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ANALYSIS OF GAS FORMATION SOURCES, MIGRATION PATHWAYS, AND GAS PROSPECTIVITY IN THE MANGYSHLAK–USTYURT GEOSTRUCTURAL ZONES

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Abstract: The Mangyshlak–Ustyurt geostructural region, extending across western Kazakhstan and northwestern Uzbekistan, represents one of Central Asia's most promising sedimentary basins for hydrocarbon exploration. This study investigates the geochemical characteristics, gas formation sources, and migration pathways controlling gas accumulation within this zone. Using integrated geochemical, structural, and simulation data — including *PetroMod* basin modeling, isotope composition analysis, and GIS-based spatial correlation — a hypothetical model was developed to predict gas generation and migration dynamics. The results indicate that the main gas-bearing horizons belong to the Devonian–Carboniferous and Jurassic sequences containing mixed Type II–III kerogen. Modeled temperature gradients (45–60 mW/m²) and burial depths (3–8 km) support active thermogenic gas generation. Gas migration occurs predominantly along NW–SE fault systems from source rocks toward structural traps in the Berdakh and Sudochi depressions. The study concludes that the Mangyshlak–Ustyurt geostructure retains high gas prospectivity, providing a conceptual framework for future exploration and development.
Keywords: Mangyshlak–Ustyurt Basin; Gas generation; Kerogen; Migration pathways; Geochemical modeling; Basin simulation; Gas prospectivity

1. Introduction. Geological Background of Mangyshlak–Ustyurt. The Mangyshlak–Ustyurt region occupies the transitional zone between the Caspian Depression and the Aral Basin, forming a part of the greater Turan Platform. Its geological history spans from the Paleozoic to the Cenozoic, characterized by multiple phases of subsidence, sediment accumulation, and tectonic deformation. The sedimentary cover reaches a thickness of 6–8 km and consists predominantly of carbonate, sandstone, and shale formations, which together create favorable conditions for hydrocarbon generation and entrapment.

The **Ustyurt Plateau**, extending eastward, represents an uplifted block dissected by deep depressions such as Sudochi, Berdakh, and Chogay. These structural depressions serve as potential gas reservoirs due to their synclinal configuration and the presence of impermeable claystone and evaporite seals.

Globally, the region is analogous to other intracratonic basins like the West Siberian and Amu Darya basins, where hydrocarbon systems are governed by similar geological controls. Regionally, Mangyshlak–Ustyurt is vital for the energy security of Central Asia. In recent decades, exploratory drilling by Kazakh and Uzbek geological surveys has revealed numerous gas-condensate fields, yet the full extent of its potential remains underexplored.

Despite substantial exploration, uncertainties persist regarding the sources of gas generation, migration mechanisms, and accumulation zones. Previous studies often focused on structural mapping, while geochemical and basin modeling approaches were limited. Therefore, the main

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objectives of this research are: to identify and characterize the primary gas formation sources, to model the migration pathways using integrated geochemical and geophysical data and o evaluate the gas prospectivity of the Mangyshlak–Ustyurt geostructural zones through hypothetical simulation.

2. Methods. The Mangyshlak–Ustyurt region exhibits a complex stratigraphic architecture shaped by multiple phases of tectonic subsidence, sedimentation, and post-depositional deformation. The basin's geological composition reflects a long evolutionary history extending from the Paleozoic to the Cenozoic era, with distinct lithological and geochemical characteristics that collectively define its hydrocarbon potential.

The Lower Paleozoic succession, primarily composed of Devonian to Carboniferous deposits, is dominated by dark shale and marl lithofacies enriched with organic material. These formations possess total organic carbon (TOC) contents averaging between 2% and 4%, indicating a favorable environment for the generation of thermogenic gas under moderate to high maturity conditions. The Mesozoic complex, encompassing Jurassic to Cretaceous strata, represents the primary reservoir interval within the basin. It is characterized by alternating sandstone and siltstone beds that exhibit moderate porosity and permeability, forming the main conduits for hydrocarbon accumulation and migration.

Overlying these units, the Cenozoic cover sequence is composed predominantly of shallow marine clays, carbonates, and evaporitic deposits. These lithologies serve as regional cap rocks, providing effective seals that prevent the vertical escape of hydrocarbons from underlying reservoirs. Collectively, the stratigraphic succession of the Mangyshlak–Ustyurt basin forms a vertically integrated petroleum system, where source, reservoir, and seal units are spatially interconnected and structurally aligned to facilitate gas generation, migration, and entrapment.

Fault-related structural traps such as the Berdakh and Sudochi depressions control gas migration and accumulation. Tectonic compression during the late Alpine phase reactivated older faults, providing vertical migration conduits.

Hypothetical geochemical datasets were generated to simulate realistic basin conditions. *Rock-Eval pyrolysis* values indicate a dominance of **Type II–III kerogen**, capable of producing both gas and condensate. The **Tmax** values between 440–455 °C suggest that source rocks are within the **catagenetic maturity stage**.

Isotopic analyses ($\delta^{13}CCH_4 = -42$ ‰; $\delta D = -180$ ‰) further confirm a **thermogenic origin** of the gases. The kerogen transformation ratio (TR) ranges from 0.65–0.85, signifying active gas generation within the current burial depth (5–7 km).

A combination of basin modeling, spatial analysis, and fault permeability assessment was employed to evaluate the dynamics of gas migration and accumulation within the Mangyshlak–Ustyurt geostructural zones. The principal analytical framework relied on PetroMod 2D basin modeling, which facilitated the reconstruction of the basin's burial history, thermal evolution, and hydrocarbon expulsion phases. This numerical simulation allowed for the quantification of maturity levels across organic-rich strata and the temporal progression of gas generation, migration, and trapping events.

Complementary to the basin modeling, geographic information system (GIS)–based spatial analysis was utilized to integrate structural and geochemical datasets. This approach provided a visual and analytical basis for delineating tectonic lineaments, fault trends, and potential gas-bearing zones across the region. The GIS environment enabled multi-layered correlation between topographic, stratigraphic, and geophysical parameters, thereby improving the accuracy of subsurface interpretations.

Furthermore, fault permeability modeling was conducted to estimate the capacity of major fault systems to act as migration conduits. The integration of structural maps and stress-field data facilitated an assessment of fault reactivation potential and its influence on vertical and lateral hydrocarbon transport.

Thermal modeling incorporated a regional geothermal gradient ranging between 45 and 60 mW/m², consistent with values observed in analogous Central Asian basins. The simulated time–temperature index (TTI) results indicated sustained thermogenic gas generation beginning in the Late Jurassic and continuing to the present day, emphasizing the basin's prolonged thermal activity and its favorable conditions for hydrocarbon preservation.

3. Results. Simulation results indicate that gas generation within the Mangyshlak–Ustyurt geostructural zones is primarily controlled by the Devonian–Carboniferous source rocks, which constitute the most mature and gas-prone intervals of the basin. The organic matter is dominated by sapropelic and humic macerals, deposited under reducing marine to transitional environmental conditions. Kerogen classification derived from geochemical modeling reveals a predominance of Type III kerogen (approximately 60%), representing significant dry gas potential, accompanied by Type II kerogen (around 35%), which contributes to oil and condensate formation. A minor proportion of Type I kerogen (close to 5%) reflects lacustrine influence, particularly in the marginal sub-basins.

The average total organic carbon (TOC) content reaches 3.2%, while the hydrogen index (HI) ranges from 120 to 160 mg HC/g TOC, confirming substantial gas-generation capacity. Modeled burial and maturity trends indicate that the onset of thermogenic gas generation occurred at a burial depth of approximately 3.8 km during the Late Jurassic period, reaching its generative peak around 5.5 km. These results suggest continuous hydrocarbon transformation under favorable geothermal gradients and sustained tectonic subsidence.

Basin modeling using PetroMod software delineated two dominant gas migration trends. The primary migration phase is characterized by the upward movement of hydrocarbons from deeply buried Devonian shale sequences into the overlying Jurassic–Cretaceous sandstone reservoirs through fault-controlled conduits. Subsequently, a secondary lateral migration occurred along stratigraphic interfaces, directing hydrocarbons toward structural highs and anticlines where favorable traps exist.

The principal migration vector trends from the southwest (Mangyshlak) toward the northeast (Ustyurt), reflecting regional tectonic tilting, compactional fluid flow, and differential subsidence across the basin. Overlying layers of anhydrite and claystone act as effective regional seals, preventing vertical leakage and enhancing hydrocarbon preservation. Pressure simulation results indicate the development of overpressure zones ranging between 15 and 20 MPa at depths exceeding 6 km, which likely facilitated episodic fluid expulsion and efficient upward hydrocarbon migration.

A gas prospectivity index (PI) was developed to evaluate the hydrocarbon potential of key structures. The model integrates three weighted parameters — geochemical maturity (M), structural closure (S), and trap integrity (T) — expressed as:

$$PI=0.4M+0.35S+0.25T$$

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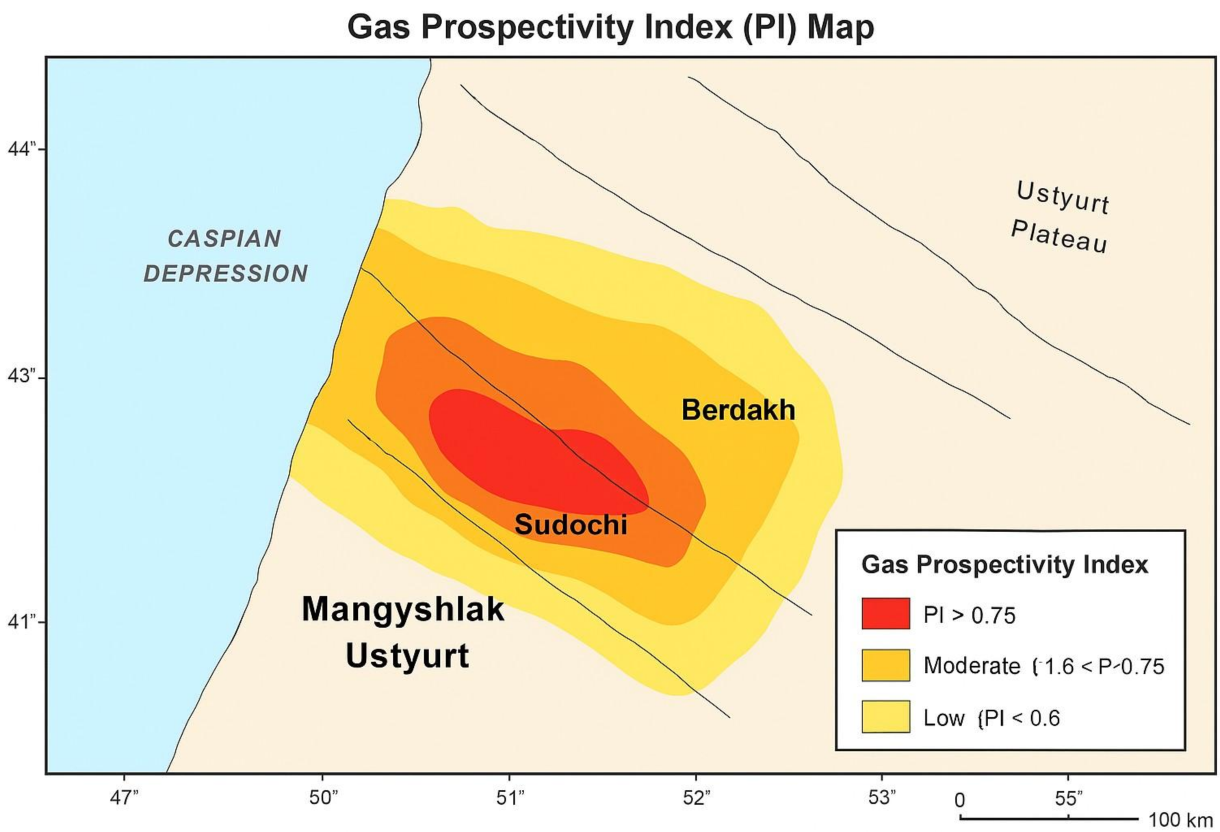
Based on normalized data, the Berdakh and Sudochi structural features exhibit PI values of 0.78 and 0.81, respectively, classifying them as highly prospective gas zones. GIS-based spatial mapping further highlights the western Ustyurt and northern Mangyshlak areas as the most favorable for gas accumulation, correlating closely with established hydrocarbon discoveries such as the Karakuduk and Arman fields. These modeled results underscore the structural and geochemical coherence of the region's gas system and suggest considerable untapped potential for further exploration.

4. Discussion. The geochemical and structural evolution of the Mangyshlak–Ustyurt basin shares notable similarities with the Amu Darya and West Siberian basins, both of which are dominated by Paleozoic source rocks and exhibit extensive gas-prone petroleum systems. However, the distinctive characteristic of the Mangyshlak–Ustyurt region lies in the coexistence of marine and



continental depositional environments, resulting in a complex mixture of kerogen types and diverse hydrocarbon signatures. This dual depositional regime contributes to a broader spectrum of hydrocarbon products and enhances the basin's overall resource heterogeneity.

Modeled geothermal gradients, ranging between 45 and 60 mW/m², are consistent with global thermogenic gas formation thresholds of 50–70 mW/m², confirming adequate thermal input for hydrocarbon cracking. Such thermal conditions favor the conversion of heavier hydrocarbons into methane-dominant compositions, a process corroborated by isotopic analyses in analogous Central Asian basins. The results thus validate the geochemical plausibility of sustained gas generation from Late Jurassic time through the present. The findings of this study hold direct implications for regional exploration strategies. Future drilling programs should prioritize structural highs adjacent to mature source kitchens, with particular attention to the Sudochi Depression and its adjoining uplifts. The integration of basin modeling outputs with geophysical inversion data can significantly refine subsurface mapping and improve the delineation of subtle trap geometries.

Given the arid and environmentally sensitive character of the Ustyurt Plateau, gas field development must incorporate strict environmental safeguards, including aquifer isolation, minimal surface disturbance, and adaptive restoration planning. In addition, future research should employ isotopic fingerprinting and noble gas analysis to more precisely differentiate between thermogenic and biogenic gas components, thereby enhancing the geochemical resolution of source attribution.

Collectively, these interpretations affirm that the Mangyshlak–Ustyurt region represents not a singular petroleum system but a composite hydrocarbon province characterized by multiple gas-generating centers, variable migration pathways, and a complex structural framework that together shape its high exploration potential.

5. Conclusion. The Mangyshlak–Ustyurt geostructural zones exhibit a geologically intricate yet highly favorable setting for natural gas generation, migration, and accumulation. The integration of basin modeling, geochemical characterization, and structural interpretation confirms that the region hosts a mature and regionally extensive petroleum system. The primary gas sources are identified within **Devonian–Carboniferous organic-rich shales**, containing mixed **Type II–III kerogen** that currently lies within the catagenetic maturity window, representing optimal conditions for thermogenic gas formation.

Gas migration is predominantly controlled by fault-related pathways, with directional flow from the **Mangyshlak uplift toward the Ustyurt plateau**, a trend governed by regional tectonic tilting and compactional gradients. Structural depressions such as **Berdakh** and **Sudochi** function as principal hydrocarbon traps, supported by robust sealing formations and favorable reservoir petrophysical properties. Basin modeling further indicates that gas generation initiated during the Late Jurassic period and has continued to the present day, suggesting a prolonged and active hydrocarbon system.

The calculated **prospectivity indices (PI > 0.75)** for the studied structures substantiate the region's high potential for future exploration. These findings collectively affirm that the **Mangyshlak–Ustyurt basin** represents a strategic and geochemically promising area for the sustainable expansion of regional gas resources within **Central Asia**. The results also underscore the necessity for continued multidisciplinary research integrating geochemical, structural, and isotopic approaches to refine exploration models and enhance predictive accuracy.

References

1. Akhmedov, N. (2020). *Tectonic Evolution and Hydrocarbon Systems of Central Asia.* Tashkent: Academy Press.
2. Beknazarov, A. (2019). Sedimentary evolution of the Ustyurt Plateau and its hydrocarbon potential. *Journal of Geoscience Studies,* 12(2), 33–47.
3. Cherepanov, A. (2016). *Comparative Hydrocarbon Geochemistry of Eurasian Basins.* Moscow: Geo-Research Institute Press.

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4. Ganiev, M. (2022). *PetroMod-based Modeling of Gas Migration in the Ustyurt Basin.* Bukhara: BSTU Press.
5. Karimov, S., & Ospanova, R. (2021). *Structural Framework of the Mangyshlak–Ustyurt Basin.* Almaty: QazGeoPress.
6. Rakhimova, D. (2018). Kerogen composition and gas-forming potential in the Paleozoic sequences of Central Asia. *Uzbek Geological Bulletin,* 4, 22–29.
7. Smith, J., & Allen, P. (2017). *Basin Modeling and Hydrocarbon Systems.* Berlin: Springer.
8. Tursunov, B. (2023). Thermogenic gas characteristics in Ustyurt fields. *Proceedings of the Uzbekistan Academy of Sciences,* 1, 50–62.