

On the Study of Abnormally High Formation Pressures and Their Role in Oil and Gas Field Development

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Abstract. Formation pressure is a key geological and reservoir parameter in well planning and hydrocarbon-field development. This study examines abnormally high formation pressure (AHFP) in the Bulla-Deniz gas-condensate field of the Baku Archipelago. Geological, pressure, temperature, well-depth, productive-interval, and production data for Horizons V, VII, and VIII of the Balakhani Suite were evaluated. Measured and calculated pressure values were compared with normal hydrostatic pressure, and the abnormality coefficient was used to identify high-pressure intervals. The productive horizons occur at depths of approximately 4,645–6,145 m and exhibit pressure values above normal hydrostatic conditions. Formation pressures of approximately 48.5 MPa in Horizon V, 70–72 MPa in Horizon VII, and 80 MPa in Horizon VIII demonstrate the persistence of AHFP with increasing depth. The findings indicate that deep burial, tectonic activity, hydrocarbon generation, elevated temperature, restricted fluid migration, and effective sealing formations may jointly control the pressure regime. Although high reservoir energy may support initial production, AHFP also increases drilling, completion, well-control, and development risks. Accurate pressure prediction and continuous monitoring are therefore essential for the safe and economically efficient development of the Bulla-Deniz field.

Keywords: abnormally high formation pressure, Bulla-Deniz field, productive horizon, reservoir pressure, hydrocarbon accumulation, abnormality coefficient

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Anomal yüksək lay təzyiqlərinin tədqiqi və onların neft-qaz yataqlarının işlənməsində rolu

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Xülasə. Lay təzyiqi quyuların planlaşdırılmasında və karbohidrogen yataqlarının işlənməsində mühüm geoloji və kollektor parametridir. Bu tədqiqatda Bakı arxipelaqında yerləşən Bulla-dəniz qaz-kondensat yatağındakı anomal yüksək lay təzyiqi (AYLT) araşdırılır. Balaxanı lay dəstəsinin V, VII və VIII horizontları üzrə geoloji məlumatlar, təzyiq və temperatur göstəriciləri, quyu dərinlikləri, məhsuldar intervallar və hasilat məlumatları qiymətləndirilmişdir. Yüksək təzyiqli intervalları müəyyən etmək üçün ölçülmüş və hesablanmış təzyiq göstəriciləri normal hidrostatik təzyiqlə müqayisə edilmiş, anomallıq əmsalından istifadə olunmuşdur. Təxminən 4 645–6 145 m dərinlikdə yerləşən məhsuldar horizontlarda təzyiq normal hidrostatik göstəricilərdən yüksəkdir.

V horizontda təxminən 48,5 MPa, VII horizontda 70–72 MPa, VIII horizontda isə 80 MPa lay təzyiqinin qeydə alınması dərinlik artdıqca AYLТ-nin davam etdiyini göstərir. Nəticələrə əsasən, böyük dərinlik, tektonik fəallıq, karbohidrogenlərin əmələ gəlməsi, yüksək temperatur, flüidlərin miqrasiyasının məhdudlaşması və etibarlı örtük süxurları təzyiq rejiminə birgə təsir göstərə bilər. Yüksək lay enerjisi ilkin hasilata müsbət təsir etsə də, AYLТ qazma, quyunun tamamlanması, quyuya nəzarət və yatağın işlənməsi ilə bağlı riskləri artırır. Buna görə də Bulla-dəniz yatağının təhlükəsiz və iqtisadi cəhətdən səmərəli işlənməsi üçün təzyiqin dəqiq proqnozlaşdırılması və davamlı monitorinqi vacibdir.

Açar sözlər: *anomal yüksək lay təzyiqi, Bulla-dəniz yatağı, məhsuldar horizont, kollektor təzyiqi, karbohidrogen yığılı, anomallıq əmsali*

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Introduction

Formation pressure is one of the principal subsurface parameters used in evaluating hydrocarbon reservoirs and planning oil and gas wells. Accurate pressure determination is particularly important in fields characterized by complex stratigraphy, considerable burial depth, active tectonic processes, and variable reservoir properties. Pressure data influence drilling-fluid density, casing design, well-control measures, production strategy, and reserve estimation (Zhdanov, n.d.; Ovchinnikov, 2017). Inaccurate assessment may result in drilling complications, uncontrolled fluid influx, formation damage, and unreliable estimates of hydrocarbon reserves.

Formation pressure is considered abnormally high when it substantially exceeds the normal hydrostatic pressure expected at a given depth. AHFP may develop through rapid sedimentation, compaction disequilibrium, hydrocarbon generation, thermal expansion, tectonic compression, clay-mineral transformation, osmosis, and restricted fluid migration (Aleksandrov, 1987; Belonin et al., 2005; Grausman, 1999). Its preservation is commonly associated with low-permeability seals that prevent pressure dissipation.

The South Caspian Basin is characterized by thick sedimentary successions, intensive tectonic activity, mud volcanism, and deeply buried hydrocarbon-bearing formations. These conditions favour the generation and preservation of AHFP (Ali-Zade et al., 1972; Guliyev et al., 2014; Kerimov et al., 2001; Kocharli, 2015; Yusifov & Aslanov, 2018). The Bulla-Deniz field is therefore an appropriate case for examining the influence of abnormal pressure on drilling, reservoir evaluation, and hydrocarbon production.

AHFP is generally regarded as a polygenic phenomenon because several geological and physicochemical mechanisms may operate together. Hydrocarbon generation increases fluid volume within confined pore space; thermal processes promote fluid expansion and organic-matter transformation; tectonic compression reduces pore volume; and vertical migration can introduce deeply generated fluids into sealed reservoirs (Aleksandrov, 1987; Belonin et al., 2005). The dominant mechanism depends on depth, lithology, temperature, tectonic setting, permeability, sealing capacity, and migration pathways.

The objective of this study is to examine the occurrence and vertical distribution of AHFP in the Bulla-Deniz field, identify the principal geological factors controlling it, and evaluate its implications for the development of oil and gas accumulations.

Materials and Methods

The study used geological, pressure, temperature, and production data from the Bulla-Deniz field. The analysed materials included well depths, productive intervals, hydrocarbon and water production rates, direct pressure measurements, calculated pressure values, and information on Horizons V, VII, and VIII of the Balakhani Suite. Field-specific values were obtained from the archival materials of SOCAR's Oil and Gas Research and Design Institute (SOCAR Oil and Gas Research and Design Institute, n.d.).

Where direct downhole measurements were available, recorded pressure values were corrected to the depth of the productive interval. Where direct measurement was restricted by high pressure and temperature, formation pressure was estimated from wellhead-pressure stabilization, available well data, and laboratory analyses of reservoir-fluid samples. These procedures are consistent with established approaches to deep, high-pressure well evaluation (Ovchinnikov, 2017).

Normal hydrostatic pressure was calculated as follows:

$$P_h = \rho g H$$

where P_h is hydrostatic pressure, ρ is formation-water density, g is gravitational acceleration (approximately 9.81 m/s^2), and H is formation depth. A water density of approximately $1,000 \text{ kg/m}^3$ was used for the general calculation.

The pressure-gradient form of the calculation was expressed as:

$$P_h = G_p H$$

where G_p is the pressure gradient and H is formation depth. The normal hydrostatic gradient is approximately 0.01 MPa/m , whereas values of approximately $0.015\text{-}0.025 \text{ MPa/m}$ may occur under AHFP conditions (Aleksandrov, 1987; Belonin et al., 2005).

The abnormality coefficient was calculated as:

$$K_a = P_f / P_h$$

where K_a is the abnormality coefficient, P_f is measured or calculated formation pressure, and P_h is normal hydrostatic pressure. Values of 1.3 or greater were classified as abnormally high. Pressure behaviour was compared across productive horizons and wells in relation to depth, production history, and hydrocarbon withdrawal. Reservoir permeability and pressure were treated as related but distinct properties (Gurbanov et al., 2022).



General overview map of the Bulla-Deniz area in the Azerbaijani sector of the Caspian Sea

The Bulla-Deniz field, located within the Baku Archipelago of the South Caspian Basin, was discovered in 1975. Productive Horizons V, VII, and VIII of the Balakhani Suite occur at depths of approximately 4,645-6,145 m. Pressure values above normal hydrostatic conditions were identified in all three horizons, demonstrating that AHFP is a field-wide characteristic rather than an isolated occurrence (SOCAR Oil and Gas Research and Design Institute, n.d.).

Horizon V was brought into production through Well No. 14 on 19 January 1975. Its perforated interval was 4,573-4,601 m. Initial production was approximately 300 thousand m³ of gas and 56.6 t of condensate. Formation pressure measured at 3,100 m was 43.1 MPa; after correction to the productive interval, it was 48.5 MPa, approximately 2.63 MPa above hydrostatic pressure. Well No. 9 penetrated Horizon V at 4,811-4,842 m and produced approximately 200 thousand m³ of gas, 168 t

of condensate and oil, and 53 m³ of water. After approximately 18 months, average formation pressure was 48.9 MPa, indicating depletion following hydrocarbon withdrawal (SOCAR Oil and Gas Research and Design Institute, n.d.; Zhdanov, n.d.).

Pressure determination in Horizon VII was more difficult because values reached approximately 70–72 MPa. Formation pressure was therefore calculated using available well data rather than direct downhole measurement alone. Laboratory fluid analysis under high-pressure and high-temperature conditions provided supplementary information, but condensation pressure was not treated as an exact substitute for formation pressure.

Horizon VIII was brought into production through Well No. 56 in the northwestern part of the pericline. The reported production comprised 1,100 m³ of gas and 550 t of condensate. Formation pressure measured several months after production began was approximately 80 MPa and was treated as an approximation of initial pressure (SOCAR Oil and Gas Research and Design Institute, n.d.).

The abnormality coefficient frequently exceeded 1.5 in the deepest productive intervals. Formation pressure generally increased with depth, and its persistence indicates effective sealing and hydraulically isolated reservoir compartments. Deep burial, tectonic compression, mud volcanism, hydrocarbon generation, and restricted fluid migration are consistent with the regional geological setting (Ali-Zade et al., 1972; Guliyev et al., 2014; Kerimov et al., 2001).

Discussion

The occurrence of AHFP in Horizons V, VII, and VIII supports a polygenic interpretation of abnormal pressure in Bulla-Deniz. Deep burial favours elevated temperature, hydrocarbon generation, and fluid expansion, while tectonic compression and low-permeability seals restrict fluid escape. These findings are consistent with established explanations of AHFP development in petroleum basins (Aleksandrov, 1987; Belonin et al., 2005; Grausman, 1999).

High reservoir energy may support hydrocarbon movement and strong initial production; however, AHFP does not automatically increase the intrinsic permeability of reservoir rock. Pressure may improve fluid mobility or activate existing fractures under particular conditions, whereas permeability remains a separate petrophysical property (Gurbanov et al., 2022).

Pressure depletion after production begins explains why current pressure may be lower than initial pressure and why late measurements may underestimate original reservoir energy and reserves (Zhdanov, n.d.). Mathematical modeling of oil-production trends can also support the interpretation of field performance and facilitate more informed resource-management decisions (Humbataliyev et al., 2025). High-pressure and high-temperature conditions complicate drilling, well completion, equipment selection, monitoring, and well control, particularly in deep and operationally challenging wells (Humbatova, 2025).

The presence of separate high-pressure intervals suggests reservoir compartmentalization and limited hydraulic communication. When multiple pressure regimes occur in one well, additional casing strings, carefully selected drilling-fluid density, specialized well-control equipment, and continuous monitoring may be required. These measures increase development costs but reduce the likelihood of kicks, blowouts, formation damage, and inaccurate reserve estimates.

Conclusion

The study confirms AHFP in Horizons V, VII, and VIII of the Bulla-Deniz field at depths greater than approximately 4,000 m. The increase in pressure with depth and abnormality coefficients frequently exceeding 1.5 demonstrate the persistence of a high-pressure regime across several productive intervals.

The pressure system is most plausibly associated with the combined effects of deep burial, elevated temperature, hydrocarbon generation, tectonic compression, vertical fluid migration, and effective low-permeability seals. The findings therefore support a polygenic origin of AHFP in the field. Elevated pressure preserves substantial reservoir energy and may support initial productivity, but it also increases drilling, completion, well-control, and economic risks. Each productive horizon should therefore be evaluated individually, and pressure prediction should be updated throughout field development.

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