ADVANCED SEISMIC METHODS FOR RISK REDUCTION IN SUBSURFACE CHARACTERISATION OF COMPLEX GEOLOGICAL STRUCTURES

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Abstract

The Absheron archipelago, situated in the South Caspian Basin, is a geologically complex region with significant hydrocarbon potential. This study focuses on the geologically complex structures of the Absheron archipelago, employing 2D seismic exploration data to assess subsurface structures and reservoir distribution. The research involved stratigraphic correlation, tectonic fault mapping, and seismic attribute analysis. Structural interpretation identified multiple fault-controlled traps, influencing hydrocarbon migration and accumulation. Seismic attribute analysis, including Root Mean Square (RMS) amplitude, Chaos and Relative Acoustic Impedance, was conducted to identify potential reservoir zones. The integration of seismic attributes with well log data allowed for improved reservoir characterization, reducing exploration risks. High RMS values corresponded to sand-prone facies, while amplitude variations suggested lateral changes in fluid content and reservoir quality. These results enhance the understanding of hydrocarbon distribution in the Absheron Archipelago, providing valuable insights for future exploration efforts. The study demonstrates the effectiveness of advanced seismic methods in delineating potential hydrocarbon reservoirs in structurally complex geological settings.

Keywords: seismic attribute analysis, fault systems, seismic anomalies, geological assessment, reservoir characterization

I. Introduction

The Absheron Archipelago, located in the South Caspian Basin, is a structurally complex and hydrocarbon-rich region that plays a crucial role in Azerbaijan's petroleum system. Comprising a series of islands, submerged ridges, and faulted blocks, the archipelago has been a key target for seismic exploration and reservoir characterization. The geological complexity of the region is driven by active tectonics, sedimentary processes, and hydrocarbon migration, leading to the formation of various structural and stratigraphic traps [1,2].

Among the key structures in the region, the research area exhibit intricate fault systems and diverse lithological formations, influencing hydrocarbon accumulation. Traditional seismic imaging methods face challenges in accurately mapping these complex subsurface structures. To address these challenges, seismic attribute analysis provides valuable insights into reservoir characteristics by enhancing the interpretation of seismic reflections.

This study aims to assess the geological and seismic attributes of the complex structured areas of the Absheron archipelago using 2D seismic data. By integrating attribute analysis with well log data, the research seeks to improve reservoir characterization and reduce exploration risks. The findings contribute to a better understanding of hydrocarbon distribution in the Absheron archipelago, offering a more refined approach to identifying prospective oil and gas reservoirs in structurally intricate settings.

II. Geological settings and methods

The Absheron Archipelago, located in the South Caspian Basin, is a structurally complex region with significant hydrocarbon potential. This archipelago consists of a chain of islands, submerged ridges, and faulted blocks that extend into the Caspian Sea, forming a critical part of Azerbaijan's petroleum system. Being target for seismic exploration and reservoir characterisation, the Absheron Archipelago is geologically evolving under the influence of tectonics, sedimentary processes, and hydrocarbon accumulation. The research area covers the Absheron Bank, Western Absheron, Darwin Bank oil and gas fields, as well as the Aghburun-Deniz, Mardakan-Deniz structures, and the Gala Bay shown in Fig. 1.

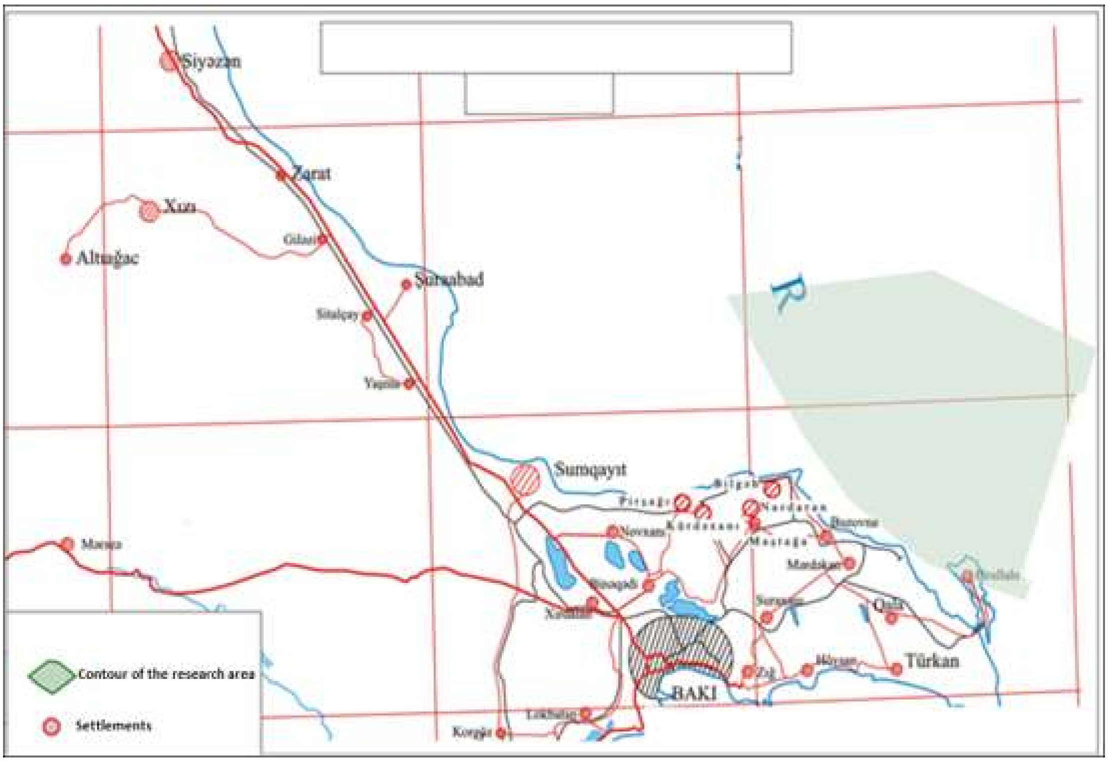

Figure 1. *Scale representation of the research area (1 cm = 5 km)*

The Mardakan-Deniz structure is an asymmetric anticline extending in a northwest-southeast direction and influenced by multiple fault systems. The structure's complexity arises from its steeply dipping limbs, numerous fault zones, and the presence of the Buzovna mud volcano, which plays a significant role in fluid migration. The anticline's southern limb has a dip angle ranging from 35° to 45°, while the northern limb is less steep, with an inclination between 12° and 22°.

Stratigraphically, the area consists of Middle Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary deposits. These formations include alternating layers of sandstones, siltstones, clays, and carbonates. The presence of discontinuous shale layers influences the migration and accumulation of hydrocarbons by acting as seals. The tectonic activity in the region has significantly impacted the structural configuration, forming multiple hydrocarbon traps and affecting reservoir connectivity [3].

A critical aspect of the region's geological setting is the presence of faulted stratigraphic traps, particularly along the southern limb of the anticline [4,5]. These faults create compartmentalized reservoir zones, necessitating precise seismic imaging to map hydrocarbon-bearing formations accurately. Additionally, tectonic activity has resulted in tilted fault blocks that serve as potential hydrocarbon reservoirs [3].

The sedimentological characteristics of the region indicate a complex depositional history, with transgressive and regressive cycles affecting reservoir quality. The lower sections of the stratigraphic sequence contain poorly sorted sands, whereas the upper sections exhibit well-sorted, high-porosity sands that are ideal for hydrocarbon accumulation.

The region's tectonic evolution is characterized by a series of longitudinal and transverse fault systems that segment the anticline into smaller tectonic blocks. The main fault line trends northwest-southeast, forming a series of structural highs and lows that influence hydrocarbon entrapment.

Seismic interpretation of the research area reveals distinct seismic reflectors that indicate multiple depositional environments. The seismic reflections show sharp contrasts between high-density carbonate layers and low-density siliciclastic sediments. The presence of chaotic seismic signatures in some areas suggests zones of intense deformation, likely associated with fault activity. A significant feature observed in the study area is the angular unconformity between the Neogene and Paleogene formations, which serves as an important exploration target [6]. This unconformity marks a depositional hiatus and is associated with truncated reservoirs where hydrocarbons can accumulate.

The relief of the seabed is uneven throughout the area. As a result of underwater surveys, , and studies of seabed rocks, it has been found that the relief of the sea in the area is erosive in nature. Similarly, the coastline depends on the tectonics and lithofacies composition of the sediments that lie above and reach the seabed.

The complicated geology of the Absheron archipelago, including faults, folds, and varied rock types, has made it difficult for conventional seismic tools to image the subsurface clearly. This issue is resolved by seismic characteristics such as acoustic impedance, spectrum decomposition, coherence, and RMS amplitude. For instance, by identifying significant reflections, RMS amplitude identifies regions that may contain hydrocarbon deposits. Understanding the movement of fluids beneath requires the ability to detect faults and fractures. The detection of thin rock strata that might contain hydrocarbons is improved by spectral decomposition. Separating different types of rock and identifying potential oil and gas-containing zones are made easier by acoustic impedance.

By combining these seismic attributes with well data and geological models, one can get a clearer picture of the underground structures [7]. This reduces the risk of drilling dry wells and improves the chances of finding productive reservoirs. In the Absheron Archipelago, using seismic attributes makes oil and gas exploration more efficient and reliable.

III. Results

The geological assessment of 2D seismic exploration data from the Absheron archipelago was conducted using "IHS Kingdom Suite" and "Petrel" software packages. The study involved stratigraphic correlation of seismic horizons in time and depth sections, mapping tectonic faults, and performing attribute analysis. The area's tectonic features were considered, and seismic reflections were correlated using a disjunctive interpretation model, linking multiple closed-contour time and dynamic depth sections. Geological evaluation incorporated well log data from nearby wells, previous seismic survey results, and dynamic wave characteristics. The structure's crest and flanks were found to be affected by complex tectonic faults, complicating correlation efforts. Numerous longitudinal, transverse, and radial tectonic fault planes of varying amplitudes were identified, with faults being more prominent in the crest and flank areas.

To predict the distribution of reservoirs, attribute analysis was performed on 2D seismic data. The physical basis of attribute analysis is related to seismic wave dynamic parameters, including amplitude, frequency, and phase, as well as the lithological characteristics of rocks [7]. The reservoir properties of rocks depend on sediment genesis and subsequent geodynamic conditions. As the acoustic impedance contrast between layers increases, the amplitude of reflected waves rises, while wave frequency is influenced by layer thickness and lithology. Various seismic attributes such as amplitude and frequency were calculated and compared with well and core data to characterize the overall geological environment. To identify high-quality reservoir zones, attributes like RMS, Chaos and Relative Acoustic Impedance were analyzed alongside well test data and geophysical logging. The seismic data covered a time interval of 0–4500 ms, and the RMS attribute variations across the study area were presented. High RMS values correspond to sand-rich facies, while low values indicate clay-rich facies, revealing sand/clay ratio variations in the attribute cross-section. The research area is systematically divided into two distinct seismic profiles, designated as Profile 1 and Profile 2. The time section of the Profile 1, extending from Qala Bay to the Absheron structure, reveals significant amplitude variations that correlate with lithological changes in the subsurface and shows local objects within the Qirmaky (QD) and Lower Qirmaky (QA) deposits. The RMS attribute analysis highlights high-amplitude anomalies in the lower sections of the QD horizon and QA sediments, particularly near the Qala Bay shown in Fig.2.

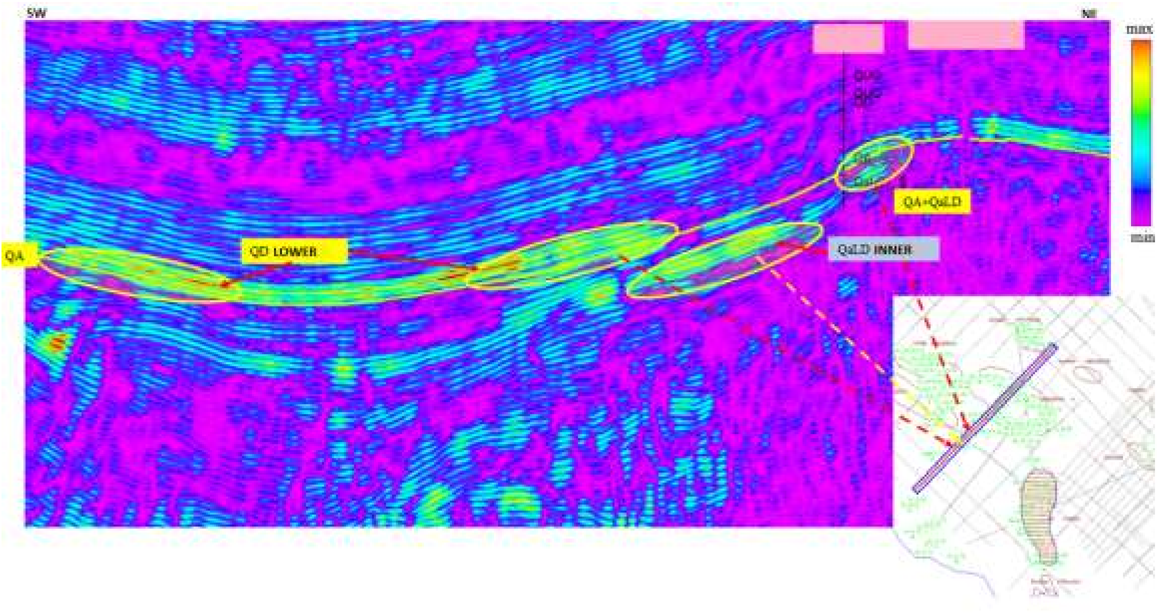

Figure 2: *RMS Amplitude Map of Profile 1*

These high amplitudes are indicative of sand-prone facies, which are potential hydrocarbon reservoirs. The analysis also suggests the presence of localized depositional features, such as channelized sand bodies or stratigraphic traps, that may contribute to hydrocarbon accumulation. Additionally, seismic attribute mapping along this profile shows lateral changes in amplitude strength, potentially indicating variations in reservoir quality and fluid content.

Running parallel to Profile 1 but slightly offset, Profile 2 provides additional confirmation of the seismic anomalies observed in the previous section. This profile further delineates local high-amplitude objects in the lower sections of the QD horizon and Miocene sediments. The amplitude distribution suggests possible hydrocarbon-bearing zones with a distinct separation between sandy and clay-rich facies. Moreover, the profile highlights potential reservoir compartmentalization, where variations in seismic response may correspond to structural or stratigraphic barriers. The attribute analysis along this section provides critical insights into the lateral extent of reservoir-quality sediments, reinforcing the interpretation of hydrocarbon potential in the area shown in Fig. 3.

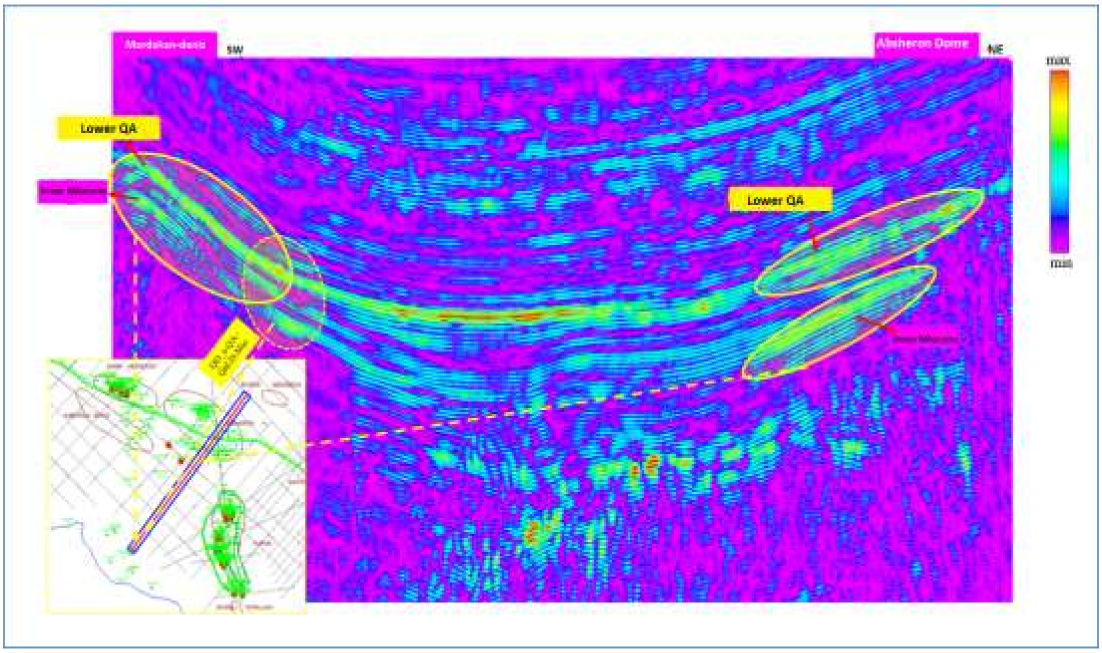

Figure 3: *RMS Amplitude Map of Profile 2*

Using the Relative Acoustic Impedance (RAI) attribute, it is possible to observe the acoustic contrast reflected at layer boundaries in time sections, the sequence of layer deposition, unconformity surfaces, and fault structures shown in Fig.4.

Based on the Relative Acoustic Impedance attribute calculated for the time section of the research area, which intersects the Darwin Bank structure in a southwest-northeast direction, the erosion surface within the Miocene sediments can be identified.

The Chaos attribute is applied as a stratigraphic attribute and provides precise information about wave pattern characteristics, including fracturing, disjunctive dislocations, channels, anomalies, gas migration pathways and so on. As observed in the Chaos attribute calculated for the time section of Profile 1, a complex seismic data zone associated with faults is clearly traceable in the crest area of the studied area, shown in Fig. 5.

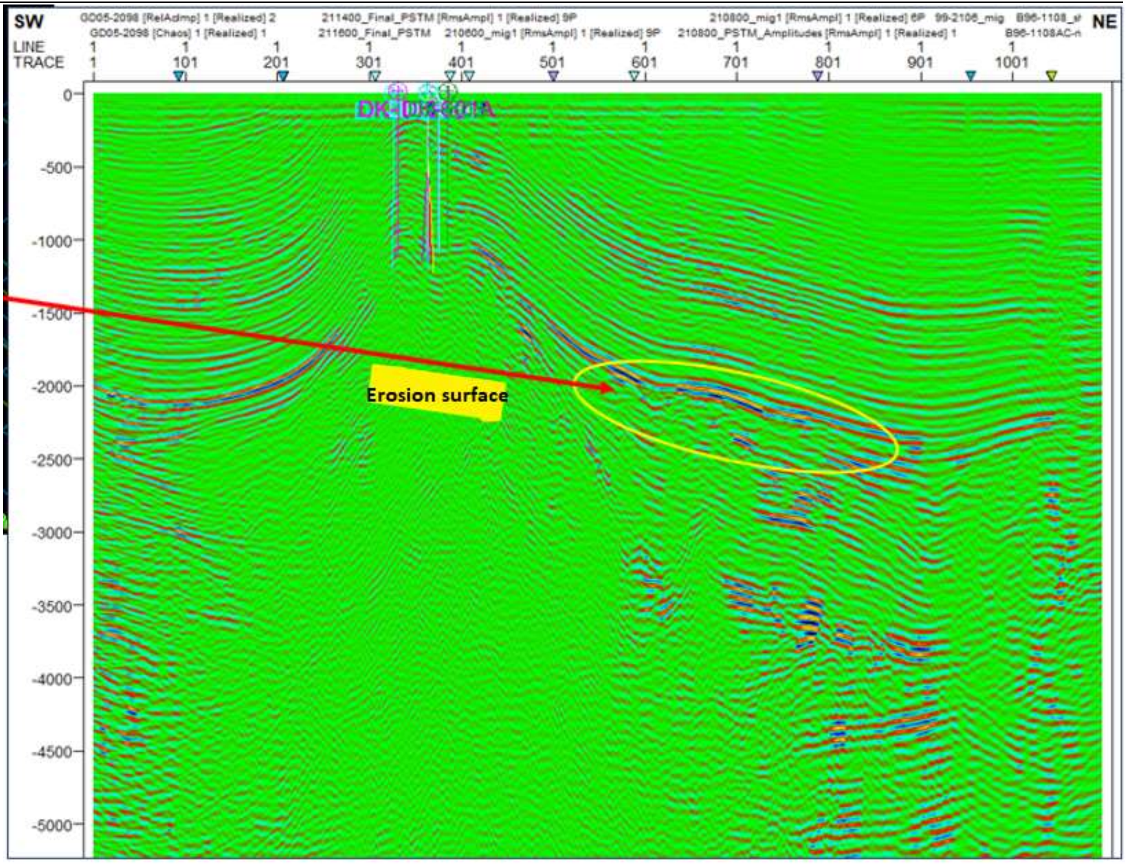

Figure 4: *Relative Acoustic Impedance Map of the Research Area*

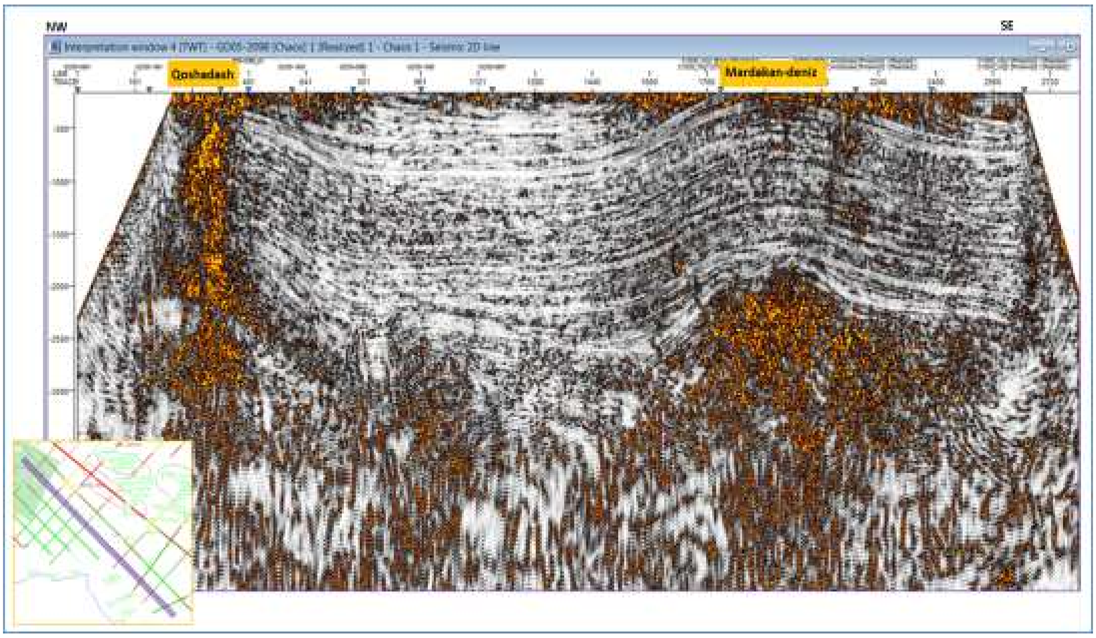

Figure 5: *Chaos attribute Map of the Profile 1.*

IV. Conclusion

- The integration of seismic attributes, such as Relative Acoustic Impedance, Chaos and RMS Amplitude has enhanced subsurface imaging. RMS amplitude variations indicate sand-rich facies suitable for hydrocarbon accumulation, while Chaos attributes effectively delineate faulted zones and potential fluid migration pathways.
- Structural maps created from 2D seismic data have provided detailed insights into depth variations and tectonic faults. High-amplitude anomalies in the QD and QA horizons indicate potential hydrocarbon-bearing zones, highlighting reservoir compartmentalization.

CONFLICT OF INTEREST.
Authors declare that they do not have any conflict of interest.

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