PS Petroleum System Evaluation of the Korotaikha Fold-belt and Foreland Basin, Timan-Pechora Basin, Russia*

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Abstract

The 4MM acre Korotaikha foreland basin and foldbelt is situated in the northeastern Timan-Pechora Basin, adjacent to producing acreage in the Varandey-Adzva Structural Zone (VAZ). A screening-level exploration analysis was carried out in 2011 in this Cimmerian and younger-aged basin to evaluate exploration potential. This poster will focus on the petroleum system analysis. Three main plays based on structural and fluid-flow migration regimes have been identified in the study area. Five main trap styles exist, however only the sub-thrust and imbricate thrust sheet trap types are present within the blocks offered for tender that encompass the Fold-Belt (FB) and Flank FB Plays. Significant running room has been identified in both plays. The petroleum system analysis indicates that historical heat flow is a critical uncertainly, and the main imbricate thrust Yangarey lead, located within the fold-belt play, is likely to be primarily charged with gas.

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1. Introduction

This poster is designed for the reader to 'walk through' each of the figures, starting with figure 1 below. Captions are expanded to include the necessary level of detail.

Figure 1 below illustrates the infrastructure and license status in the northern Timan-Pechora regions. The study area is noted within the blue circle, however the study focused on the Verkhne-Yangarey, Yangarey and Sibiransky blocks.

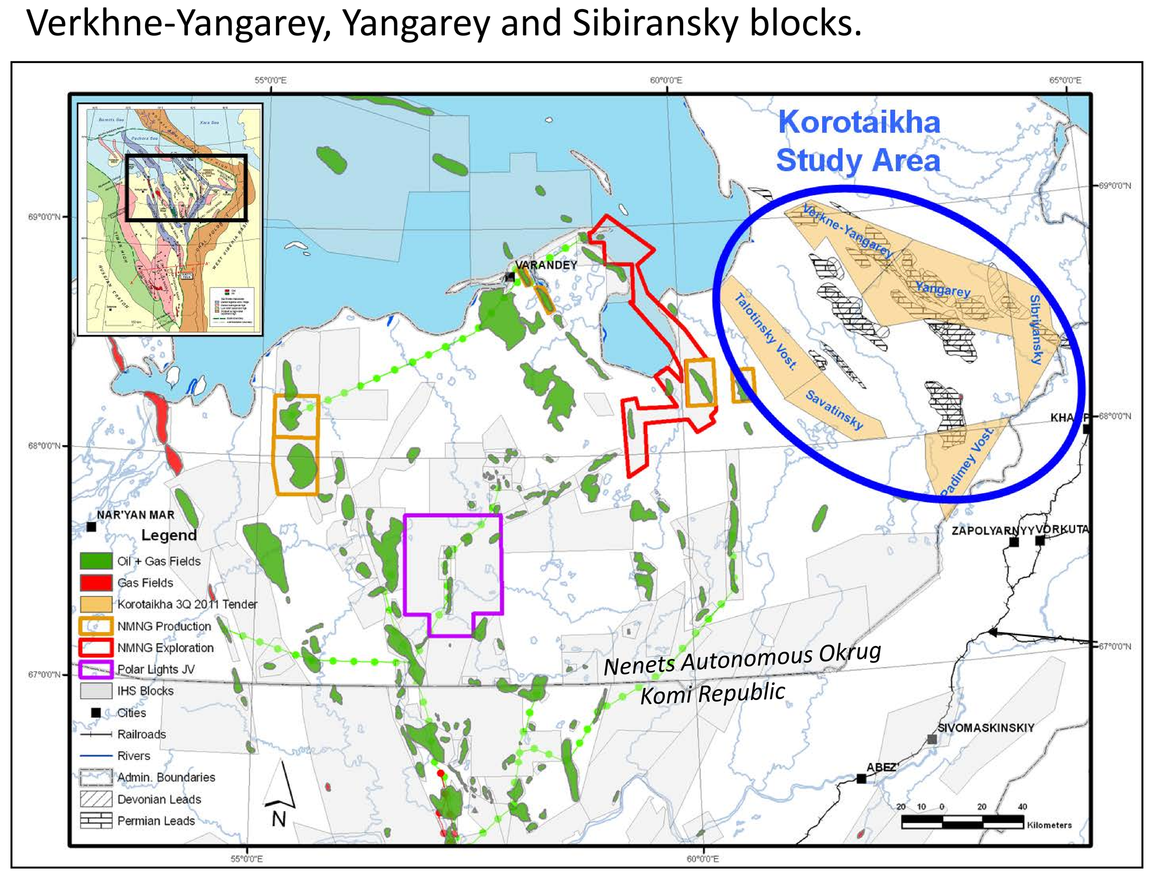


Figure 1. Location map, northern Timan-Pechora Basin, Russia. ConocoPhillips acreage (NMNG & PLC) noted.

2. Database

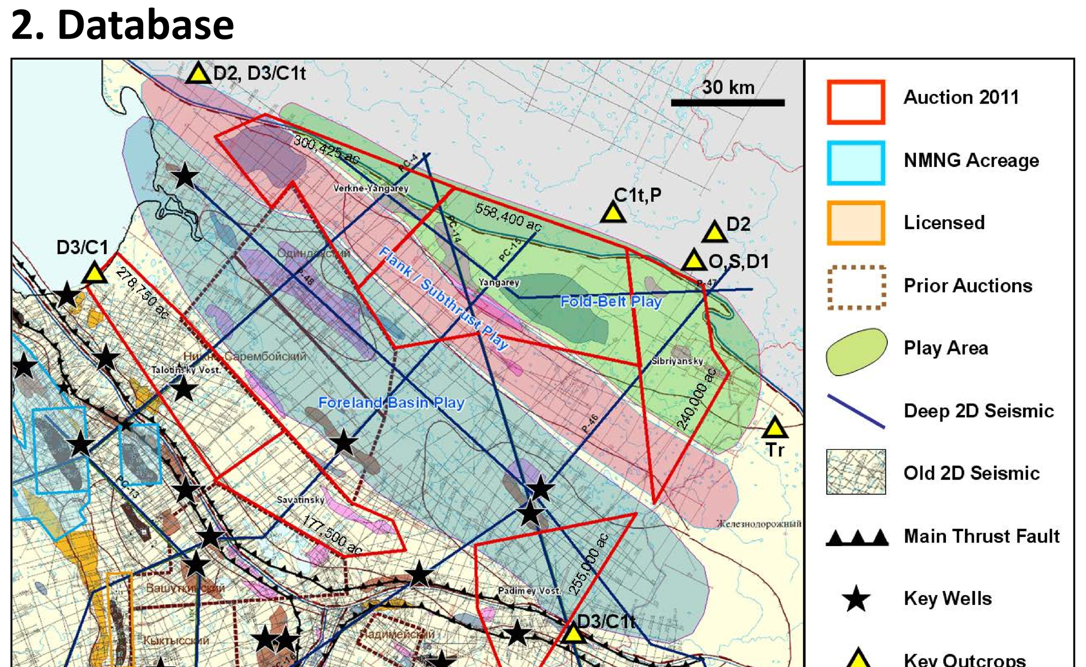


Figure 2. Seismic, well and outcrop database, Korotaikha study area. Seismic data consists of Soviet-era 2D data (1970s – 1980s) and recent deep 2D long offset transects. The NE – SW striking 2D lines (PC-4, PC-15 and P-46) were utilized for balanced structural reconstruction (Grant, 2011). In addition to the key wells and outcrops, information from nine Permian coal mine wells were utilized to calibrate the 1D maturity models. See figure 12 for location of coal mines.

3. Tectonic Setting

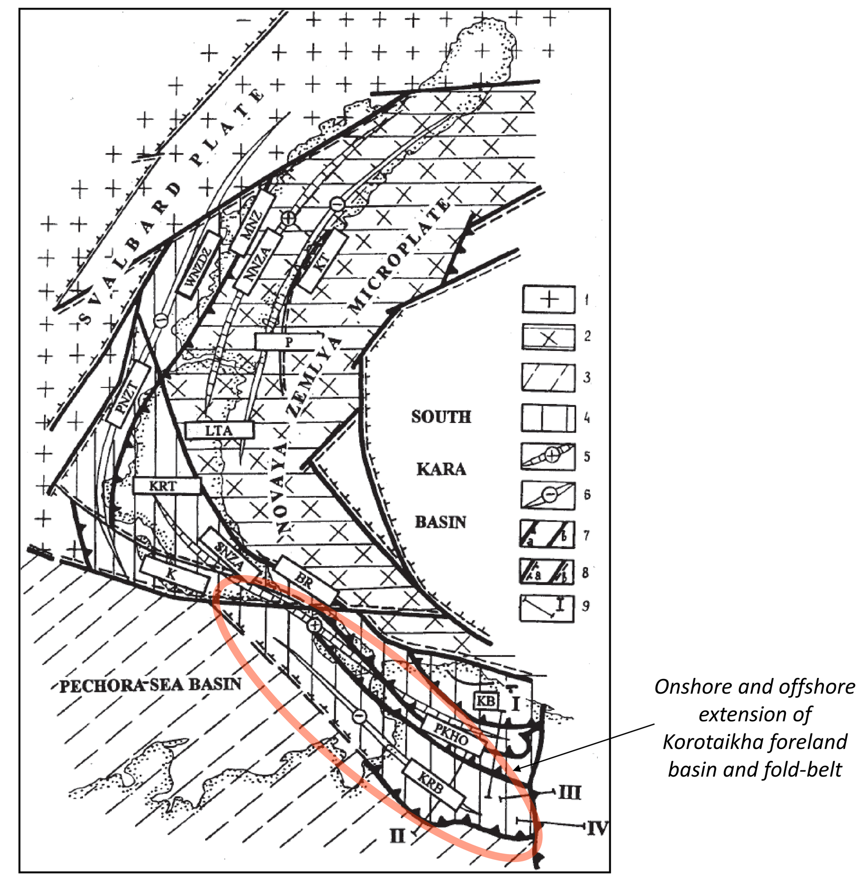


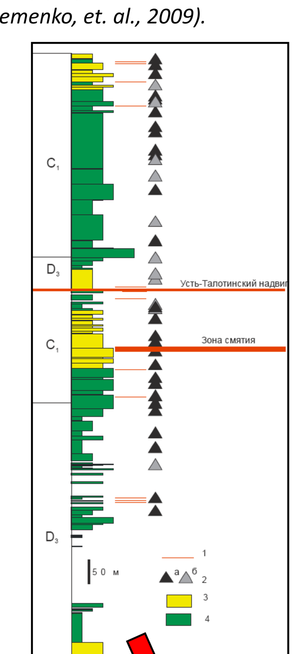
Figure 3. Tectonic scheme of the Pai-Khoi (Korotaikha) – Novaya-Zemyla region (Bogatskiy, 1996), Polar Ural Mountains. Key: (1) - Svalbard plate, (2) - Svalbard plate affected by Early Cimmerian tectonics, (3) - Timan-Pechora plate, (4) - Early Cimmerian Pai-Khoi – Novaya-Zemyla foldbelt, (5) & (6) - axes of major structures where (5) is positive and (6) is negative, (7) & (8) – tectonic dislocations where (7a) are thrusts and 7b are normal faults, (9) – lines-of-section. Names: NNZA = North Novaya Zemyla anticline, SNZA = South Novaya Zemyla anticline, PKNO = Pai-Khoi overthrust, KRT = Karmakul trough, WNZDZ = West Novaya Zemyla dislocation zone, PNZT = Pre-Novaya Zemyla trough, KT = Kara trough, LTA = Litkin anticline, ***KRB = Korotaikha basin****, KB = Kara basin. Thrusts: MNZ = Main Novaya Zemyla, BR = Baidaratsky, P = Pakhtusovsky, K = Kalodkin.*

Key insights pertaining to regional tectonic history to the south in the Ural Mountains were based on Puchkov (2009).

4. Stratigraphy, Hydrocarbon Occurrence and Plays

Figure 4. Summary stratigraphic section, Talota outcrop, north-eastern Timan-Pechora Basin, Russia. Demonstrates prolific bitumen seep occurrences in Upper Devonian and Lower Carboniferous reservoirs. Location of outcrop denoted in index map from figure 6. See figure 12 for location of other bitumen seeps.

Legend: (1) Red lines denote faults, (2) Black triangles denote bitumen seep occurrences [a = macro seeps, b = micro seeps], (3) yellow denotes clastics and (4) green denotes carbonates (Eremenko, et. al., 2009).



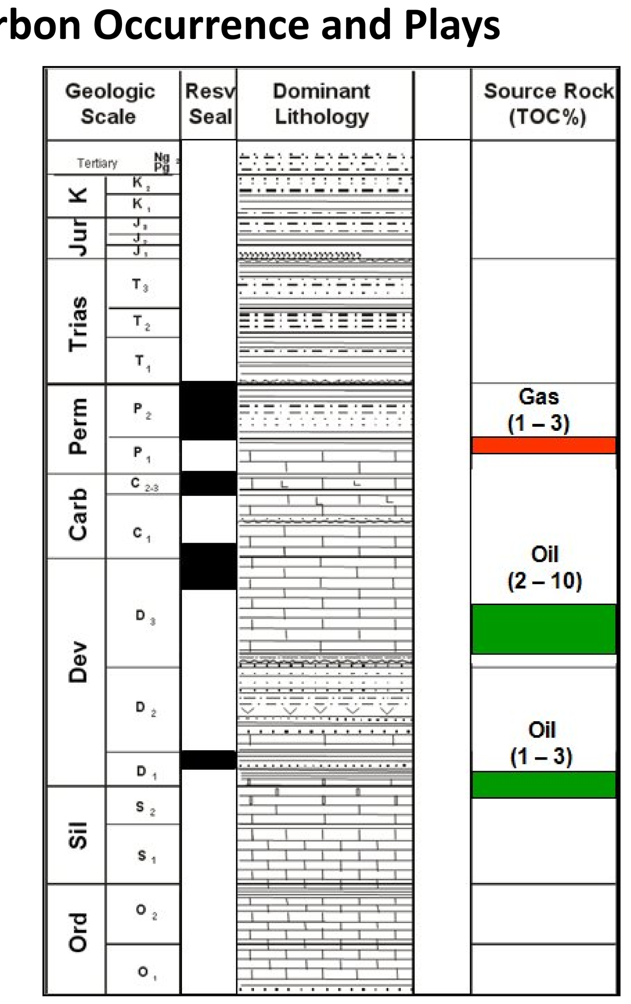


Figure 5. Representative stratigraphy in the Korotaikha fold-belt and foreland basin, northeastern Timan-Pechora Basin, Russia. Includes proposed source rock intervals with average T.O.C. (wt. %) ranges and reservoir-seal pairs.

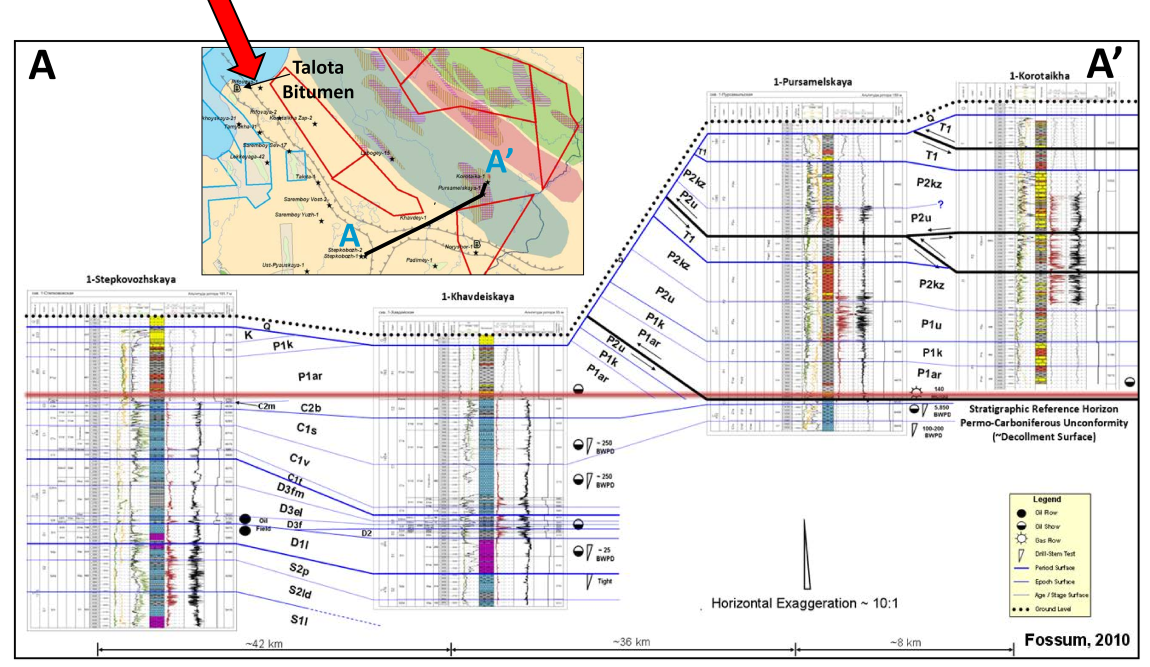


Figure 6. Southwest to northeast A-A' stratigraphic cross-section illustrating vertical and lateral hydrocarbon distribution and major interpreted faults. Flattened on major unconformity Permian-Carboniferous boundary. See inset map for line-of-section, existing fields, key wells (black stars), license blocks (red) and Korotaikha foreland basin deformation front fault system (gray with triangles in direction of foreland basin).

In general, all wells drilled to the west of the deformation front encountered flowable or commercial quantities of oil and those wells drilled inside of the deformation front and within the foreland basin encountered only oil shows (Rapoport, 2010), with the exception of the Pursamelskaya well that encountered a gas reservoir. Refer to discussion on next poster panel for explanation.

5. Structural History and Trap Characterization

A 2D structural interpretation project (Grant, 2011) was carried out utilizing three deep-penetrating 2D dip seismic lines in time (fig. 8), that were later depth-converted using regional velocity control. Results of line PC-15, which traverses the key calibration Labogei-15 well and the large four-way dip closure lead Yangarey (maximum area under closure of >40,000 acres) is displayed in figure 7. Interpretation of the three transects was carried out to be 'visually balanced' and to demonstrate a consistent structural style emphasizing detached thrusting. Initial structural balancing is demonstrated below. Main implications for the petroleum system include: (1) the distribution of thrusting and levels of detachment influence the potential trap types within the fold-thrust belt. See identified trap types in figure 7, (2) the syn-tectonic foreland basin molasse of Permo-Triassic age is a clastic system with poor source rock potential, (3) the most interesting structures are the large imbricate thrust sheets within the fold-belt proper (e.g. Yangarey). These sheets have been uplifted to depths that can be reached by the drill bit, (4) if preserved Triassic strata is all pre-tectonic, it probably implies significant erosion across the area.
Insights from the structural analysis were integrated in the 1D basin modeling illustrated on poster panel 2 (figures 12-21).

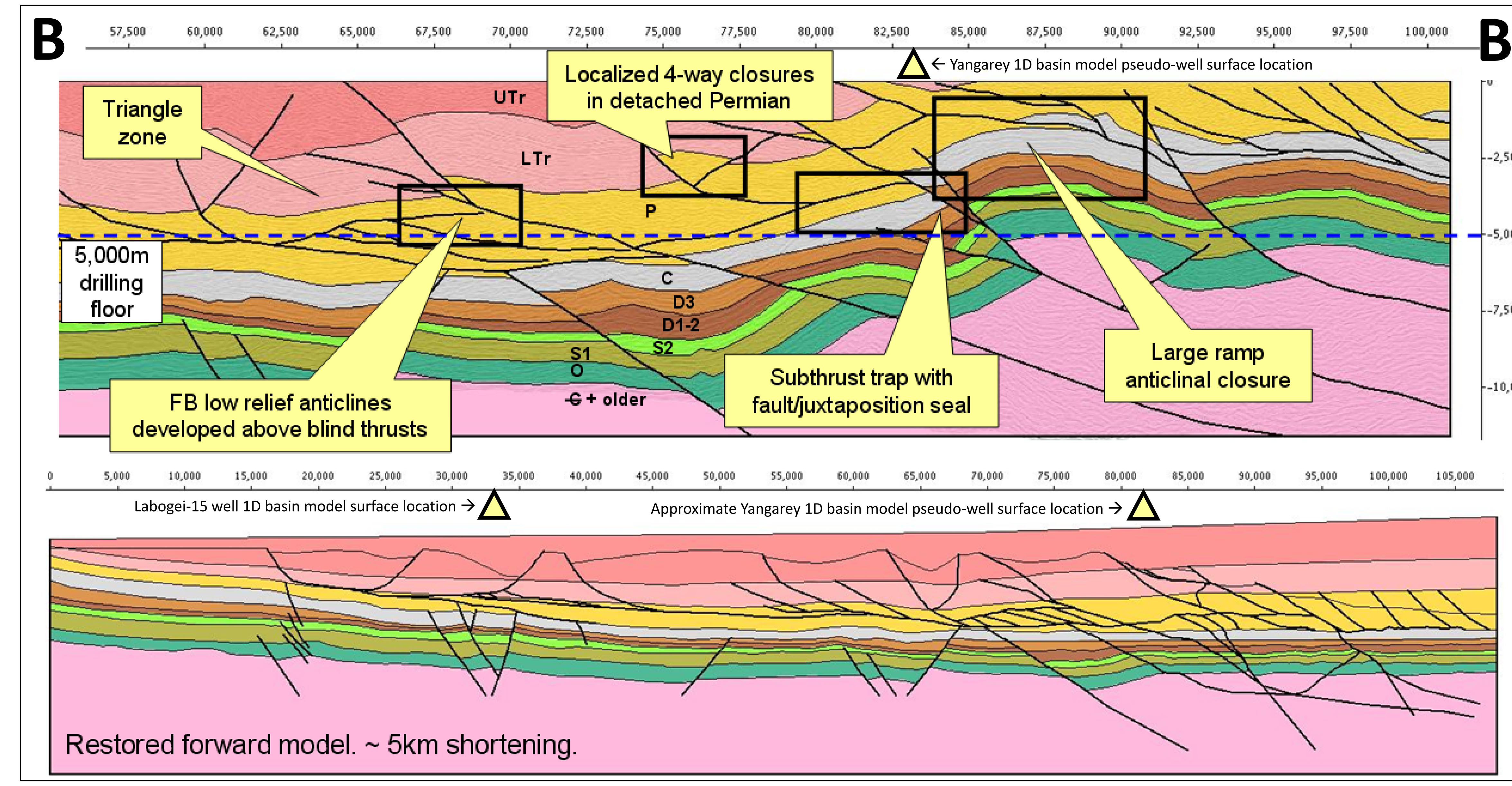


Figure 7. Structural interpretation and restored forward model of line PC-15 (see figure 8 for line-of-section). Top image in depth; conversion based on extrapolated velocity control from area wells. Main sub-play types and proposed maximum drilling depth denoted on section (Grant, 2011). Horizontal scale in meters for upper and lower images; vertical scale in meters for upper image while vertical scale for lower restored image is different. 1D basin model locations displayed with yellow triangles, see figures 12-21 for discussion.

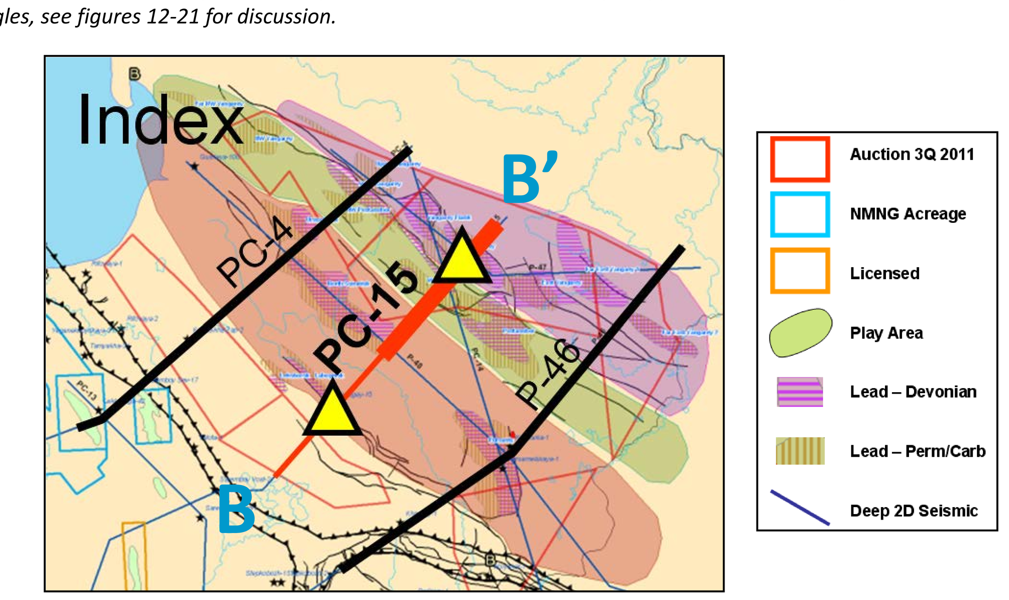


Figure 8. Index map showing the location of the three structural reconstructions carried out on deep seismic transects PC-4, PC-15 and P-46 (Grant, 2011). Line PC-15 (B-B'), which ties the foreland basin Labogei-15 well and crosses the Yangarey lead pseudo-well location is displayed in figure 5. 1D basin models were prepared for both the Labogei-15 and Yangarey flank pseudo-well location (yellow triangles). PC-15: thin red line depicts entire seismic line that was interpreted, thick red line depicts portion of interpretation displayed above in figure 7.

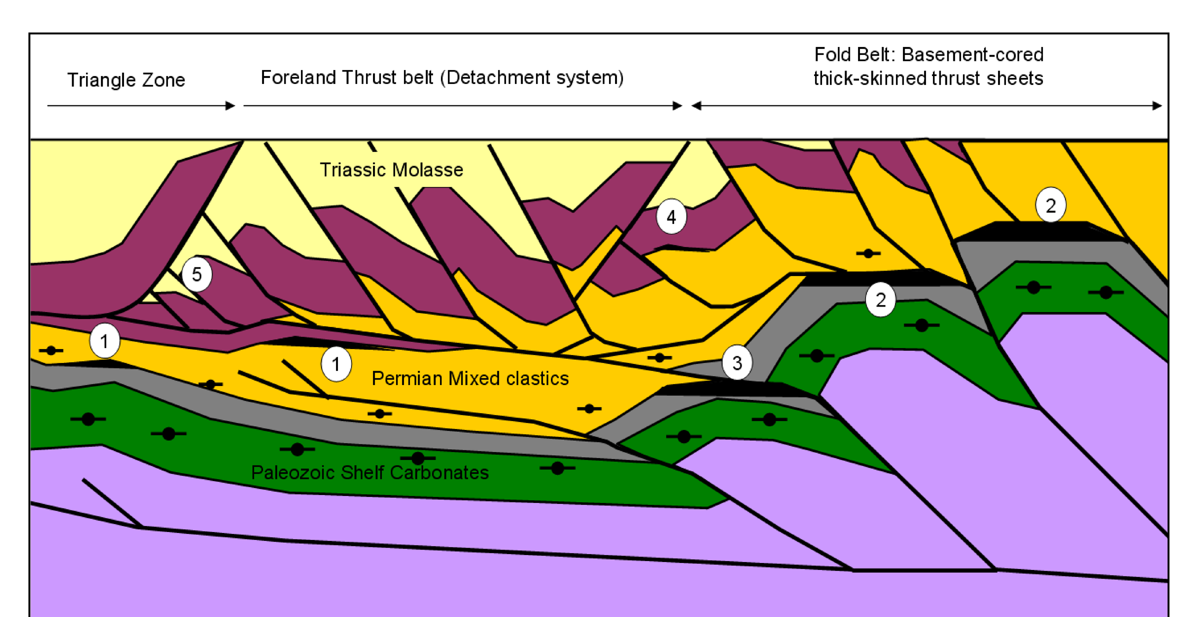


Figure 9. Summary cartoon for the Korotaikha Basin showing structural styles and potential hydrocarbon plays (Grant, 2011). Approximate orientation southwest (left) to northeast (right).

Key:(1) Foreland basin low-relief anticlines above blind thrusts, (2) Fold-belt ramp anticlines with Paleozoic carbonates, (3) Sub-thrust trap, (4) Localized 4-way closures with detached Permian clastics, (5) Triangle zone (sub-thrust).

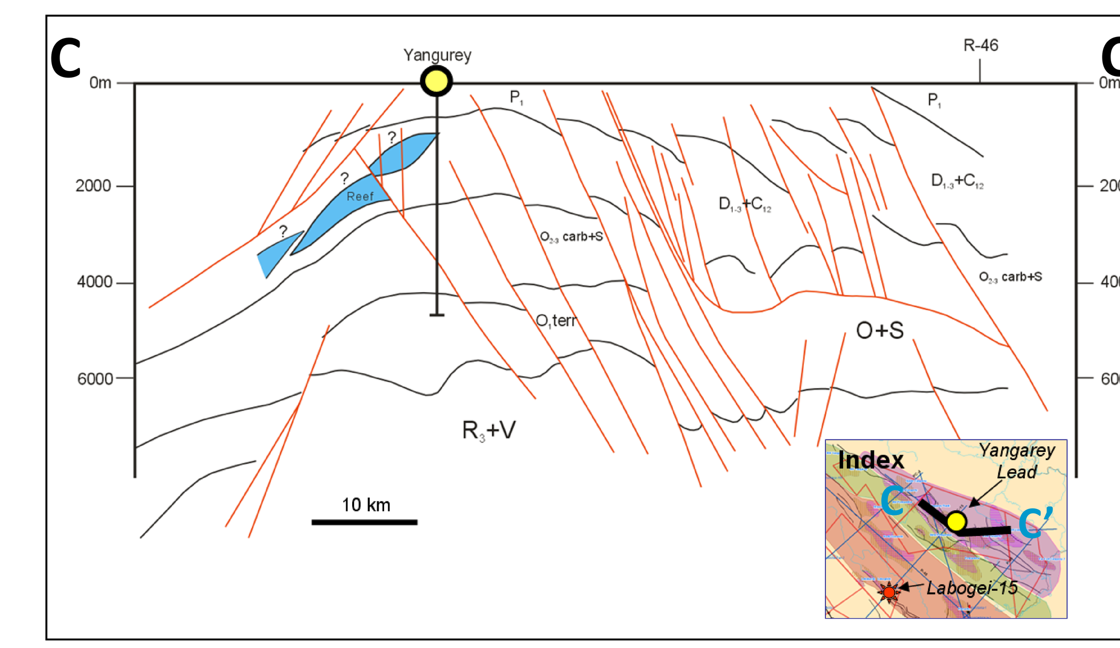


Figure 10. Representative geoseismic line drawing, Line P-47 strike seismic line across Yangarey lead. Depth in meters.

See inset map for line-of-section. Proposed well location per VNIGRI state geological institute, St. Petersburg, Russia. Due to Russia Federation data export restrictions, the original seismic data could not be displayed on the poster.

6. Structural Analogs – Vuktyl / Yugid-Vuktyl Fields

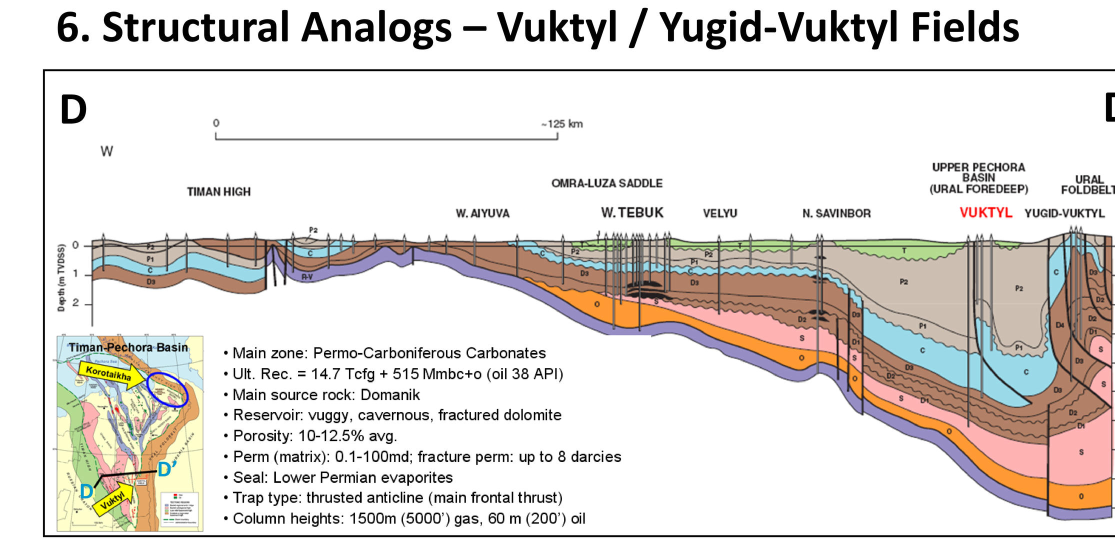


Figure 11. South-west to east-northeast D-D' geoseismic cross-section (C&C Reservoirs, 2004) across the Pre-Cambrian aged Timan Ridge on the west (Puchkov, 2009), to the giant Vuktyl Field on the east, within the Ural Mountains fold-belt and foreland basin. The Vuktyl / Yugid-Vuktyl Field complex is considered to be a viable analog for leads and prospects within the Korotaikha Basin.

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7. Petroleum System Analysis

A screening-level petroleum systems analysis was carried out for the Korotaikha region, with the main goals of determining the presence of an active petroleum system, high-grade the play types and determine the likelihood of oil vs. gas charge. Maturity and AFTA data were available in the calibration well Labogei-15 (Duddy, 2011), and critical coal rank maturity (Anashenko, 2004) and geothermal gradient data were available across the mapped leads in the fold-belt and flank sub-thrust plays. Lithology data were available throughout the region, and tops were driven by well log correlations and results of the structural analysis.

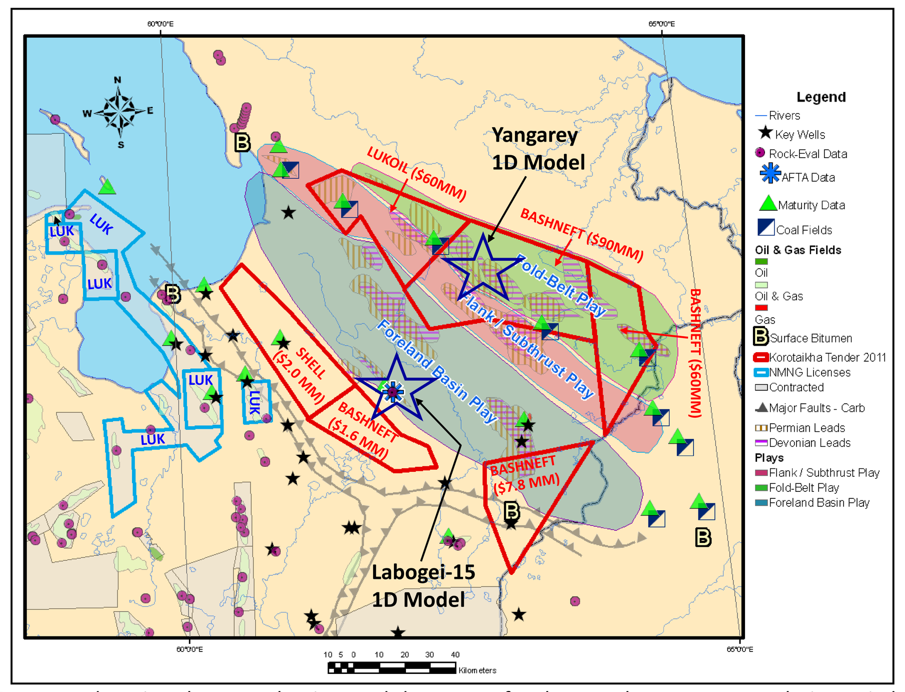

Figure 12. Basemap denoting the control points and data types for the petroleum system analysis carried out in the Korotaikha region. Generally, lithology data are available for each key well. Main plays, structural leads and 2011 tender license areas denoted (red blocks), along with 2011 + 2012 results reported by Rosnedra (red text). Labogei-15 is considered to be a key well due to the high level of data available including rock-eval, maturity, lithology, well logs and AFTA. Locations for the Labogei-15 and Yangarey pseudo-well 1D basin models noted.

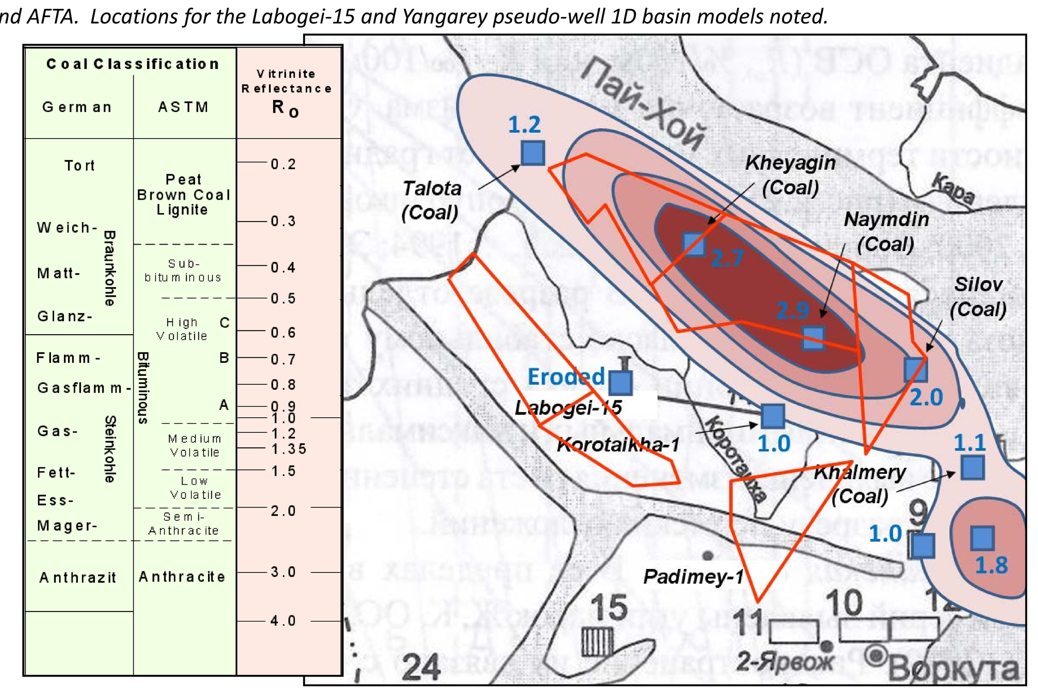

Figure 13. Maturity (Ro) map of Upper Permian Intinskaya Formation, northeast rim of Korotaikha foreland basin. Maturity based on coal rank data (Anashenko, 2004), converted to Ro based on standard conversion charts (Michael, 2011). Similar Ro maturity patterns have been mapped in the Lower Permian Vorkuta Formation.

Note present day high maturity dry gas generation region in vicinity of Kheyagin and Naymdin coal wells (area of Yangarey lead) – this is hypothesized to be related to a magmatic plume that originated during Devonian rifting (Lobkovsky, 1996) and continued to impact sediments in the Mesozoic during and following the Permo-Triassic Cimmerian Orogeny. Andreichev (2007) dates basalt flows in the region based on Rb-Sr (250 +-15Ma) and Sm-Nd (249 +-17Ma), which is correlative in age to the Siberian plateau basalts to the east in the West Siberia Basin. Available low-resolution magnetic data suggests the presence of a plume in this region (Flanagan, 2010). Alternatively, the source of the heat flow may be due to thrust stacking in the fold belt, followed by subsequent uplift (isostatic plus erosion). However due to the relative focused area of the higher maturities, the plume model is preferred.

Leads in the cooler Talota and Khalmery coal regions are more conducive to present-day oil generation.

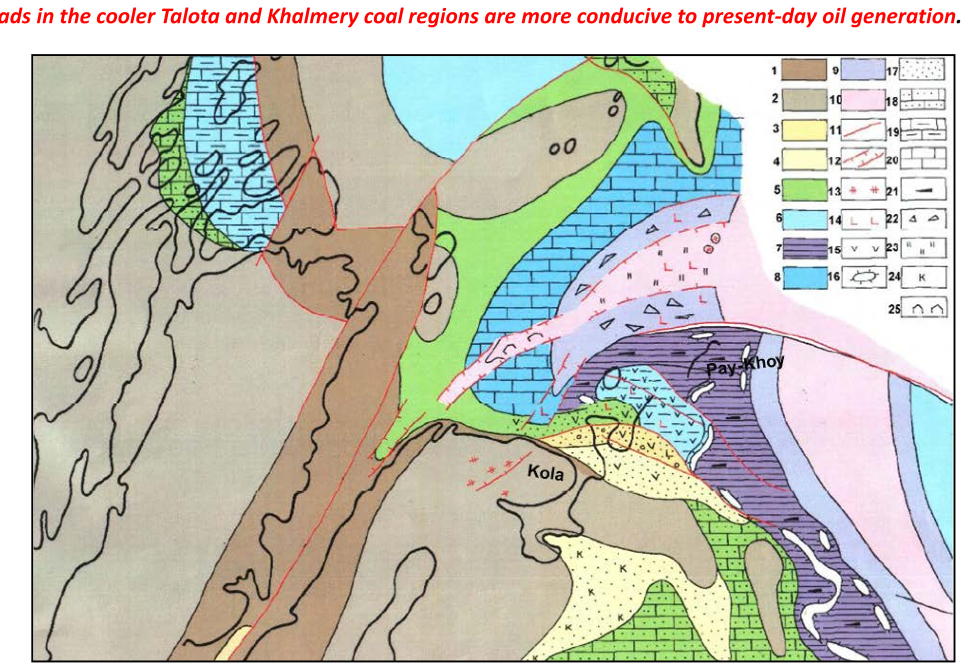

Figure 14. Upper Devonian paleogeography map (Margulis, 2009) illustrates the Domanakoid source rock facies (facies 7 and 21) present in the Pay-Khoi / Korotaikha region. Structural analysis by Grant (2011) indicates a minimal amount of shortening (~5 km) occurred during the syn- and post-Cimmerian event in the Yangarey region and as much as ~50 km towards Novaya Zemyla (north) and southeast towards the Urals, therefore in general the interpreted paleogeography supports oil-prone Domanik facies in the region. Source rock intervals also recognized in the oil-prone Lower-Middle Devonian and gas-prone Lower Permian (Prischepa, 2011 & Bazhenova, 2008), based on area outcrop and well control whole core data.

*Key: (1) high mountains, (2) low relief, (3) alluvial, (4) lagoonal-continental, (5) coastal marine, (6) marginal marine, **(7) shelf shales** (8) outer shelf, (9) continental slope, (10) bathyal, (11) main faults, (12) rifts, (13) alkaline intrusions, (14) basalts, (15) volcanic & sedimentary rocks, (16) reefs, (17) terrigenous, (18) sandy limestone, (19) argillaceous limestone, (20) limestone, **(21) kerogen-rich,** (22) olistostromes, olistoliths; (23) chert, (24) red beds, (25) evaporites.*

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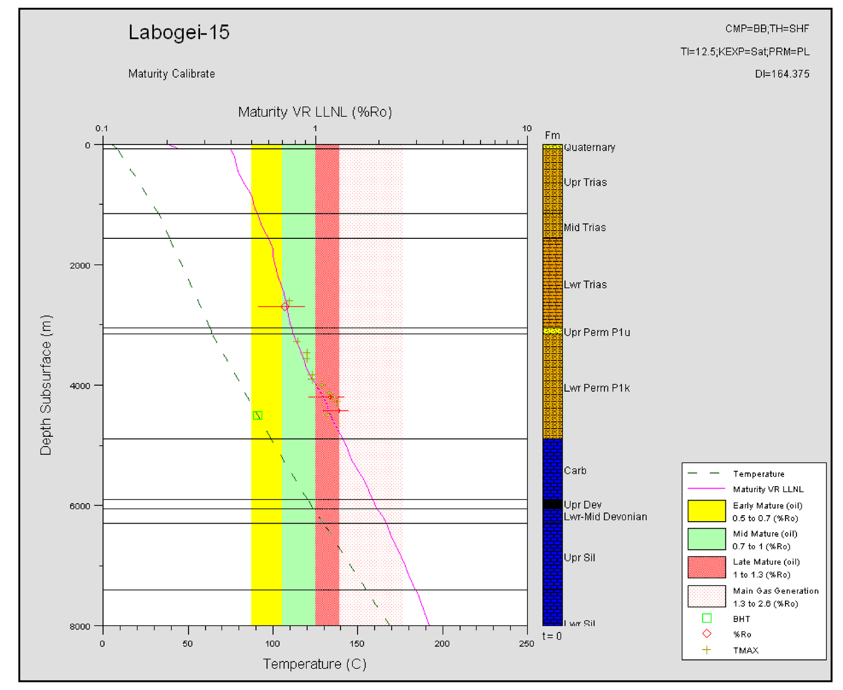

Figure 15. Labogei-15 1D basin model (Basinmod v1.64) present-day and historical heat flow calibration panel. Bottom-hole temperature and Ro data from Duddy (2011). Rock-eval Tmax data from Wavrek (1997). Lithology data to Lower Permian based on cuttings and whole core taken from the Labogei-15 well; lithology information from section older than Lower Permian from adjacent well control. Steady-state heat flow of 47 mW/m² utilized. Baldwin and Butler compaction algorithm utilized, calibrated by Gardner-generated density data from sonic log data available in the Labogei-15 well. See figure 12 for well location.

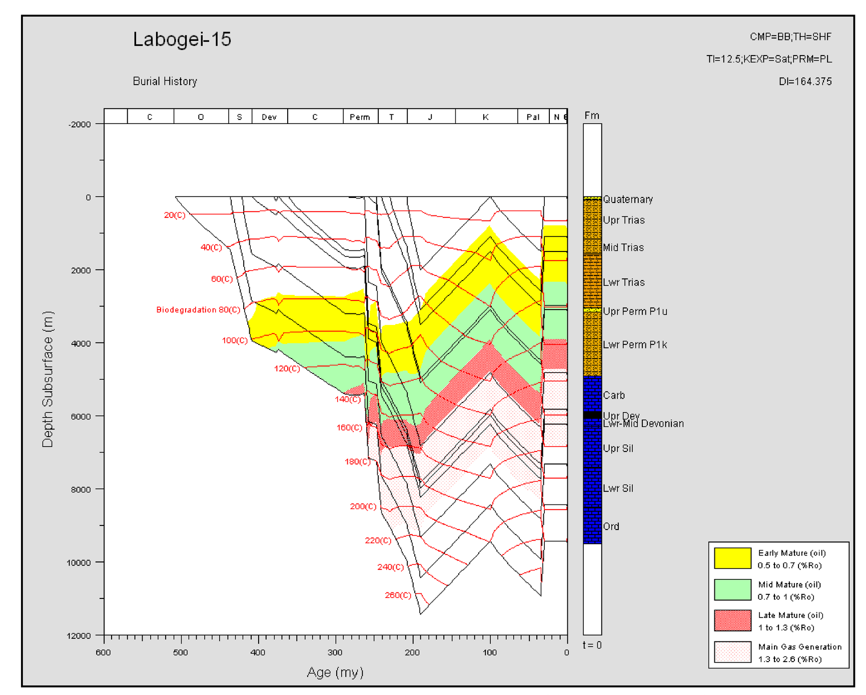

Figure 16. Labogei-15 burial history panel. Burial history constrained by regional studies, 2D structural reconstruction (Grant, 2011) and AFTA data in the Labogei-15 well (Duddy, 2011). Main source rock intervals per Wavrek (1997), Bazhenova (2008) and Prischepa (2011) recognized in the Lower – Middle Devonian (Type II oil prone, iTOC = 3 wt.%, iHI = 500 mg/g TOC)), Upper Devonian Domanik (Type II oil prone, iTOC = 5 wt.%, iHI = 500 mg/g TOC) and Lower Permian P1k (Type III gas prone, iTOC = 2 wt.%, iHI = 100 mg/g TOC).

Burial history analysis demonstrates the main oil-prone source rock intervals in the Devonian are in the present-day gas window, and the gas-prone source rock in the Permian is in the main and late mature oil window. A documented oil show in the Lower Permian Labogei-15 well, suggest that the gas-prone source rock may have the potential to generate oil, but it is expected to be minor.

Results suggest that the observed bitumen around the rim of the foreland basin and the numerous oil shows in the wells on the southwest region of the foreland basin (figures 4 & 12) was generated syn- and post-Permian and Triassic Cimmerian tectonic event. It is hypothesized that the generated oil from the oil-prone Devonian source rocks migrated west towards the main fault deformation front that is on the northeastern margin (figure 17) of the Varandey-Adzva Structural Zone (VAZ), and into traps within that structural region. Ablia (2005) concluded from biomarker analyses that oils from the Lekkeyaga, Sev. Saremboy and Toboy-Medyn-Mydsey VAZ Fields were charged from Silurian, Lower Devonian and Upper Devonian source rocks.

Pre-Permian structural traps that are situated between the main axis of the Korotaikha foreland basin and the VAZ deformation front on the west would receive generated hydrocarbons from this maturation event. Seal is a critical uncertainty (Rapoport, 2010). The Upper Devonian Rifovaya reefs are positioned in the described structural position (figure 17), however the Rifovaya-1 well encountered water, suggesting top and side seal where not present, or structural tilting took place after hydrocarbon charge resulting from the Korotaikha foreland basin development.

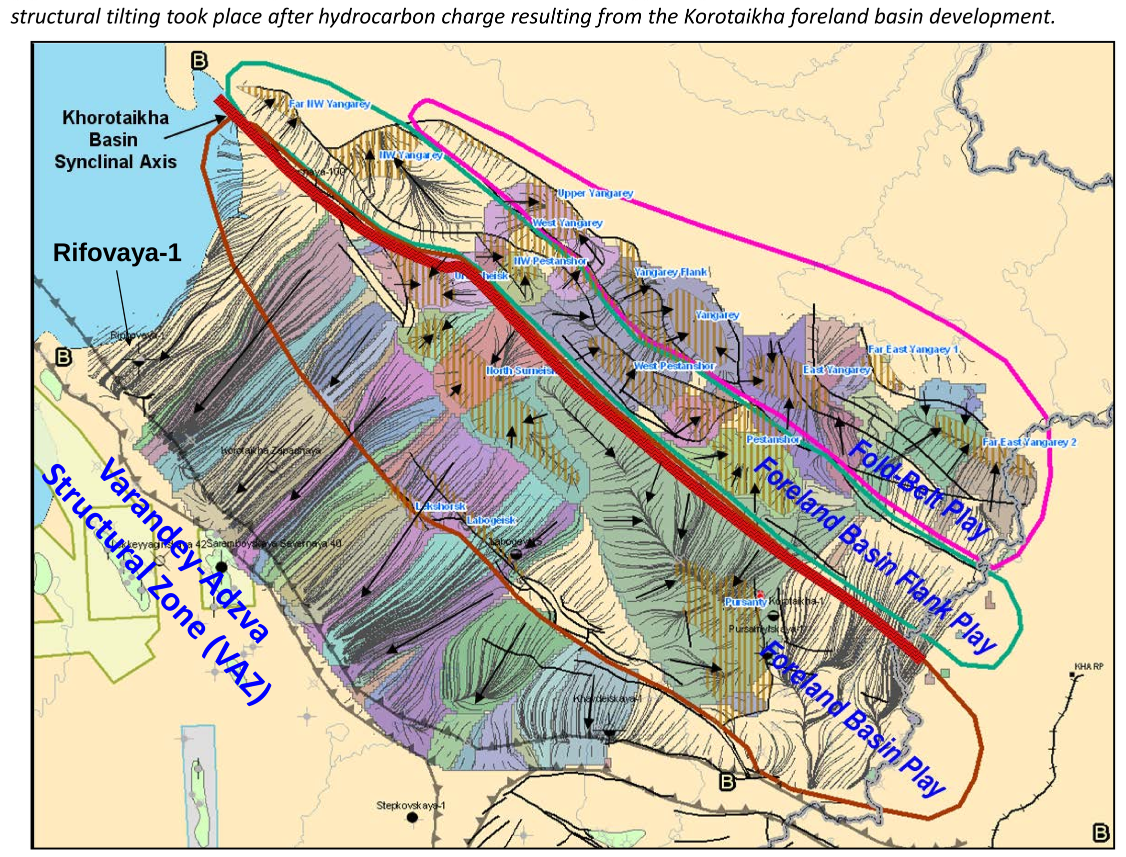

Figure 17. Present-day fluid flow dip vector map, prepared at the top of the Carboniferous depth structure (Prischepa, 2011). The main axis of the Korotaikha basin is denoted, which represents the deepest portion of the present-day foreland basin. The axis separates present day fluid flow regime into two main regions - to the southwest towards the deformation front and eventually the VAZ region, and to the northeast, into the numerous leads within the foreland basin flank and fold-belt plays. Assuming a present-day hydrocarbon migration system and fault seal, it is hypothesized that the series of leads structurally adjacent to the foreland basin axis would have a lower risk of charge e.g. these are the first traps to capture generated hydrocarbons from the deeper basin axis. However it is recognized that top and side seal are a critical uncertainty in that region.

The foreland basin leads in general depend on fault seal, while the fold-belt leads depend on both fault seal and three-way dip – except for the large Yangarey lead, which is largely a four-way closure. Leads within the foreland basin play, which is quite deep, in general are four-way closures, perhaps related to deep structural culminations formed during the foreland basin development.

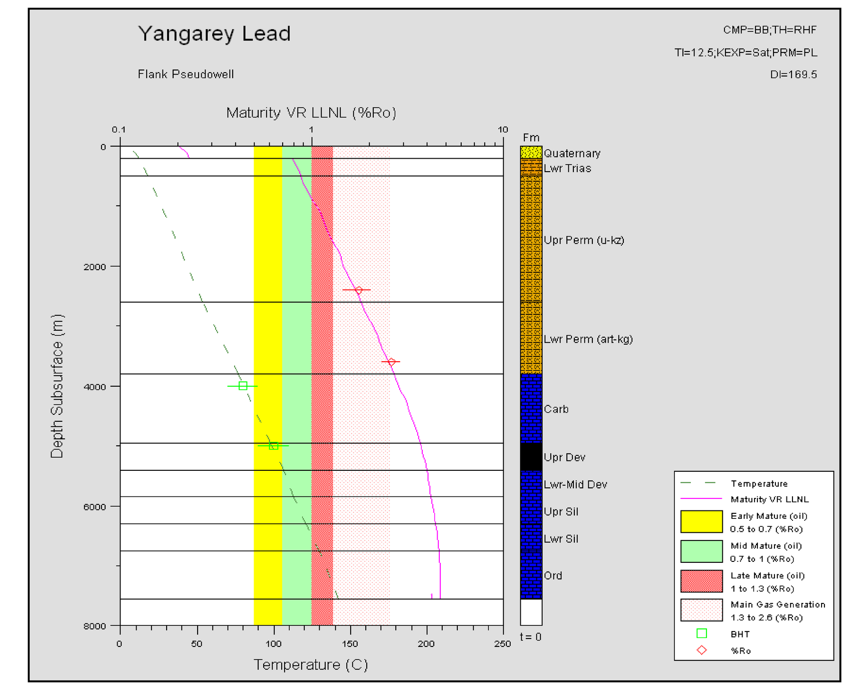

Figure 18. Yangarey pseudo-well 1D basin model present-day and historical heat flow calibration panel. Bottom-hole temperatures and maturity (Ro converted from coal rank) data based on reported geothermal gradients in Anashenko (2004) and Timochenko (1997). Lithology data based on paleogeography in Margulis (2009) and Prischepa (2011) and offset well control. Historical heat flow (figure 18) per magmatic activity demonstrated in figure 13 and discussed in Lobkovsky (1996) and Andreichev (2007). Baldwin and Butler compaction algorithm utilized, calibrated by Gardner-generated density data from sonic log and interval velocity data available in the region. See figure 12 for location.

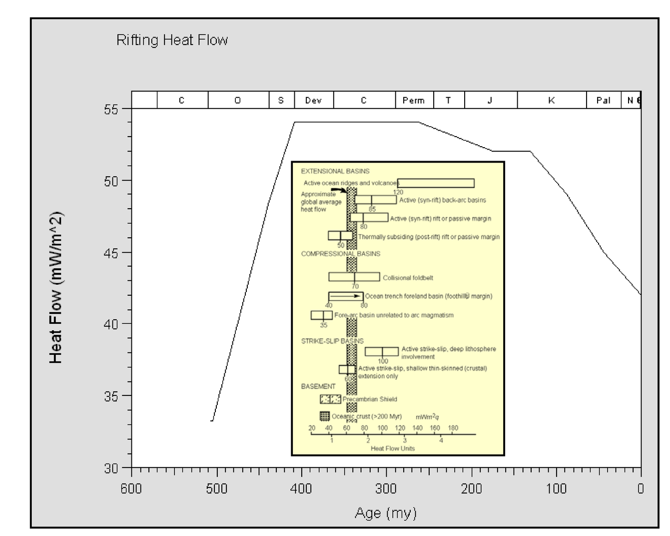

Figure 19. Heat flow profile utilized in the Yangarey pseudo-well 1D basin model, which was necessary to calibrate the maturity Ro data, generated from the coal rank information from Anashenko (2004) in the Kheyagin and Naymdin coal wells (figure 12) and calibrated to Paleozoic rift history from Ismail-Zadeh (1997). No radiogenic heat utilized. Per Allan and Allan (1990), the modeled heat flow values fall within a reasonable range, given the current quiescent tectonic setting and compressional foldbelt geological history (figure 19 inset).

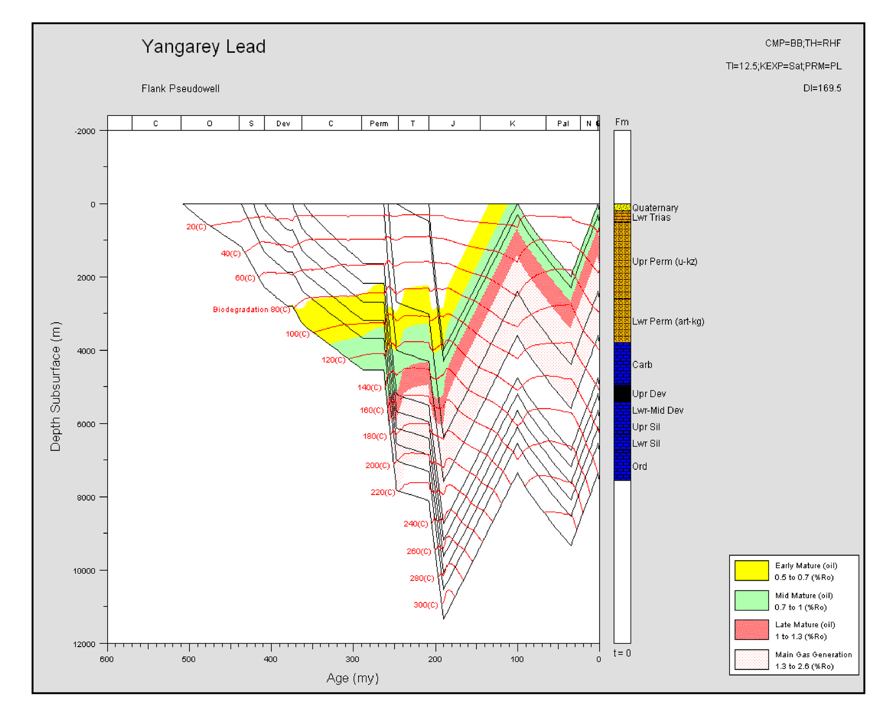

Figure 20. Yangarey pseudo-well burial history panel; location situated on the southwest flank of the main structure for Yangarey lead. Burial history constrained by regional studies, 2D structural reconstruction (Grant, 2011) and extrapolated AFTA events from the Labogei-15 calibration well (Duddy, 2011). Main source rock intervals per Wavrek (1997), Bazhenova (2008) and Prischepa (2011) recognized in the Lower – Middle Devonian (Type II oil prone, iTOC = 3 wt.%, iHI = 500 mg/g TOC)), Upper Devonian Domanik (Type II oil prone, iTOC = 5 wt.%, iHI = 500 mg/g TOC) and Lower Permian P1k (Type III gas prone, iTOC = 2 wt.%, iHI = 100 mg/g TOC).

*Burial history analysis demonstrates the main oil-prone source rock intervals in the Devonian are in the present-day cracked gas window, and the gas-prone source rock in the Permian is in the main gas generation window. **Results suggest that the Yangarey lead is charged with mainly gas.***

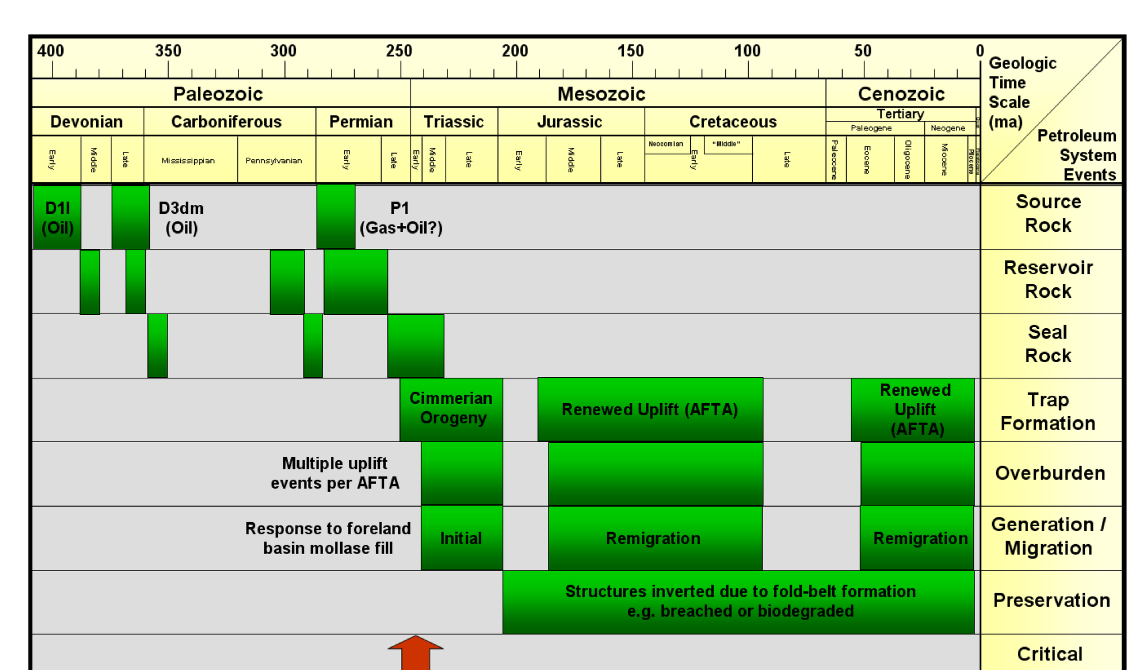

*Figure 21. Generalized petroleum system chart for the Korotaikha foreland basin. The critical point has been designated as the onset of the Permo-Triassic Cimmerian tectonic event, however it should be noted each phase of uplift (Duddy, 2011) that leads to fluid re-migration and source rock generation are important as well. **The critical uncertainty is heat flow, and it is proposed that the best chance to discover liquid hydrocarbons in the Korotaikha region are in areas of lower historical heat flow. This occurs in the Talota and Khalmery regions (figure 13).***

8. Discussion and Conclusions

The exploration maturity of the Korotaikha region is low, with a limited 2D seismic database of varying vintages and a handful of exploration wells. Three main structural play types with numerous large traps and significant running room have been identified. Based on available outcrop and regional well log data, three primary source rock intervals are hypothesized; oil-prone Ordovician / Silurian carbonates, oil-prone Devonian "Domanik" carbonates and gas-prone Permian clastics. Reservoir / seal pairs are recognized in four zones – Lower Devonian Carbonates, Upper Devonian / Lower Carboniferous Carbonates, Carboniferous Carbonates and Permian Clastics.

Regional present-day temperature data from down-hole measurements and burial history modeling support a relatively cool present-day foreland trough and fold-belt, with a geotherm of around 19 °C per km., suggesting the top and base of the present-day oil window is at 1,000 and 4,800 meters respectively.

However, historical heat flow values calibrated to nearby coal rank maturity data, coupled with the burial and uplift history, suggest that the main Yangarey block lead in the fold-belt is gas-charged. The data also suggest that the heat flow history is cooler in the Verkhne-Yangarey and Sibiransky blocks, suggesting a better chance of oil-charged traps in those regions. Additional risks include adverse effects of deep burial on reservoir quality, and loss of containment due to uplift and erosion.

9. Key References

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