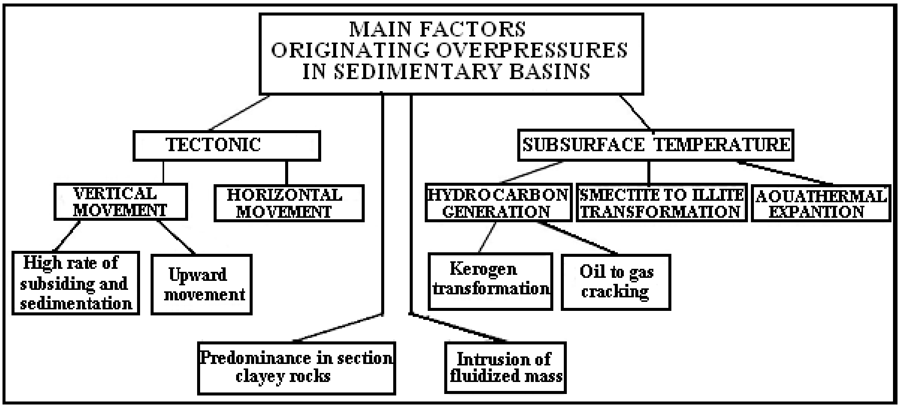

Figure 2. Classification scheme of main factors and conditions of overpressure formation in sedimentary basins.

## 2.2. Overpressure in the South Caspian Basin: Formation Conditions and Distribution Patterns

The SCB is one of the striking examples where peculiarities in a basin's history and up-to-date geologic structures have provided quite favorable conditions for overpressure. In the Pliocene-Quaternary there was rapid sedimentation (up to 3 km/million years) and the formation of a thick (up to 25 km) sedimentary cover in which plastic terrigenous rocks predominate. Shales account for 80 to 90% of the rocks in the SCB Cenozoic sequence, and the SCB is characterized by an abnormally low temperature gradient, which varies from 15 to 18°C/km in the central-most downwarped part of the basin. As a result, pore pressures are 1.5 to 2 times greater than hydrostatic pressure. For example, at the Zafar-Mashal structure in the deepwater part of the SCB, measured pore pressure at a depth of 6475 m was 132 MPa, which is more than twice the hydrostatic pressure and is equal to approximately 90% of lithostatic pressure. Consequently, the SCB structures are, as a rule, piercement types and mud volcanism is widely developed.

The mechanisms of overpressure formation in the SCB still have not been adequately studied and remain a topic of debate. The most important studies of this subject were conducted in the 1970s to early 1990s (Yusufzade *et al.*, 1976; Khalilov and Imanov, 1979; 1980; Buryakovsky *et al.*, 1982; 1986; 1995).

An analysis of reservoir pressures and pressure gradient data for the SCB made it possible to determine their uneven geographical distribution with more pronounced values in the west and southwest, consistent with the variations of rock shaliness and shale sequence thicknesses in this direction (Buryakovsky *et al.*, 1986) (Fig. 3, Table1).

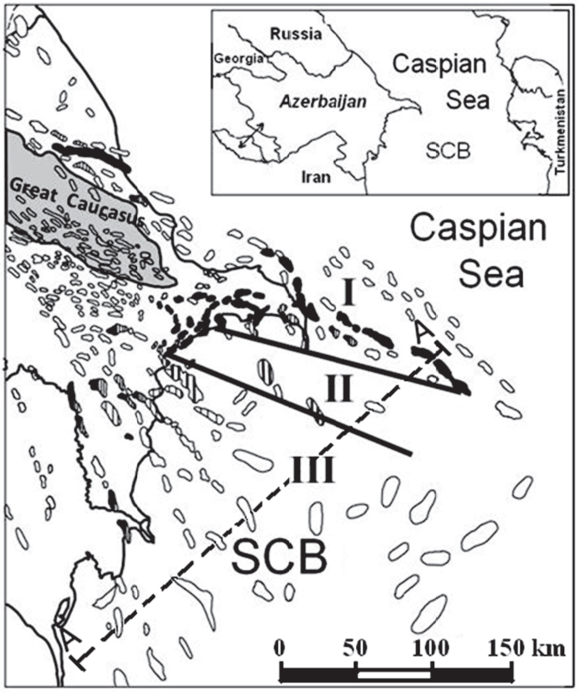

Figure 3. Formation pressure distribution zones in the SCB:
I-Absheron Peninsula and Absheron Archipelago; II - South Absheron Water Area; III - Baku Archipelago and location of regional profile A-A (Buryakovsky *et al*., 1986).

**Table 1. SCB. Spatial variations of shale sequence thicknesses and pressure gradients.**

| Zones | Average shale sequence thicknesses at different depth intervals, km | | | | Average pressure gradients, MPa/km |
|---|---|---|---|---|---|
| | 1-2 | 2-3 | 3-4 | 4-5 | |
| I–Absheron Peninsula and Absheron Archipelago | 50 | 40 | 30 | 20 | 13.5 |
| II– South Absheron Water Area | 750 | 235 | 185 | 150 | 16.3 |
| III–Baku Archipelago | 900 | 725 | 460 | 350 | 18.0 |

As shown in Figure 3, the highest fluid pressures are observed in the Baku Archipelago (Zone III), where average pressure gradients are 18 MPa/km (see Table 1). Such is a reflection of rock compaction processes. In the Baku Archipelago overpressures retard rock compaction, as is evident from the variation of rock porosity with depth in the Baku Archipelago compared to the Absheron Archipelago, with its relatively moderate fluid pressures (average pressure gradient of approximately 13.5 MPa/km) (Fig. 4).

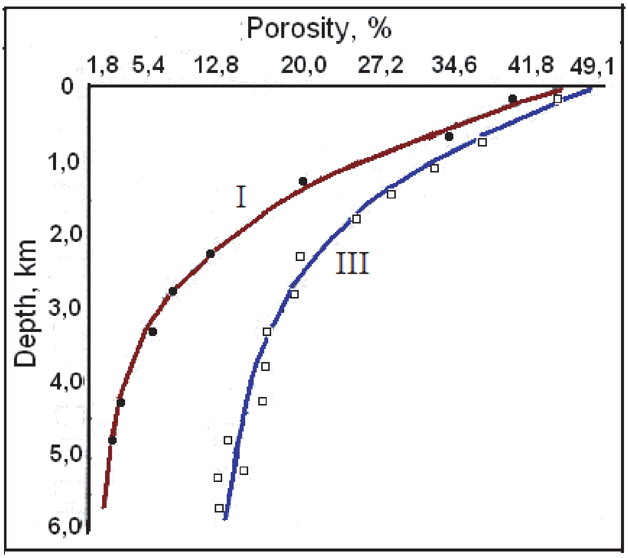

Figure 4. Porosity vs. depth for Absheron and Baku Archipelagoes (Zones I and III on Fig. 3)

A study of the variation of shale pore pressure gradients with depth based on well logs and mud weights, using the Bulla-Deniz field as an example, revealed that, regardless of well locations on the structure, the upper boundary of overpressure is situated in the 600 to 1230 m depth range. Stratigraphically, this depth range includes the lower Pleistocene (Caspian sediments and Absheron suite), the Upper Pliocene (Akchagyl suite) and, in several wells, the top of the Lower Pliocene - Productive Series (PS) (Yusufzade *et al.*, 1976; Khalilov and Imanov, 1980) (Fig. 5). In this range pore pressure gradients are as high as 23 MPa/km.

The second abrupt change along the well column in the SCB is observed at depths below 5 km (Khalilov and Imanov, 1979; 1980; Buryakovsky *et al.*, 1982) (Fig. 6). This zone is the most distinctive and is where overpressures become comparable to geostatic pressure.

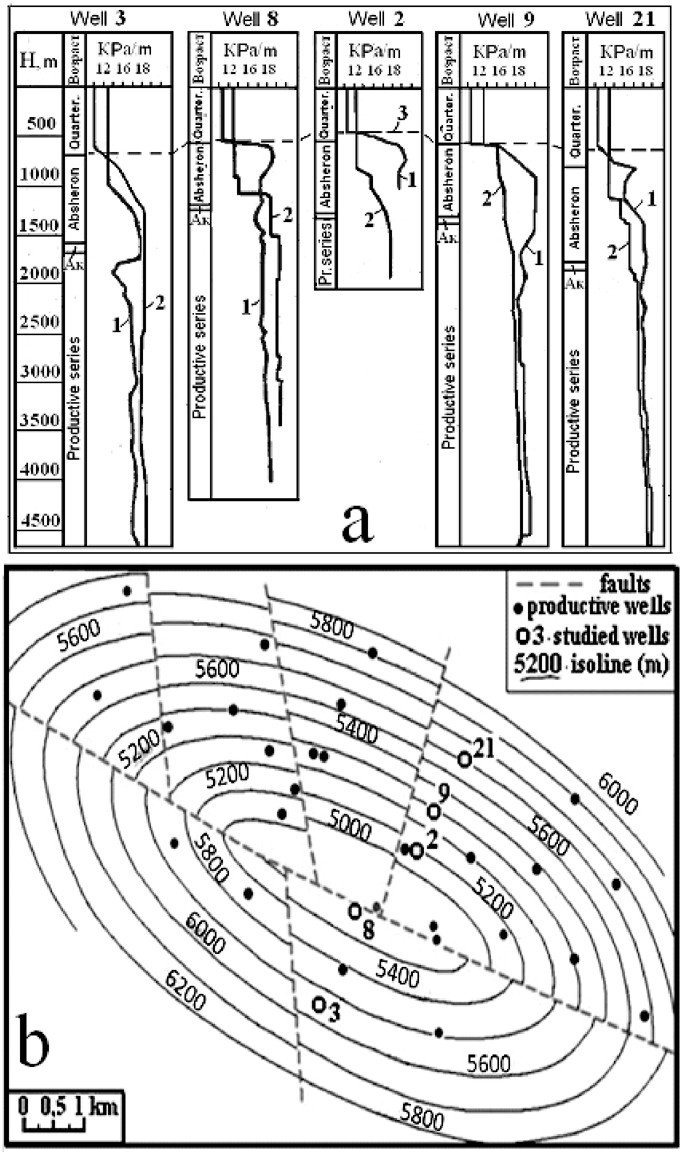

Figure 5. a) Change of pressure gradients along a section:1-calculated; 2- measured (at specific gravity of drilling mud); 3- upper boundary of overpressure (Yusufzade *et al*., 1976);
(b) Structural map at the VII horizon of the Productive Series (Lower Pliocene) and location of the studied wells on the Bulla-deniz field, SCB.

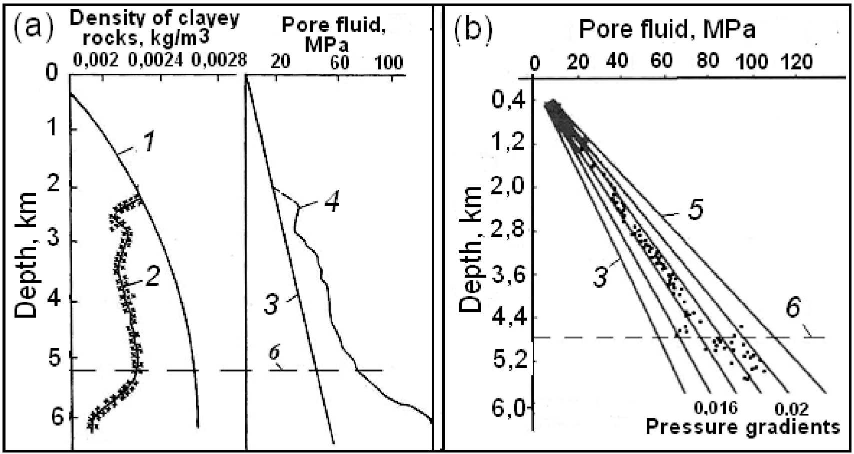

Figure 6. SCB. Shale density and pore pressure vs. depth at the Bulla-Deniz Field. (a) and the Bakhar field (b): 1 and 2 - normal and actual compaction curves; 3, 4 and 5 - hydrostatic, actual and geostatic pressures curves; 6 - upper threshold of overpressure, caused by the start of hydrocarbons generation.

## 3. DISCUSSION

A summary of the results of all earlier studies of the patterns of distribution of fluid pressure in the SCB, on the basis of well logs and actual downhole measurements to a depth of 7 km, has made it possible to identify two major overpressure zones in this interval, which are most distinctive in the Baku Archipelago. Depending on the lithofacies of the section, the top of the first overpressure zone is located in the 600 to 1200 m interval. Below that marker, and reaching to a depth of approximately 4 km, the pressure gradients are quite stable, even though still high. A new, more pronounced, overpressure zone starts at a depth of approximately 5 km. Equally one cannot exclude the possibility of shallow abnormal pressure caused by formation of biochemical gases, together with their accumulation in sandy lenses bounded from all sides by plastic impenetrable rocks. Commercial reserves of such gas have been encountered at the Bulgarian Coast of the Black Sea, in the valley of the Po River (Italy) and in Japan.

Khalilov and Imanov (1979) have noted, "The sections of these intervals primarily consist of shales with interlayers of sandstone-siltstone rocks, in which drillers have been troubled by water and gas manifestations, lost circulation, cave-ins, and sloughing." There have been cases where permanent offshore platforms in the SCB have collapsed because of the presence of such gas pockets. In addition, near the Caspian coast (the Neftchala area), crews digging an irrigation canal at a depth of 6 m encountered natural gas with a distinct methane-carbon biochemical isotope marker ($^{13}$C -81.5-82.3‰).

High gas saturation zones in Pleistocene deposits have been observed in the SCB on the basis of mud logging data (Fig. 7).

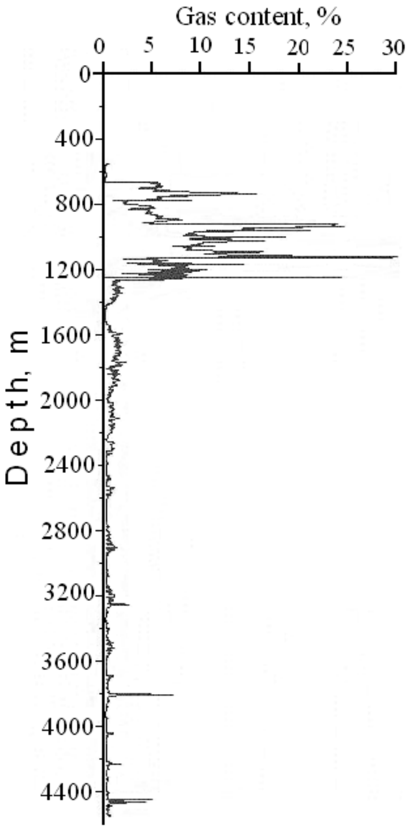

Figure 7. Mud logging at Shakh-Deniz field with abnormal hydrocarbon gas content in Pleistocene deposits.

The first uppermost overpressure zone can most likely be attributed to non-equilibrium compaction (undercompaction) of the rock because of high sedimentation rates. This zone is easy to predict and usually causes no problems in drilling.

The lower overpressure zone poses the greatest risk, because its intensity is difficult to predict, making it challenging to choose the right mud weight in drilling this part of the section. At great depths (that have still not been drilled) the extent of this zone is unclear. This overpressure zone may be most likely attributed to the onset of hydrocarbons generation as has been confirmed by the results of analyses of vitrinite reflectivity vs. depth and its equivalents calculated on the basis of petroleum biological markers and the isotope composition of the methane and ethane carbon of fields and mud volcanoes in the SCB (Feyzullayev and Tagiyev, 2008). According to these data, oil generation also begins at a depth of approximately 5 km (Fig. 8).

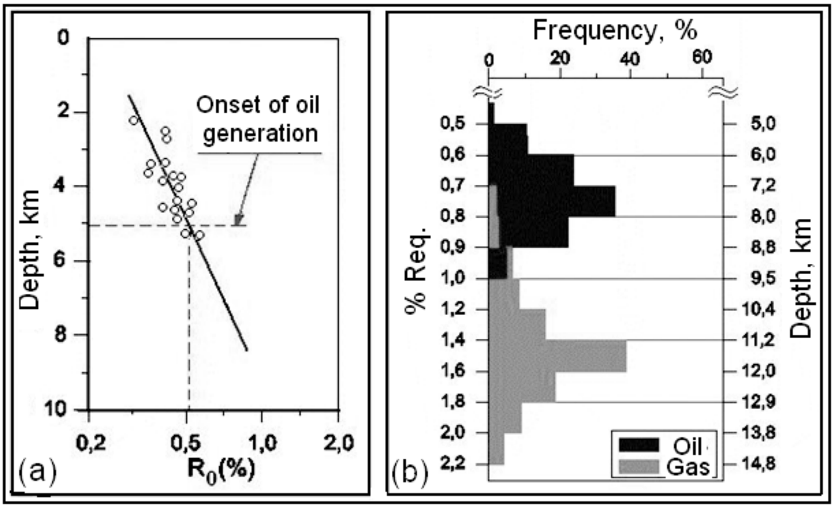

Figure 8. The predicted onset of oil generation based on (a) vitrinite reflectivity vs. depth curve and (b) estimated oil and gas generation depths calculated on the basis of their maturity

Figure 8 indicates that the highest pressure gradients and higher drilling risks should be associated with depths below 9 km, where intensive gas formation begins as is also confirmed by forecasts based on 2D basin modeling of the SCB (Fig. 9).

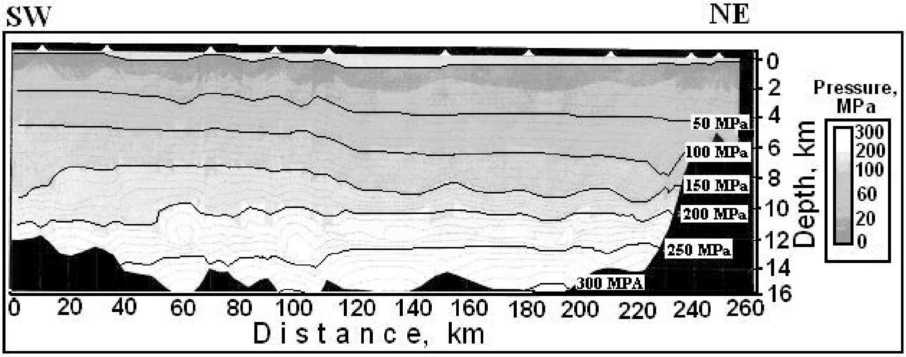

Figure 9. Distribution of geofluid pressures in the deepwater part of the SCB according to 2D modeling data (see location of profile on Fig. 3).

As has been noted above, gas generation has been predicted as a significant factor for overpressures in a large number of other basins under the assumption that such is the predominant factor in the latter stages of development of a basin.

The Baku Archipelago is characterized by the greatest overpressure. Essentially one has a relatively closed system where the escape of generated hydrocarbon fluids is hindered by the large thickness of the organic matter-rich shale strata.

Physical chemistry informs that preventing reaction products from escaping a system leads to a decline in the reaction rates. From this standpoint, on the one hand, the progressive rise in temperatures caused by downwarping of the basin and thermal decomposition of organic matter result in a steady increase in the volume of hydrocarbons generated in massive shale sequences, while on the other hand the low migration capability delays the process of organic matter decomposition. This slowing of the oil and gas generation processes was identified on the basis of a comparative analysis of processes in three different basins (Helgeson, 1985; Hao *et al.*, 2007). It was found that the maturity of organic matter in wells located close to one another with similar thermal histories in overpressure zones was much lower than in intervals with normal pressures (Hao *et al.*, 2007). The cessation of the shale dehydration process (constancy of smectite content) was also observed at depths interval with abnormal high pressures (Dódony and Lovas, 2003).

The rates of thermochemical and organic matter transformation reactions can undergo another dramatic rise if any factor (tectonic, thermal and chemical convection, the gravitational ascent of a fluidized unstable shale mass, etc.) results in the removal of the resultant products from the system (such as during a mud volcano eruption). Consequently, primary hydrocarbons migration is sporadic in nature, which may also be facilitated by shallow earthquakes in a basin.

With respect of other potential factors in the formation of overpressure in the SCB the following observations are pertinent.

Over most of the SCB, the shales consist of smectite at about 40-50% and sometimes more (Buryakovsky *et al.*, 1986; Kerimov *et al.*, 2001). At the same time the SCB is a basin with abnormally low transient-temperature conditions. For example, the temperature gradient in the Baku Archipelago, which is characterized by the most extensive development of overpressure, varies from 15 to 18° C per km. As indicated above, the temperature required for the transformation of smectite into illite is in the 75 to 150°C range (on average approximately 110°C). Most probably therefore, shale dehydration in the SCB should be expected at depths greater than 7 km. In reality, the results of a study of the shale mineralogy vs. depth reveal that, despite the variations, averages do not change significantly to at least a depth of 6200 m (Buryakovsky *et al.*, 1986; Kheirov, 1979) (Fig. 10).

According to Buryakovsky *et al.* (1986), the maximum depths of montmorillonite distribution in the SCB are 15 to 17 km. The preservation of smectite in the SCB at great depths has been confirmed by studies of mud volcano ejecta.

Thus, the effect of this factor on overpressure in the SCB can be expected at great depths. However, it is most likely that the role of this factor will be overshadowed by overpressure initiated by hydrocarbon gas generation.

The excess pressure generated by the thermal expansion of water is considerably lower than other factors, especially in the SCB with its abnormally low temperatures.

The recent structure of the SCB, which is located within the mobile Alpine-Himalayan tectonic belt, is controlled by the ongoing collision of the Arabian and

Russian Plates (Philip *et al.*, 1989; Axen *et al.*, 2001; Jackson *et al.*, 2002). Consequently, there are all the preconditions for the generation of overpressure by lateral tectonic stresses. Such has been confirmed by the results of GPS modeling conducted in the SCB (Guliyev *et al.*, 2002), which indicated that there has been a decline in the rate of horizontal movements to the NW from 12-14 mm/yr (in the area of the Talysh Mountains) to 0-2 mm/yr in the foothills of the southeast end of the Greater Caucasus, where mud volcanoes and diapirism are quite common. Nevertheless, the role of horizontal stress in the generation of overpressure in the SCB still needs to be studied in detail.

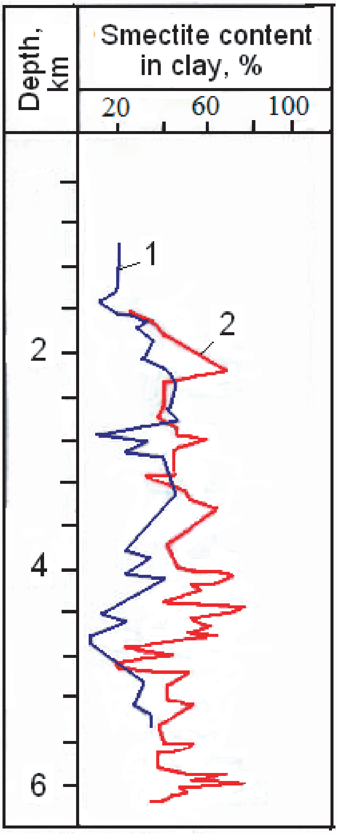

Figure 10. Percentage of smectite in shales vs. depth:1-Absheron Archipelago; 2-Baku Archipelago (Kheirov, 1979).

The growth of diapirs generated by overpressure, which are quite common in the SCB, is continuing at the present time and can be observed on the surface (the Cheildag diapir, Azerbaijan). Such may be also a contributory cause of the overpressure relative to the pressures in the overlying deposits into which the diapirs are squeezed.

Another possible reason for overpressure is the predominance of several anticlinal uplifts of the outer margins of the South Caspian Depression (Kyanizadag, Sangachal-deniz, Khamamdag-deniz, Absheron kyupasi, Khazri) in the anthropogenic phase of tectogenesis, as evidenced by the total lack of Quaternary and Upper Pliocene deposits on the crests of these structures and partial erosion of the Lower Pliocene. However, considering the deep erosion of these structures (300 to 900 m) and the lack of a regional fluid seal (the Akchagyl suite) it is doubtful that this factor is important (at least in the upper interval of the sedimentary section).

Thus, each of the aforementioned processes results in excess pore pressure in shales, which is also reflected in reservoir pressures. Consequently, commercial hydrocarbon accumulations are often associated with overpressure (Kan *et al.*, 1999).

Extreme overpressure (anomaly factor up to 2.0 or greater) in the sedimentary section is best explained by processes controlled by temperatures (the generation of oil and gas in particular, the transformation of smectite into illite) accompanied by the formation of zones of rock decompaction.

## 4. CONCLUSIONS

Overpressure zones identified in the SCB are caused by disequilibrium rock compaction (undercompaction of rocks; upper overpressure zone) and hydrocarbon generation (decompaction of rocks; lower overpressure zone). The lower overpressure zone is the most intense, and the degree of overpressure depends on the thickness of the shale sequence, the concentration of organic matter in shale, the type of organic matter, and the temperature conditions of OM transformation to hydrocarbons. In this zone the greatest risk may be associated with the start of gas generation at depths greater than 9 km, due to both more intense thermal breakdown of kerogen and the cracking of liquid hydrocarbons generated earlier.

An analysis of extensive published material has shown that the overwhelming majority of the studies of this topic have been designed to find ways of reducing the technical and economic risks of drilling exploration wells. However, the study of this topic is not just of great practical interest but is a topic of basic interest, because overpressure is a major cause of diapirism and mud volcanism. The mechanism of this process has not been studied adequately, but attempts to create a model of mud volcano formation have already been made (Feyzullayev *et al.*, 2005; Arafin, 2005).

Objective knowledge of the nature of overpressures can contribute to a better understanding of the processes of the formation of hydrocarbon accumulations, because overpressure is one of the main driving forces of hydrocarbon migration. In this respect, the conclusion that overpressure may contribute to the slowing down of organic matter maturation, the generation of hydrocarbons, and the thermal decomposition of liquid hydrocarbons is of great fundamental interest.

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