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Original article

Detailed geological and tectonic study of the Khara-Zira structure and surrounding territories of South Caspian Basin based on seismic-velocity models

E.Y. Abbasov^{1,2}, A.B. Hasanov^{2,3}, G.O. Veliyev⁴, Z.C. Axundov¹

¹ The State Oil Company of the Republic of Azerbaijan (SOCAR),
121 G. Aliev Ave., Baku AZ 1010, Azerbaijan, e-mail: zaur.axundov@socar.az;

² Azerbaijan State Oil and Industry University, 20 Azadlig Ave., Baku AZ 1029, Azerbaijan,
e-mail: elmaddin.y.abbasov@socar.az, abbasovmeddin530@gmail.com;

³ Oil and Gas Institute, Ministry of Science and Education of the Republic of Azerbaijan,
9 F. Amirov Str., Baku AZ 1000, Azerbaijan,
e-mail: adalathasanov@yahoo.com;

⁴ Baku State University, 33 Z. Khalilov Str., Baku AZ 1148, Azerbaijan,
e-mail: humbat2007@mail.ru

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Abstract: A comprehensive analysis of the seismic conditions, tectonic structure, and hydrocarbon potential of the Khara-Zira, Sangachal-Deniz, and Duvanny-Deniz structural zones in the southwestern sector of the Caspian Sea remains a significant geological challenge. This assessment, based on modern geophysical data, is essential for improving the understanding of the region's structural framework and resource potential. **The aim** of the study was to investigate the geodynamic characteristics, morphological structure of sedimentary complexes, and the hydrocarbon potential of above named structural zones. **Research methods** included analyzing new data obtained using seismic logging, vertical seismic profiling (SL-VSP), and the common depth point (CDP) methods. Mapping of the main structures – Khara-Zira, Duvanny-Deniz, and Sangachal-Deniz – based on 2D seismic data and numerous seismic profiles covering the study area. Tectonic deformations and fault systems complicating these structures were also analyzed, taking into account the location, trajectory, and amplitude of longitudinal and transverse faults. These data allowed us to assess the influence of tectonics on the geodynamic evolution of the region. **Results.** Based on seismic velocity parameters, averaged vertical traveltimes curves (hodographs) were constructed, which were used as a reliable basis for converting dynamic time dependency into depth sections. Furthermore, the morphological features of the Productive Suits and deeper sedimentary complexes were refined, including the contours of synclinal and periclinal zones, strike zones of tectonic faults, and the geological characteristics of structural elements. It was shown that a reliable interpretation of the structural-tectonic setting and velocity models provides a trustable basis for hydrocarbon exploration in these areas. Summarizing the obtained results, the final conclusion is that the hydrocarbon potential of the productive series and deeper layers is estimated to be considerable.

Keywords: seismic logging, vertical hodograph, seismic velocity model, fault.

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Оригинальная статья

Детальное геолого-тектоническое исследование и оценка структуры Хара-Зира и прилегающих территорий Южного Каспийского бассейна на основе сейсмо-скоростных моделей

Е.Ю. Аббасов^{1,2}, А.Б. Гасанов^{2,3}, Г.О. Велиев⁴, З.Д. Ахундов¹

¹ Государственная нефтяная компания Азербайджанской Республики (SOCAR), Республика Азербайджан, AZ 1010, г. Баку, пр. Г. Алиева, 121, e-mail: zaur.axundov@socar.az;

² Азербайджанский государственный университет нефти и промышленности, Республика Азербайджан, AZ 1010, г. Баку, пр. Азадлыг, 20, e-mail: elmaddin.y.abbasov@socar.az, abbasovmeddin530@gmail.com;

³ Институт нефти и газа Министерства науки и образования Азербайджанской Республики, Республика Азербайджан, AZ 1000, г. Баку, ул. Ф. Амирова, 9, e-mail: adalathasanov@yahoo.com;

⁴ Бакинский государственный университет, Республика Азербайджан, AZ 1148, г. Баку, ул. З. Халилова, 33, e-mail: humbat2007@mail.ru

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Резюме: Комплексный анализ сейсмогеологических условий, тектонического строения и перспектив углеводородосодержания структурных зон Хара-Зира, Сангачалы-море и Дуванны-море, расположенных в юго-западном секторе Каспийского моря, проведенный на основе современных геофизических данных, остается одной из **актуальных** геологических задач. **Цель исследования** – изучение геодинамических характеристик, морфологической структуры осадочных комплексов и углеводородного потенциала рассматриваемых структурных зон. **Методы исследования.** Проанализированы новые данные, полученные с помощью сейсмокаротажа, вертикального сейсмического профилирования (SL–VSP) и метода общей глубинной точки (МОГТ). В основу картирования главных структур: Хара-Зира, Дуванны-море и Сангачалы-море были положены 2D сейсмические данные и многочисленные сейсмические профили, охватывающие исследуемую территорию. Также были проанализированы тектонические деформации и системы разломов, осложняющие эти структуры, с учетом местоположения, траектории и амплитуды продольных и поперечных тектонических разломов. Эти данные позволили оценить влияние тектоники на геодинамическую эволюцию района. **Результаты.** На основе параметров сейсмической скорости, были построены усредненные вертикальные годографы, которые использовались в качестве надежной основы для преобразования динамических временных разрезов в глубинные разрезы. Кроме того, были уточнены морфологические особенности Продуктивной Толщи и более глубоких осадочных комплексов, включая контуры синклиналий и периклиналий зон, зон простираения тектонических разломов и геологические характеристики структурных элементов. Показано, что надежная интерпретация структурно-тектонической обстановки и скоростных моделей обеспечивает надежную основу для разведки углеводородов в этих районах. Таким образом, из всех описанных деталей можно сделать вывод о достаточно высоком углеводородном потенциале продуктивной толщи и подстилающих горизонтов.

Ключевые слова: сейсмический каротаж, вертикальный годограф, сейсмическая скоростная модель, разломы.

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Introduction

The study area is located in the southeastern extension of the Utelgi–Kanizadag–Khara-Zira anticlinal zone of the Sangachal-Sea uplift. This anticlinal zone is separated from the Kanizadag structure by a shallow saddle where sediments of the Akchagyl stage have accumulated. In the crest of the fold, sediments of the Productive Series (PS) are observed, while on the flanks and in the southeastern pericline, Akchagyl and Absheron sediments are present. Quaternary sediments overlie the distant northeastern flank of the structure [Abdullayev et al., 2024; Abbasov, 2004; Alizadeh et al., 2024].

An integrated comparative analysis of newly acquired geological and geophysical data, coupled with advanced structural modeling, provides substantial scientific and practical value. This approach facilitates the expansion of existing production areas, the identification of new oil- and gas-bearing prospects, and the delineation of productive zones within deeper stratigraphic intervals.

At present, conducting such research is considered a highly relevant and significant scientific direction.

The objective of this study is to construct velocity models based on seismic-logging and Vertical Seismic Profiling (VSP) data from wells drilled in the research area – Sangachal-Deniz-124, Sangachal-Deniz-440, Khara-Zira-568, and Well No. 578 of the 8 March field. The study also involves analyzing the results of VSP surveys conducted in these wells and refining the geological and tectonic structure of the area using data obtained from Common Depth Point (CDP) seismic exploration. Ultimately, the goal is to provide an accurate assessment of the hydrocarbon prospectivity of the studied structures.

The Sangachal-Deniz fold has an asymmetrical brachyanticlinal structure with a **north-west-southeast (NE–SE) trend within of South Caspean Basin (SCB)**. The structure is asymmetrical in both the transverse and longitudinal directions. The south-west (SW) flank of the fold (20–30°) is less inclined than the north-east (NE) flank (35–45°). The dip angles on the flanks decrease with depth, and in the VII horizon of the PL the dip angle of the layers decreases to 15–20°.

The Sangachal-Deniz brachyanticline, that was drilled here according to the data of the wells, is complicated by three main longitudinal faults (Report. Azerbaijan SSR, 1963–1964, SP 1/63, 2/63. Goberman, K. I.). These faults are traced stepwise and sequentially, where the northeastern block is lowered relative to the southwestern block. The amplitude of displacements along the tectonic fault varies between 100–200 m. As the depth increases, these faults approach each other and in the lower levels of the Productive layer (PL) sedimentary complex, in the upper part of the Miocene, they merge into a single fault [Alizadeh et al., 2024; Babeshko et al., 2025; Chernov et al., 2020; Ding et al., 2023].

The northeastern flank of the fold is divided into tectonic blocks by six transverse and two relatively small-scale longitudinal faults. The displacement amplitude between these blocks varies from 40–50 m to 100–200 m. The arch part of the fold and the southwestern flank are complicated by two main transverse faults. These faults separate the northwestern periclinal of the fold from the main part, directing it from the northeast to the southwest (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields) (Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A., et al.). As a result, the southeastern block has subsided relative to the northwestern block, each with an amplitude of 50–200 m. It is assumed that these transverse faults die out on the flanks before reaching the axis of the

synclines. The southeastern periclinal of the fold is twice as short as the northwestern periclinal [Chernov et al., 2020; Di Toro et al., 2011; Ding et al., 2023].

The short southeast periclinal, where the Sangachal-Deniz structure meets the Duvanni-Deniz structure, is also complicated by transverse tectonic faults. The Duvanni-Deniz uplift lies southeast of the Sangachal-Deniz uplift and is separated from it by a slight compression of the strata. The small saddle located between the structures is complicated by transverse faults [Yusubov, Guliyev, 2015; Di Toro et al., 2011; Babeshko et al., 2025]. Here the direction of the layers is partially inclined and the convex side is directed to the northeast. The axis of the Duvanni-Deniz fold turns southeast towards the Khara-Zira island.

Tectonically, the Duvanni uplift is an asymmetric anticlinal fold, the northeastern flank has a dip angle of 25–30°, and the southwestern flank has a dip angle of 20–25°. Through the seabed in the arch of the fold and in the northwestern periclinal PL sediments, and in the southeastern periclinal – upper Pliocene Quaternary sediments are observed. The southeastern periclinal extension is four times longer than the northwestern periclinal, and the structure dips towards the island of Khara-Zira (Report Marine Seismic Party, No. 23/84, No. 2/84. Baku, 1985/Алиева А.К.).

The arch part of the fold is complicated by longitudinal tectonic faults associated with Zambil Island, Khara-Zira Island and Abikh mud volcanoes. The central longitudinal fault in the Sangachal-Deniz uplift merges with the northern part of the Zambil Island uplift in the southeast, and is then followed by only two faults to the southeast. As a result of these faults, the central block has descended in the form of a graben (Report. Marine Seismic Party, No. 23/84, No. 2/84. Baku, 1985/Алиева А.К.).

The displacement amplitude of the central block increases to 100–120 m in the southwestern flank of the structure and up to 1500 m in the northeastern part. Then, towards the southeast from the transverse fault, the central block has risen in the form of a horst by 1300 m relative to the southwestern flank and 400 m relative to the northeastern flank [Babeshko et al., 2025; Di Toro et al., 2011; Ding et al., 2023] (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A. et al.).

The two main longitudinal faults converge with increasing depth and probably merge into a single fault in the underlying sediments [Abdullayev et al., 2024; Chernov et al., 2020]. Another arcuate longitudinal fault with a displacement amplitude of 300 m is observed on the northeastern flank of the structure, which caused the lowering of the northeastern block. In addition, the northeastern flank of the structure is complicated by several small transverse fractures with an amplitude of 40–50 m. These faults gave a blocky structure to the northeastern flank of the fold.

Structural outcrop is observed on all horizons of the PL on the far northeastern flank of the Duvanni fold. It increases the probability of the formation of saddle-type structural structures in the sediments below the PL within the Jeyrankechmez depression [Abdullayev et al., 2024; Hasanov et al., 2022, 2023; Iskenderov et al., 2017] (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A. et al.).

The Duvanni-Deniz Fold has a more complex geological and tectonic structure compared to neighboring structures. Its central part is complicated by large transverse and longitudinal tectonic faults, large mud volcano and graben-type dislocations (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A. et al.). From the island of Zambil (Duvanni) to the northwest,

PL sediments are observed in the form of tectonic breccias, and the fractures are filled with mud volcano breccias. These breccias are oriented southwest and northwest from the Abikh volcano and are covered by modern sediments with a thickness of more than 100 meters [Alizadeh et al., 2024; Di Toro et al., 2011; Ding et al., 2023] (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A. et al.).

The main longitudinal fault associated with the mud volcano divides the central part of the graben into southwest and northeast segments in the anticline zone. The Khara-Zira Island structure is located approximately 25 km southeast of Cape Sangachal and represents the last uplift within the Sangachal-Deniz–Duvanni-Deniz–Khara-Zira (SDXZ) anticline fold zone (Fig. 1).

Methodological Approach

Seismic logging (SL) and vertical seismic profiling (VSP) were carried out on wells drilled in the study area – Sangachal-Deniz-124, Sangachal-Deniz-440 and Khara-Zira-568, as well as well No. 578 of the 8 March field. The velocity model was built based on data from SL-VSP surveys and Common Depth Point (CDP) seismic surveys conducted in these wells. In well No. 124, located in the northwestern part of the Sangachal-Deniz structure, the geological section begins at a depth of 4,145 meters. In this well, SL and VSP surveys were conducted in the depth interval of 140–2280 meters. In well No. 440, also located in the northwestern part, the geological section begins at 4,769 meters and SL-VSP works were carried out in the depth interval of 2,750–4,500 meters within the same structure [Yusubov, Guliyev, 2015; Valiyev, 2016; Di Toro et al., 2011; Ding et al., 2023]. The geological section in well Khara-Zira-568, located in the southern part of the site, begins at a depth of 5126 meters. In this well, the SL-VSP data covers the interval 0–4537 meters, which allowed the structure to be studied at a wider depth interval.

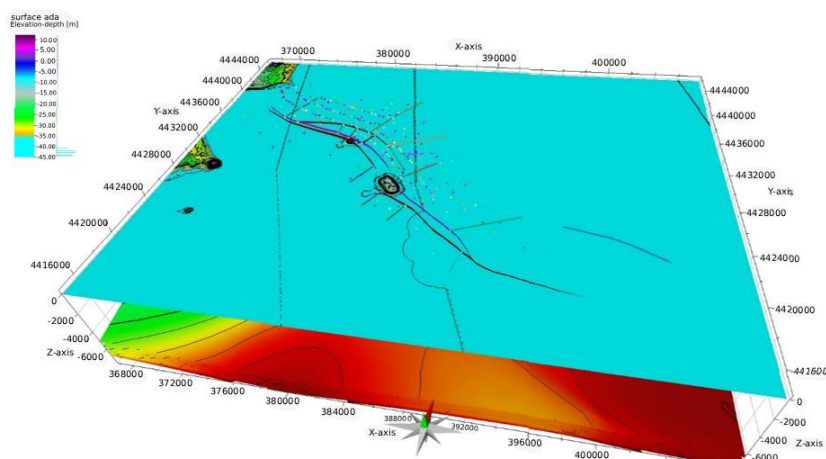


Fig. 1. 3D model of the SDXZ structure in the study area constructed based on bathymetric data

The geological section in well No. 578, located in the northern part of the 8 March area, covers a depth interval of 430–5653 meters. The SL and VSP surveys conducted here were carried out in the interval of 0–4967 meters.

The research work carried out in all the mentioned wells is of great importance both in terms of accurately defining the structure of geological sections and in terms of identifying potential oil and gas reservoirs. The variety of research intervals reflects the geological complexity of the structure and the depth variability in the area [Liu et al., 2024; Hasanov et al., 2022, 2023; Iskenderov et al., 2017]. SL-VSP surveys in these wells cover the interval

0–4967 meters and the vertical hodograph in the sections after the mentioned depth was formed by extrapolation. The conversion of dynamic time sections into depth sections and the transformation of seismic horizons into depth coordinates were carried out based on the averaged vertical hodograph [Mitchell et al., 2015] presented in the Figure 2.

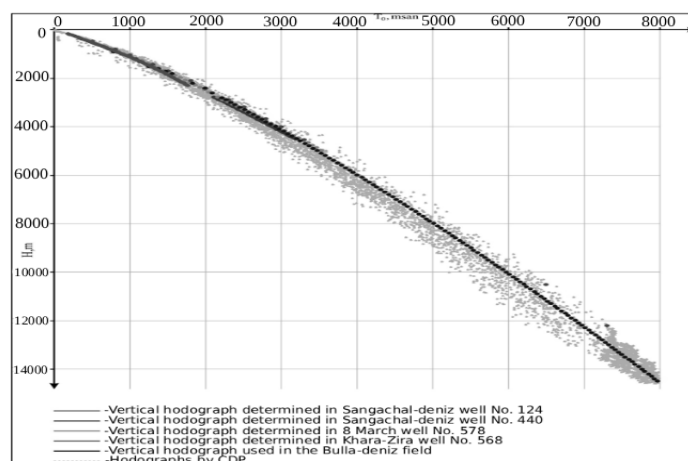


Fig. 2. Average vertical hodograph computed as a result of SL-VSP work carried out in wells

Results of seismo-geological surveys and geological assessment of structures

The geological assessment was carried out based on seismic profiles developed both in the current period (on 29 profiles) and in previous years, as well as Geophysical Well Survey (GWS) data. The exploration work covered the Sangachal-Daniz-Duvanni-Daniz-Khara-Zira structures and the Jeyrankechmez depression. As a result of the seismo-geological assessment, structural maps were plotted for eight seismic horizons in the stratigraphic intervals starting from the lower parts of the Miocene sediments to the surface of the PL complex (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A., et al.) [Shakarov et al., 2005; Svalova, Zaalishvili, 2014]. Seismic sections revealed a weak, low-frequency reflection pattern across the diatom-Cretaceous interface interval (~4.6–10.1 km depth), characterized by short in-phase axes and low-amplitude seismic anomalies. In this section, an angular unconformity was observed, especially between the seismic horizons. The dip angles of the reflection surfaces of the Miocene strata complex in some cases reach 30–35°. These reflections were clearly observed only in the seismic sections of the surveys conducted in 2016–2017, and were not recorded in the sections of the profiles obtained in 1991 due to insufficient depth [Valiyev, 2016; Iskenderov et al., 2017; Shakarov et al., 2005; Mitchell et al., 2015]. Consequently, structural maps at this level were plotted only based on data from 2016–2017. Due to suboptimal seismic data in the southwestern segments of the Sangachal-Daniz and Duvanni-Daniz structures, reflective boundaries of horizons are poorly resolved in the corresponding seismic sections (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A. et al.) [Zaalishvili et al., 2023]. Along the anticlinal line connecting the Sangachal-Daniz, Duvanni-Daniz and Khara-Zira structures, which is surrounded by isohypses of 4200–6800 m on the plotted structural map, the structures extend in the North-West – South-East direction and appear as folds within seismic profile X_1 and asymmetric structure (Fig. 3).

Lithological and geological characteristics of the Khara - Zira structure

The separation of the Khara-Zira structure from the Duvanni-Daniz structure is not clearly observed on structural maps.

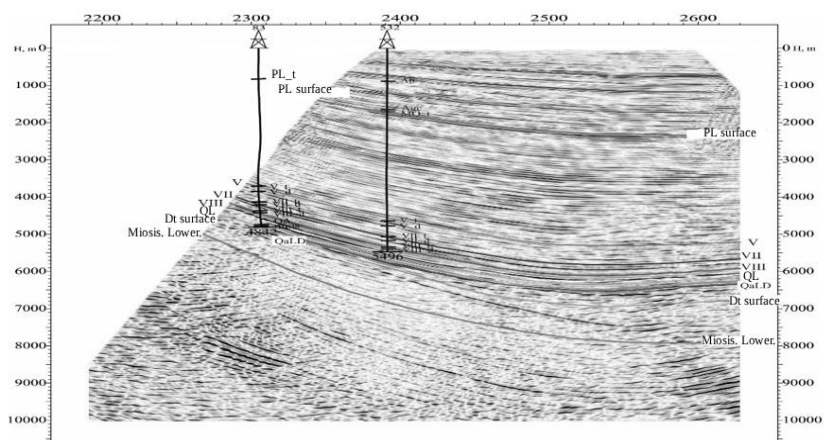


Fig. 3. Depth-time section on profile X_1

Although the axis of the structure initially extended in the North-west-South-east (NW–SE) direction, it later changed to the Northeast–Southwest (NE–SW) direction. The longitudinal faults observed along the structure are also oriented in accordance with this change in direction. The NW flank has a relatively wide and simple structure, dipping monoclinaly to a depth of 10,000 meters and joining the Jeyrankechmez depression. The southwestern flank of the structure has relatively narrow geometry and is delineated by a synclinal zone that separates it from the Bulla-Daniz structure (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A. et al.) [Ding et al., 2023; Liu et al., 2024].

Although the seismic coverage of the reflective horizons of the main layer complexes of the structure is weaker than that of the PL sediments, it also covers a wider stratigraphic range. Depths along the PL horizon vary between 4000–8000 meters in the northeast and 3100–7500 meters in the south-west.

All structures included in the anticlinal zone have an asymmetrical structure. The NE flanks of the structure lie at an angle of 25–30°, and the SW (Southwest) flanks lie at a less inclined angle of 18–20°. Weak synclinal saddles separate the structures from each other. The Duvanni-Deniz structure is more clearly traced than other structures from a hypsometric point of view, and its apical part is determined at a level of approximately 4000 m. The Khara-Zira, Sangachal-Deniz and Duvanni-Deniz structures are surrounded by an isohypse of 6200 m at this level.

In X_1 seismic profile in the western part of the northeastern flank of the Duvanni-Deniz structure, it was determined that Miocene sediments intrude beneath the PL sediments with an angular unconformity (Fig. 3). In this area, longitudinal tectonic faults extending along the arch of the structure are also clearly traced, further complicating the geological form of the structure.

Tectonic fault system and tectonic complexity of structures

The tectonic fault systems of various sizes traced in the study area had a significant impact on both the structural formation and their morphological characteristics. The I–I fault, located in the northwest of the site, extends in a southeastern direction starting from the Sangachal-Deniz structure and terminates in the profile region X_2 . The amplitude of this fault is 400 meters. The II–II fault, originating from the X_3 profile area, initially trends

southeast and subsequently bends eastward following the hinge zone of the Khara-Zira structure. The III–III fault traced on the northeastern flank of the Sangachal-Deniz uplift has an arc-shaped shape and connects with the northern part of the Duvanni Island uplift in the southeast.

As a result of this fault, the northeastern flank of the Sangachal-Deniz structure has been broken and lowered relative to the southwestern flank. In the arched part of the Duvanni structure X_4 , the amplitude of this fault approaches zero.

From this point, the kinematic sign of the fault in the southeast periclinal direction changes, and the northeast flank rises higher than the southwest flank. The amplitude of the tectonic fault in the X_4 profile region is 1300 m and near Khara-Zira Island it is 2100 m, and further east it decreases to 200 m (Fig. 4 and Fig. 5). In the study area, changes in stress regime (geodynamic stress) with depth have resulted in the northeastern (NE) flanks of the Duvanni-Deniz and Khara-Zira structures being uplifted relative to their southwestern (SW) flanks. In all three structures, the broad NE flanks are complicated not only by longitudinal faults but also by transverse faults (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A., et al.) [Iskenderov et al., 2017].

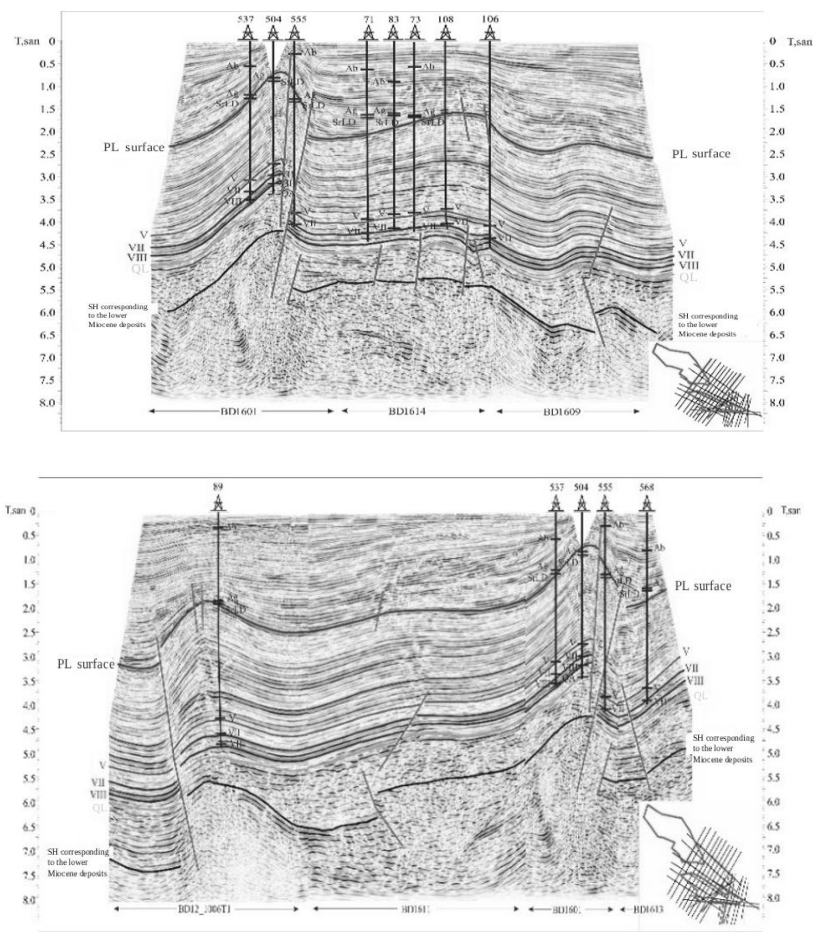


Fig. 4. Stratigraphic correlation of seismic horizons (SHs) to wells along profiles a) X_2 I-I and b) X_3 II-II

The IV–IV transverse tectonic fault, which runs through the northeastern flank of the Sangachal-Deniz structure, gradually dies out in the direction of the monoclinical dip of the layers

and is demonstrated with an amplitude of 10–50 m. As a result of this fault, the northwestern part of the flank has been broken and lowered relative to the southeastern part.

The V–V transverse fault, which passes through the arch of the Duvanni-Deniz structure, extends towards the 8 March structure, lowering the northwestern part of the structure relative to the southeast with an amplitude of 30–80 m. Transverse faults VI–VI and VII–VII caused the strata to gradually break to the northwest with an amplitude of 20–60 m in the southeastern part of the northeastern flank of the Duvanni-Deniz structure.

The Khara-Zira structure, the last uplift of the anticline zone, is separated from the Duvanni-Deniz structure by a low-strength synclinal saddle (Study of sandy horizons and evaluation of oil and gas prospectivity in the Sangachal-sea – Babek uplift zone (including 8 March and Alet-sea fields). Final Report. KMAIB. Baku. 2014. 494 p. / Guliyev Z.I., Shirinova S.A. et al.). The NE flank is wider and has a complex tectonic structure. This flank descends to the north by up to 8000 m and is a continuation of the Jeyrankechmez depression in the sea. This flank of the structure is complicated by transverse faults VIII–VIII and longitudinal faults IX–IX. As a result of the VIII–VIII fault, the strata broke to the southeast with an amplitude of 20–40 m. The IX–IX fault caused the strata to break to the center with an amplitude of 70–80 m in the central part of the structure and fall towards the center, while the amplitude gradually decreases at the edges [Iskenderov et al., 2017; Shakarov et al., 2005; Hasanov et al., 2022].

The structure has an asymmetric formation. In the north-eastern flank, the dip angle of the layers is 18–20° in the uplifted part, and in the direction of descent this angle decreases to 5–10°. In the south-western flank, these angles are 4–8°. The south-western flanks of both the Duvanni-Deniz and Khara-Zira structures are complicated by tight transverse faults with an amplitudes ranging from 10–100 m. As a result of these faults, the layers are gradually broken and dip from the northwest to the southeast. The southern part of the south-western flank of the Duvanni-Deniz structure is limited by longitudinal faults XIV–XIV and XV–XV, and these faults are represented with an amplitude of 10–40 m.

Tectonic Structure of Khara-Zira and nearby Structures in the PL Complex

The fault located in the south of the study area and starting in the X₂ profile area, together with II fault, reaches 2,300 m in the X₃ profile area, west of the Khara-Zira area (Report. Marine Seismic Party, No. 23/84, No. 2/84. Baku, 1985/Алиева А.К.).

The amplitude of these faults decreases towards the southeast. The amplitude of the II-II fault decreases to 200 m in the X₂ and X₃ profile regions. The II fault, which is observed in the grounds, dies out in the southeastern part of the area, in the profile region. In addition to tectonic faults, the geological structure of the Khara-Zira structure is also complicated by the influence of mud volcanoes. The fold along the Productive Suite (PS) complex within this structure is asymmetrical. The north-east (NE) flank of the fold dips at an angle of 14–18°, while the south-west (SW) flank dips at an angle of 11–16°. The NE flank, covering a wider area, has a simple structure; the layers dip monoclinally in this direction and merge into the marine continuation of the Jeyrankechmez depression at a depth of 6500 m [Iskenderov et al., 2017; Yusubov, Guliyev, 2015].

The thin SW flank is dislocated by two transverse tectonic faults XII-XII and XIII-XIII. Under the influence of these faults, the layers have been broken to the southeast and have displaced downward towards the syncline separating the Khara-Zira structure from the Bulla-Deniz structure. The southward descent of the layers is clearly observed in profiles. The southeastern periclinal extends for a distance of approximately 15 km, at an angle of 6–8°, and descends to a depth of 6,800 m.

The SW flank of this periclinal is thin and is limited by a large amplitude, longitudinal axis-oriented and reverse-fault type II-II fault (Report. Marine Seismic Party, No. 23/84, No. 2/84. Baku, 1985/Алиева А.К.).

As a result, the SE flank of the structure has collapsed relative to the NE flank. Slightly

north of the II-II fault, the IX-IX longitudinal fault with an amplitude of 20–40 m is observed. As a result of this fault, the arch section has collapsed relative to the northern flank.

The local syncline separating the Khara-Zira structure from the Bulla-Deniz structure has a centriclinal structure, and the NE slope is complicated by tectonic faults of the XIII-XIII longitudinal and transverse structures (amplitude 20–80 m).

The marine continuation of the Ceyrankechmez depression, located in the northeast of the site, is observed in the form of two undulations [Iskenderov et al., 2017; Hasanov et al., 2023]. Its deepest part is located in the northeast of the site and is indicated by the 6900 m isohypse. These fragments are separated from each other by the elevation noted in the profile area.

The syncline observed in the southwest of the site consists of two parts, separated from each other by the Khara-Zira Island (Report. Azerbaijan SSR, 1963–1964, SP 1/63, 2/63. Goberman, K.I.). The deepest part of this syncline (7700 m) is located in the southeast of the site. In the structural map of the V horizon of the Productive Series (PS), the general structural plan of the site is same with the structure of the VII horizon of the PS. The dip angles of the layers on the flanks of the structure, the direction and amplitude of the faults are almost at the same level. The arch parts of both the Duvanni-Deniz and Khara-Zira structures have been accurately plotted based on well data [Abdullayev et al., 2024; Yektirmishli et al., 2023; Zaalishvili et al., 2023].

On the structural map of the PL (Pliocene) complex surface, the geological-tectonic structure generally repeats the configuration of the underlying horizons however, certain differences are observed. Specifically, in the Sangachal-Deniz–Duvanni-Deniz area, within the crestal part of fold zones, the top of the PL deposits has been denuded to depths of 800–900 m. The flanks of the structure are primarily represented by the Agchagil and Absheron deposits.

The denudation of the crestal parts of the Sangachal-Deniz and Duvanni-Deniz anticlinal uplifts has made it difficult to distinguish these structures on the map. But, on the NE flank (northeastern flank), these structures are clearly separated by a broad syncline. At this level, changes are observed in the location and orientation of tectonic faults compared to lower levels. Some faults traced in the lower horizons are not observed on the PL surface. For example, Faults I-I and II-II, originating from the arch of the structure, extend south-eastward parallel to the axis of the Khara-Zira structure. Fault I-I dies out in the area of, while Fault II-II terminates slightly later in the area of Profile (Fig. 4 and Fig. 5).

In the Khara-Zira area, some tectonic faults are observed only at the PL level. The amplitude of these faults is relatively small (approximately 50 m) and they are of different directions and signs, complicating the structure's topography.

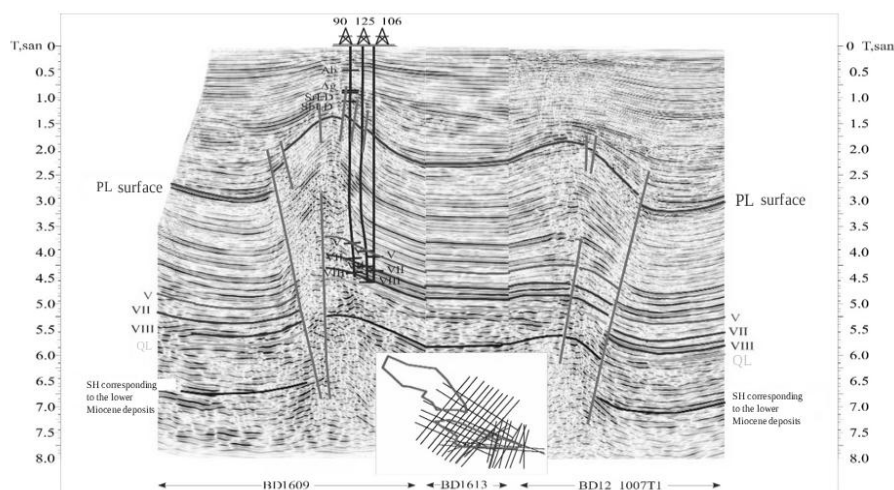


Fig. 5. Stratigraphic correlation of SS's to wells along the line of III-III

In the Khara-Zira area, some tectonic faults are observed only at the PL level. The amplitude of these faults is relatively small (approximately 50 m) and they are of different directions and signs, complicating the structure's topography.

The Khara-Zira structure separated from the syncline Duvanni-Deniz structure by a weakly expressed saddle. The northeastern flank of all three structures dips monoclinally and merges with the marine continuation of the Jeyrankechmez depression. The Jeyrankechmez depression is reflected in this area in the form of two undulations expressed at isohyps 2400 and 3100 m [Abbasov, 2004; Shakarov et al., 2005; Valiyev, 2016]. These undulations are separated from each other by the dip of the northern flank of the Duvanni-Deniz structure in that direction.

The conventionally drawn SE flank of the Sangachal structure descends and merges with the Alat-Umid syncline. The southwestern wing of the Duvanni-Deniz and Khara-Zira structures is narrow and passes directly into the Alat-Umid syncline.

Conclusion

Comprehensive analysis of WGS and other geophysical data obtained in recent years indicate, that these data are not only important for expanding the productive horizons of existing reservoirs, but also hold significant scientific and practical value for assessing the hydrocarbon potential of deeper, as-yet insufficiently studied strata. Particularly, in accordance with the objectives of the research, the following can be noted:

1. The Khara-Zira structure is separated from the Sangachal-Duvanni-Deniz synclinal structures by a weakly defined saddle. The northeastern flank of all three structures is monoclinally inclined and merges with the offshore continuation of the Jeyrankechmez Depression. All structures within the anticlinal zone, including Khara Zira, have an asymmetric form. The northeastern flanks of the structure are inclined at an angle of 25–30°, while the southwestern (SW) flanks are inclined at a lesser angle of 18–20°. In general, the axis of the structure initially extends in a northeast-southeast direction and then deviates to the east.

2. In the Khara-Zira region, some tectonic downward only at the Paleozoic level. The amplitude of these faults is relatively small (approximately 50 m), they are directed differently, and have different signs, which complicates the structure's topography. In the arched part of the Khara Zira structure, the top of the Paleozoic occurs at a depth of 950–1000 m. The structure here resembles a normally shaped anticlinal fold, and the arched part enclosed by a 950 m contour line. At this level, the northeastern pericline of the Khara Zira structure is not traceable relative to the submerged horizons, and the structure represents only an extended northeastern pericline. The bottom of the Paleozoic occurs from 4000 to 8000 meters in the northeast and from 3100 to 7500 meters in the southwest.

3. In addition to tectonic faults, the geological structure of the Khara-Zira structure is also complicated by the existing of mud volcanoes. Precisely, the thin SW flank of the Khara-Zira is complicated by two transverse tectonic faults XII-XII and XIII-XIII. Under the influence of these faults, the layers have been broken to along southeast and have displaced downward towards the syncline separating the Khara-Zira structure from the Bulla-Deniz structure. The southeastern periclinal extends for a distance of approximately 15 km, at an angle of 6–8°, and descends to a depth of 6800 m. The SW flank of this periclinal is thin and is limited by a large amplitude, longitudinal axis-oriented reverse II-II fault. As a result, the SE flank of the structure has moved relative to the NE flank. Slightly north of the II-II fault, the other (IX-IX) longitudinal fault with amplitude of 20–40 m is observed. Because of this fault, the arch section looks collapsed relative to the northern flank.

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