Structure and Development of Wedge-Shaped Thrusts in the Southern Flank of the Terek-Caspian Foredeep, Russia*

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Abstract

Wedge-shaped thin-skinned thrust configurations comprising linked thrusts of opposite vergence are recognized in the frontal zone of the Terek-Caspian foredeep flanking the Greater Caucasus on the north. Seismic data collected over the last decade constrained regional structural setting of this area. Integrated interpretation of geological and geophysical data showed considerable lateral structural variations within the thrust belt. Three structural segments are recognized: the Terek-Sunzha zone, Dagestan salient, and Maritime zone. It is interpreted that the prominent structural changes are primarily related to variations in the mechanical stratigraphy of the sedimentary column, geodynamic setting and tectonic grain of the pre-Jurassic section. The major compressional folding started in the Late Miocene and is still active. Due to the structural complexity, the fold belt has significant untapped hydrocarbon potential.

Geological Setting

The Terek-Caspian foredeep is located to the north of the eastern part of the Greater Caucasus, overlying the epi-Variscan Scythian Plate. This basin is filled up to a 15-km thick Permian-Cenozoic sedimentary section. Structural setting and depositional environments have evolved through several consecutive stages: post-collisional collapse (Permian-Middle Triassic), Late Triassic folding, back-arc rifting and following thermal sagging (Early-Middle Jurassic), stable carbonate-dominated
continental margin (Upper Jurassic-Eocene), and finally foredeep in front of the growing collisional orogen (Oligocene-Quaternary). The southern flank of the Terek-Caspian foredeep exhibits an extensive fold-and-thrust belt. Structural shortening there has resulted from ongoing collision of the Arabian Plate with southern margin of Eurasia, which started in the Oligocene.

**Petroleum Exploration**

The Terek-Caspian fold belt is the most prolific oil and gas area in the Northern Precaucasus. More than 60 fields have been found there; they are mostly oil fields. Cumulative oil production is about 500 mln tons (3.65 bln. bbls). Large volumes of oil were generated by mature Maykop (Oligocene-Lower Miocene) source rocks (Sokolov et al., 1990).

Vast majority of oil and gas fields is hosted in high-relief thrust-related folds. The main oil deposits are reservoired in shallow Miocene sandstones and deeper Cretaceous-Eocene carbonates. The former were the prime objectives of the early exploration campaign (1890-1930-ies). The latter were first discovered in 1950s due to deeper step-out drilling. The time lag between the two exploration campaigns was due to discrepancy in plan location of the structural closures at these stratigraphic levels. Eventually it became clear that the observed structural configurations resulted from complex divergent thrusting, producing disharmonic folding. Due to complex environments, geological interpretation was challenging. The existing geological concepts during the second exploration campaign were not able to provide an adequate explanation for the observed structural relationships. They failed to predict location of untested leads, which led to drilling of numerous dry wells. The disharmonic folding created uncertainty regarding the timing of folding, thus complicating understanding of spatio-temporal relationships of petroleum generation, migration, and accumulation. The structural models of the fold and thrust belt have evolved over time as new data have been acquired and processed with use of more advanced techniques along with introduction of modern geological concepts.

Integrated interpretation of geological and geophysical data showed that the Terek-Caspian fold belt is characterized by an extensive occurrence of wedge-shaped thrusts (Sobornov, 1988; Dotduev, 1990). They are presented in a variety of configurations comprising linked thrusts of opposite vergence. Lateral changes in structural styles of folding and thrusting provide important control of petroleum habitat of the fold belt. Three structural segments are recognized in the fold belt. From northwest they are: the Terek-Sunzha fold zone, Dagestan promontory, and Maritime zone of the Southern Dagestan.

Seismic data show the Terek-Sunzha zone marks the frontal zone of a composite low-taper tectonic wedge that has been formed on a weak basal detachment located within the Upper Jurassic (Tithonian) salt level. The overlying competent Cretaceous-
Eocene dominantly carbonate deposits form tight ramp anticlines separated by relatively wide and flat synclines. They are sealed by thick shales of the Maykop Formation. This interval provides a weak upper detachment for the underlying allochthonous assemblage. Thickness variations of the Maykop shales account for the discrepancies in location of crest of Cretaceous and Miocene culminations. Recently acquired high resolution seismic data show an extensive occurrence of multiple duplex deformation in the central part of the Terek-Sunzha fold zone, where the Upper Jurassic interval is the thickest (Groshev et al., 2018). It seems likely these thrust duplexes were formed due to folding and trusting of intra-salt carbonate stringers enveloped by salt.

The frontal zone of the Dagestan promontory is formed by backthrust-bounding triangle zones cored by stacked massive thrust sheets comprising of Lower Jurassic through Eocene strata. In cross-section view, a high-taper thrust wedge appears. The overlying Maykop-Quaternary strata produce a steep passive roof monocline cut by secondary back-thrust faults. The basal detachment in this part of the fold belt follows the shale-dominated Lower-Middle Jurassic deposits. Modern seismic data provide images of interpreted flat basal detachment transporting thrust sheets for more than 10 km to the north. Further north the basal detachment ramps up through the Upper Jurassic-Eocene carbonates and reaches the Maykop shale unit. There the basal detachment merges with south-vergent upper detachment in the Maykop shales. Further up-slope secondary backthrusts spin off the upper detachment and cut through the Miocene section, shaping foothill topography.

The Maritime zone of the southern Dagestan demonstrate a limited amount of shortening, which is mainly accommodated in two sub-parallel high relief anticlinal zones separated by broad flat syncline. As in the Terek-Sunzha fold zone, thickness variations of the deformed Maykop rocks accommodate structural disharmony of the Jurassic-Eocene and Miocene strata with development of triangle zones. Further seaward the Maritime zone is flanked by a buried uplift produced by folded pre-Jurassic rocks. Several unconformities are recognized within crestal parts of the anticlinal zones in this area. They manifest a series of structural inversions possibly related to transpressional deformation.

The observed lateral structural changes in structural style are thought to be attributed to several controlling factors including: general geodynamic setting of the fold belt, variations in the mechanical stratigraphy of the sedimentary column, and tectonic grain of the pre-Jurassic section. The formation of the low-taper thrust wedge of the Terek-Sunzha zone is primarily controlled by the areal extent of the Tithonian salt. It provides an efficient decoupling level facilitating far-reaching transfer of compressional deformation. The arcuate shape of the Dagestan promontory is broadly related to its juxtaposition against the tip zone of the advancing Arabian plate. Additionally its structural configuration interpretably was influenced by outlines of the large Lower-Middle Jurassic delta (paleo Volga) developed in the Eastern Caucasus. It the absence of the Tithonian salt the
Lower-Middle Jurassic shales provided basal detachment in this segment of the fold belt. In the Maritime zone of the southern Dagestan, structural style of folding was affected by the structural grain of the foreland. The buried pre-Jurassic uplift, along with transpressional sense of deformation, constrained the development of low-angle thrusting resulting in the formation of high-relief linear anticlinal zones.

**Conclusions**

Due to its structural complexity, the Terek-Caspian fold belt has significant untapped hydrocarbon potential. In the Terek-Sunzha zone the main prospective plays include pre-salt traps and intra-salt duplexes formed by carbonate stringers. In the Dagestan promontory prime leads are buried thrust sheets in front of the tectonic wedge. They are encased by the Lower Maykop shales which are the main hydrocarbon source rock interval in the area. This structural configuration provides favorable conditions for oil and gas charge of the structural closures in the composite thrust wedge comprising Cretaceous-Eocene carbonate reservoirs. In the Maritime zone of the southern Dagestan exploration potential is related to pre-Jurassic paleohighs flanking the fold belt. A productive analog is provided by the Permian and Triassic deposits in the Prikumsk swell in the northern part of the Terek-Caspian foredeep. In front of the fold belt and the adjacent axial zone of the foredeep, new exploration opportunities are related to stratigraphic traps and intraformational structures in the Miocene section produced by fluid mobilization such as sand injectites. Locally the sand injectites produce large structural closures.

**References Cited**


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Outlines

• Regional setting and data
• History of exploration
• Structural segmentation
• Timing of structuring & controlling factors of the structural segmentation
• Petroleum exploration opportunities
The Terek-Caspian fold belt: regional setting

- The Terek-Caspian trough - the biggest foredeep superimposed on the Scythian Plate
- Extensive fold-and-thrust belt in the southern flank of the basin
- Collisional folding and thrusting has been active since the Late Miocene
Northern Precaucasus: top K2 structure, oil and gas fields

Terek-Caspian foredeep: the deepest and most prolific oil and gas basin in the Northern Pre-Caucasus

- More than 60 fields, mostly oil
- Cumulative oil production: about 500 mln tons (3.65 bln bbls)
Database

✔ Regional 2D seismic data onshore and offshore
✔ Petroleum exploration wells
✔ Potential fields data
✔ Geochemical studies
✔ Field trips and mapping
✔ Public domain literature and industry reports
Exploration plays

- Early exploration, late 1890-1930 ies, targets: shallow Mid.-Miocene sands
- Second exploration campaign in 1950-70 ies, prime objectives: Upper Cretaceous carbonates, recognition of the disharmonic folding
Development of geological views
close lines, different interpretations

Interpretation based on geological mapping and shallow drilling

Interpretation based on deep drilling and low fold 2D seismic data

Early Maykopian folding?
New interpretation: wedge-shaped thrusting

Late Cenozoic wedge-shaped thrusting
✓ Opposite vergence of the trust faults and disharmonic folding above and below the Maykopian shales
✓ Tectonic (post-depositional) thickness variations of the Maykopian shales, accommodating the disharmonic folding
✓ Magnitude of the passive roof uplift corresponds to the tectonic thickening of the allochthonous complex

close lines, different interpretations
Distribution of oil and gas fields, lateral structural segmentation

Significant variations in structural styles and petroleum habitat
✔ Terek-Sunzha zone: highly prolific oil-bearing zone
✔ Dagestan promontory: small-middle-size fields, mainly gas
✔ Maritime zone: few small fields
Interpreted wedging of stacked thrust sheets comprising Pz-J1-2 strata, limited shortening

Delamination of the sedimentary cover along the Tithonian evaporites

Underthrusting, passive uplift of the J3-Kz section

Geological section on trend with seismic line

Pz-involved allochthonous unit
Line 1: western margin of the foredeep

Backthrusts

Structural and stratigraphic position of the backthrusts above the Pz-J wedge

Line location
Low-taper tectonic wedging, two structural culminations: Terek and Sunzha anticlines

Disharmonic folding of the Miocene and Mesozoic facilitated by thickness variations of the Maykop Fm.

Possible involvement of salt diapirism
Line 3: western part of the Terek-Sunzha zone

- Distribution of folding over larger area than in the central part of the Terek-Sunzha zone
- Smaller structural relief
- Deformation related to fluid mobilization and sand injection in the Miocene section in front of the fold belt in the deeper axial part of the foredeep
High-taper tectonic wedging

Multiple stacking of the thrust sheets comprising of the Jurassic-Eocene deposits

Seismic image of the allochthonous complex is obscured due to intense folding and the presence of thick olistolith intervals in the lower part of the Maykop Fm.
Significant shortening
Large-scale overthrusting
Development of compressional structures in the Caspian Sea
Line 5: central part of the Dagestan promontory
✔ Limited shortening
✔ Presence of the pre-Jurassic structural high (buttress) in front of the fold belt
Major Early Cenozoic tectonic events:
Early Maykop (Oligocene) foreland subsidence

✓ Rapid foreland subsidence in the Terek-Caspian foredeep
✓ Massive slumping on the northern flank of the basin with development of thick intervals of olistoliths including large megaclasts of the Upper Cretaceous-Eocene carbonates
✓ Southern progradation of clinoforms in the Maykop Fm.

Cretaceous-Eocene carbonate olistoliths in the Maykop Fm., Sulak, Dagestan
Major Late Cenozoic tectonic events: onset of the Late Miocene-Pliocene compression

Recognition of folding and faulting in the Middle-Late Miocene deposits in the axial part of the Terek-Caspian foredeep, not directly structurally linked to the thrust front. This deformation is interpreted to be related to the fluid mobilization in the Maykop and Mid-Late Miocene deposit. Most likely it was triggered by the collisional shortening.
Controlling factors: the Cenozoic geodynamic setting

✔ Folding of the southern flank of the Terek-Caspian basin resulted from the collision of the Arabian Plate and Eurasia.
✔ The Dagestan promontory is juxtaposed against tip of the Arabian Plate advancing to the north
✔ Compression is still active manifesting in high seismicity of the area
Controlling factors: the Tithonian evaporites in the Terek-Sunzha zone

Low-taper thrusting in the Terek-Sunzha zone is likely facilitated by the Tithonian evaporites. They provide weak lower detachment(s) for the allochthonous assemblage.
Controlling factors: the Early-Mid. Jurassic delta in the Dagestan promontory

Shape of the Dagestan promontory is likely governed by the outlines of up to 10-km thick Early-Middle Jurassic delta of the Eastern Caucasus. Lack of salt resulted in the higher-taper thrust wedge.

Jurassic fluvial deposits
Controlling factors: the buried uplift in the Maritime fold zone

- Shape of the Maritime fold zone is likely controlled by the pre-Jurassic paleohigh providing buttress.
- Repeated reactivation in Jurassic-Tertiary, reflecting episodes of structural inversion.
Remaining petroleum potential of the Terek-Caspian thrust belt

The main prospective plays
✔ Terek-Sunzha zone: pre- & intrasalt
✔ Dagestan promontory: buried thrust sheets in front of the tectonic wedge
✔ Maritime zone: buried high
New exploration opportunities

✔ Untested structural closures in front of the thrust belt
✔ These plays have been underexplored due to poor subsurface imaging in the past
✔ Modern exploration technologies are essential for success
New exploration opportunities

- Untested structural closures in front of the thrust belt
- These plays have been underexplored due to poor subsurface imaging in the past
- Modern exploration technologies are essential for success

Line location

Reinterpretation of the same line
Conclusions

- The fold belt is dominated by the Late Cenozoic wedge-shaped thrusting
- There is prominent lateral segmentation, which provides control on petroleum habitat
- Controlling factors of structural styles: interplay of the Cenozoic collisional geodynamics, mechanical stratigraphy, and structural grain of the foreland
- There is significant remaining petroleum potential
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