

# **Salt Tectonics in the Timan Pechora Basin, NW Russia: Structural Setting and Petroleum Exploration Opportunities**

**Konstantin Sobornov<sup>1</sup>**

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## **Introduction**

The Timan Pechora Basin is one of the most economically important petroliferous basins of Russia, and one of the 25 World's major superbasins (Sternbach, 2020). Oil and gas production started there in early 1930-s and peaked in 2009, reaching 32 mln. tons per year. Significant exploration efforts were taken over the last decades to arrest the declining production. Cumulative oil and gas production of the Timan Pechora Basin total 10 bln bbls of oil equivalent, two-thirds of which is oil and condensate (Prishchepa et al., 2021).

Deep drilling and seismic surveying showed the Upper Ordovician salt's widespread occurrence and important structural role in the eastern part of the basin (Sobornov and Pilnik, 1991; Belenitskaya, 2020, etc.). Interpretation of vintage and new subsurface data revealed that the underexplored NE flank of the Timan Pechora Basin includes various salt-related structures ([Slide 3](#)). They include flat-lying salt layers, salt pillows, squeezed diapirs, and allochthonous thrust sheets involving salt layers. Multiple hydrocarbon traps are associated with them. Prospective plays were interpreted in the northern part of the basin including the offshore part of the basin. Drilling of the salt-related prospects brought mixed results (e.g. Grunis et al., 2016; Danilov, 2017). Recent regional studies suggested that of prime exploration interest is an extensive backthrust play developed in the transition zone between the Kosyu-Rogov Trough and the Chernyshev Swell (e.g. Sobornov et al., 2021). New exploration opportunities related to halokinetic structures are discussed in this paper.

## **Geological setting**

The basin featured a Paleozoic continental margin of the Uralian Ocean ([Slide 4](#)). Continental collisions in Permian and Triassic times Late Paleozoic modified the continental margin into the fold and thrust belt. The sedimentary fill of the basin includes up to 15 km thick sedimentary section. Three megasequences are recognized in the Paleozoic sedimentary cover related to rifting, post-rift subsidence, and the foredeep basin in front of the advancing Uralian and Pay-Khoy-Novaya Zemlya fold and thrust belts.

The rift megasequence is composed mainly of the Ordovician deposits. The Upper Ordovician section includes evaporites. The continental margin megasequence encompasses Silurian-Lower Artinskian carbonate-dominated succession. The overlying foredeep basin megasequence includes the Upper Artinskian-Triassic mainly siliciclastic deposits.

Interpretation of subsurface data shows that the underexplored NE flank of the basin includes numerous salt-related structures. The Upper Ordovician salt interval provides basal detachment along which the suprasalt section was transported to the west (Yudin 1994 etc.). Unlike other segments of the Uralian Foreland, the NE part of the Timan Pechora basin is characterized by a much broader distribution of compressional deformation.

Folding and thrusting were mainly developed in the internal and external parts of the fold belt which are separated by broad mildly deformed Kosyu Rogov and Korotaykha synclines.

### **Backthrust play, salt**

The most promising new leads were interpreted in the eastern flank of the Chernyshev Swell, which forms a fold and thrust zone in front of the foreland thrust belt ([Slide 6](#)). Of prime interest, there are the extensive zones of salt-related backthrusts. This backthrust structural trend created migration focuses for oil and gas expelled from mature oil kitchens in the buried parts of the Uralian Foredeep Basin.

The first well, 1-Vorgamusur, targeted the sub-backthrust lead penetrated salt interval and encountered an overpressured oil pay. It went out of control and blew off, resulting in a fire that destroyed the well. The estimated initial oil flow rate was about 300-500 m<sup>3</sup> per day. The oil gusher gave rise to great expectations, suggesting a high chance of a significant subsalt oil discovery. Three deep step-out wells were spudded to test this play. Multiple shows were reported in all of them, but no commercial discovery was made ([Slide 10](#)). Post mortem study showed that there was no closure in the subthrust zone in the area of drilling. It was shown that the overpressured oil pay encountered in the first well was related to a carbonate stringer encased by the Upper Ordovician salt.

The failed attempt to score a quick discovery suggested that the following exploration well should be preceded by much more accurate studies, including a review of regional geological settings. This review high-graded the Povarnitsa High as a potential sweet spot of the sub-backthrust play ([Slides 11, 12](#)). It is situated in the southern part of the transition zone between the Chernyshev Swell and the Kosyu Rogov Trough of the Uralian Foredeep Basin. This structure forms the largest structural culmination on this structural trend flanked by a 40-45 km long backthrust zone. At the surface, this zone is marked by an extensive tectonic contact of the disturbed Upper Ordovician-Silurian rocks with the Permian fill of the foredeep basin.

To derisk the sub-backthrust play vintage data were reprocessed and new 3D seismic, magnetotelluric (MT), gravimetric and magnetometric data were acquired. The main goals of this study included: (1) to delineate the high, including its subthrust extension, and (2) to trace the salt wall ([Slide 13](#)). Integrated interpretation showed that the footprint of the Povarnitsa High is c. 250 km<sup>2</sup>, and its structural relief is about 1 km. A massive thrust sheet overlies this structure with the Upper Ordovician salt at the base which may provide the updip seal. These permitted the

identification of the large resource potential under the backthrust. Prospective are multiple stacked reservoirs in the Silurian-Lower Permian deposits sealed by salt in the base of the backthrust sheet ([Slide 14](#)).

### **Timing of salt diapirism/petroleum system development**

Regional studies suggested that many exploration wells failed because the majority of structures in the internal zone of the fold belt were created due to collisional shortening, which occurred after the major stage of the oil expulsion and migration ([Slides 15, 16](#)). In contrast, the external zone, including the Chernyshev Swell and the Povarnitsa High, provides evidence of the early salt diapirism with oil reservoirs and traps formation. Seismic data show thickness variations and changes in seismic signatures in the transition zone between the foredeep and the Chernyshev Swell ([Slides 17, 18](#)).

They interpretably record the formation of the diapir wall flanked by peripheral sinks in the Silurian-Early Carboniferous. The differential salt movement developed the oolitic shoals and provided accommodation space for reefs in Silurian-Devonian times ([Slides 19, 20](#)). The early development of the salt structures formed traps before the major hydrocarbon expulsion and migration in the Late Permian, which is favorable for the formation of prolific petroleum plays ([Slide 20](#)).

There later compressional modification of the salt wall likely includes two stages: (1) its squeezing during the onset of shortening and (2) further development of the squeezed diapir into an allochthonous salt layer in the base of a massive backthrust sheet in a passive roof fashion above a tectonic wedge ([Slide 20](#)). The horizontal displacement on the backthrust is in the order of 10 km.

### **Salt offshore**

Reinterpretation of the regional seismic dataset coupled with gravity data suggests that the Upper Ordovician salt may have broad development in the offshore part of the Timan Pechora basin ([Slides 23-25](#)). Two principal episodes of salt diapirism are recognized: extensional (early) and compressional (late). Early ones are sealed by the Frasnian unconformity. Late diapirs are mainly syn collisional. There are high-impact exploration opportunities related to salt diapirism.

### **Conclusion**

1. The Upper Ordovician salt is broadly developed in the Timan Pechora Basin;
2. Salt tectonics provided a major control upon the structural and depositional development of the basin;
3. Two principal episodes of the salt diapirism are recognized: extensional (early) and compressional (late);
4. There are new high-impact exploration opportunities related to salt diapirism.

## References

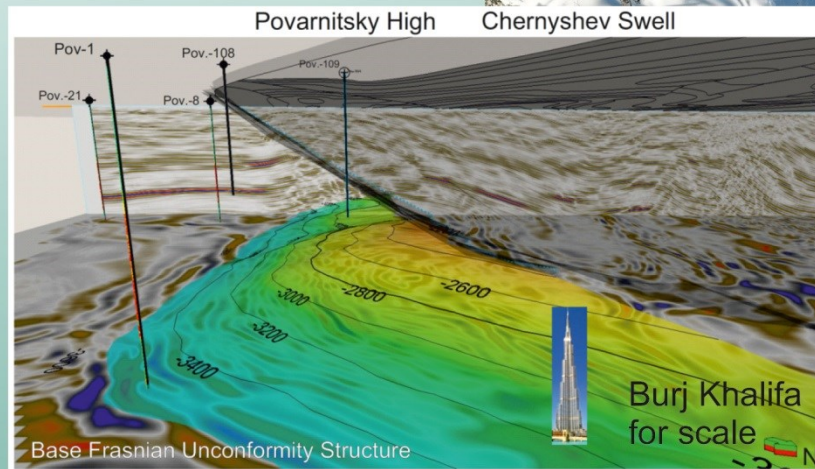
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# Salt Tectonics in the Timan Pechora Basin, NW Russia: Structural Setting and Petroleum Exploration Opportunities

Konstantin Sobornov

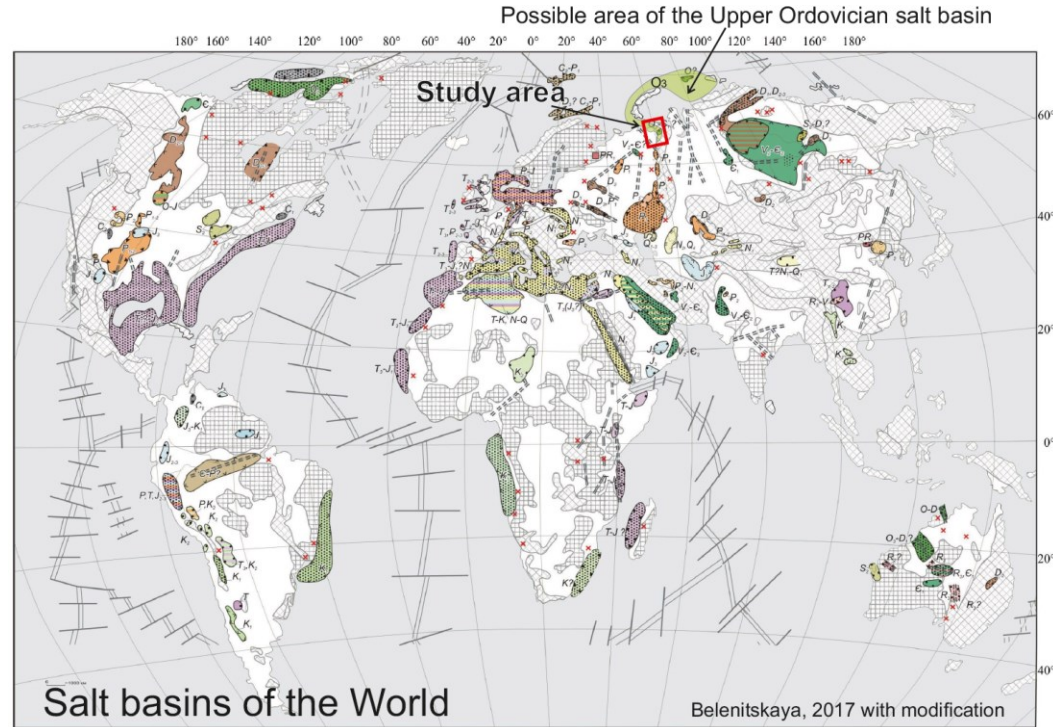
North Uralian Petroleum Company,  
Nord-West



April, 2021

# Content

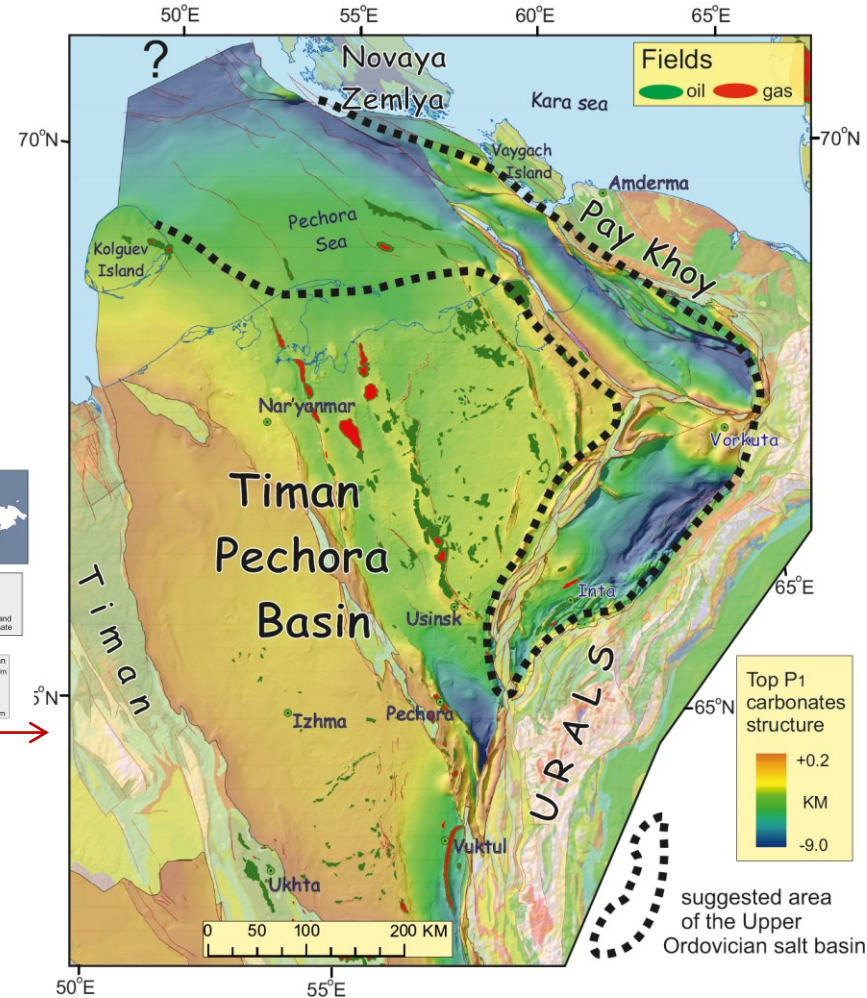
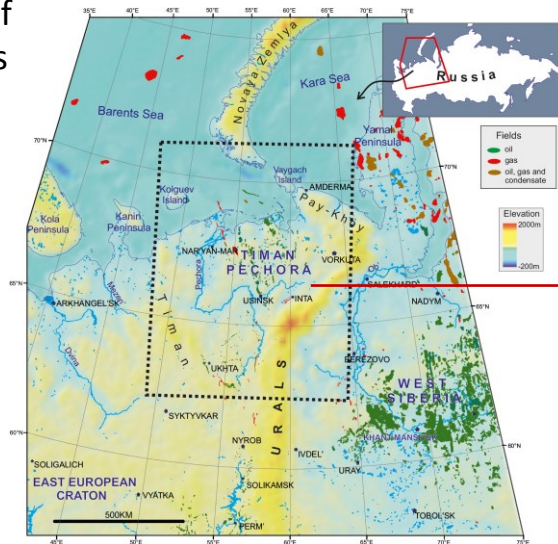
- General setting
- New interpretation
- Development of salt structures
- Petroleum systems and salt
- New exploration opportunities





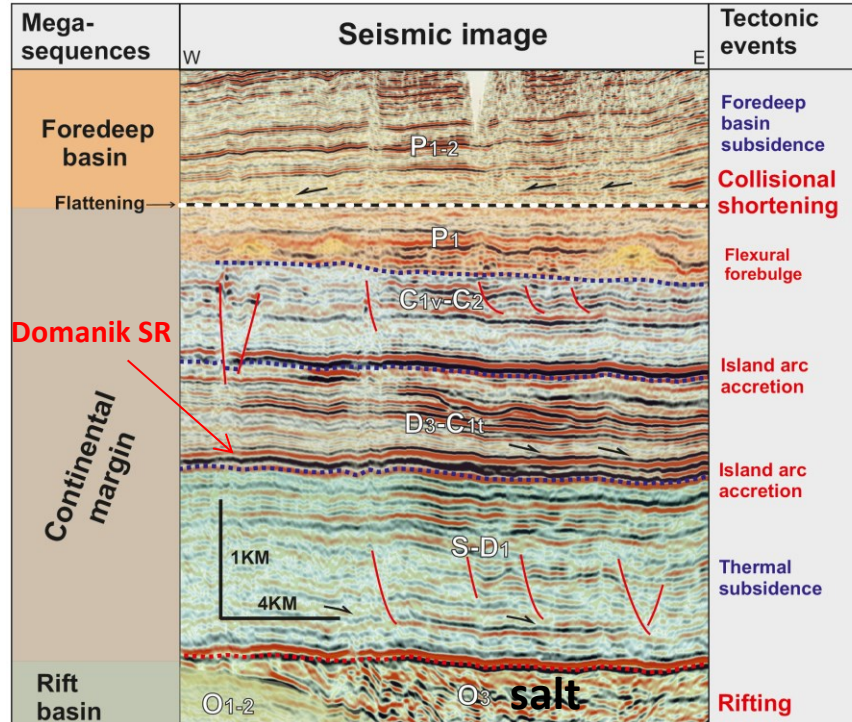
# Study area, salt

- ✓ Timan-Pechora Basin is one of the 25 World's major superbasins
- ✓ Commercial oil production there started in 1930-s and peaked in 2009, reaching 32 mlt. tons per year, cumulative oil and gas production of the Timan Pechora Basin is about 10 bln bbls of oil equivalent, two-thirds of which is oil and condensate
- ✓ Underexplored NE flank of the basin includes numerous salt-related structures



# Tectonostartigraphy

Seismic profile extracted from 3D survey of the Kochmes Dome and flattened at the base of the Upper Artinskian syn-orogenic section



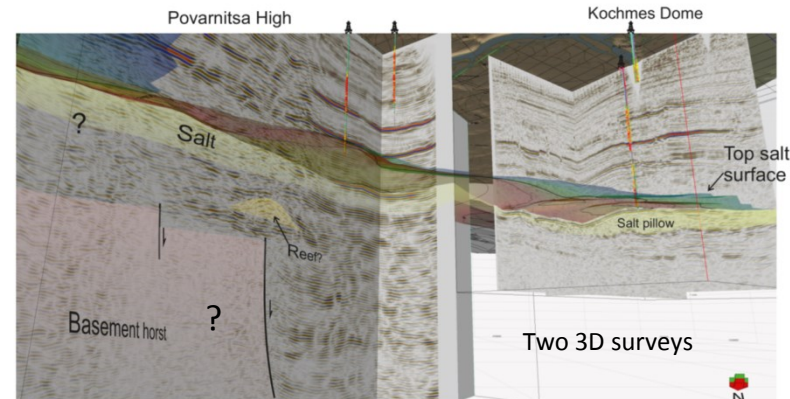
## Stratigraphic nomenclature

- P1-2 Upper Artinskian-Upper Permian
- P1 Asselian-Lower Artinskian
- C1v-C2 Vizean-Middle Carboniferous
- D3-C1t Upper Devonian-Tournaisian
- S-D1 Silurian-Lower Devonian
- O3 Upper Ordovician, inc. salt
- O1-2 Lower-Middle Ordovician

- unconformity
- clinoform, downlaps onlaps
- reef
- fault

Note the opposite progradation of clinoformal packages in the Silurian-Lower Artinskian continental margin carbonate-dominated megasequence and the overlying Upper Artinskian-Upper Permian syn-orogenic megasequence.

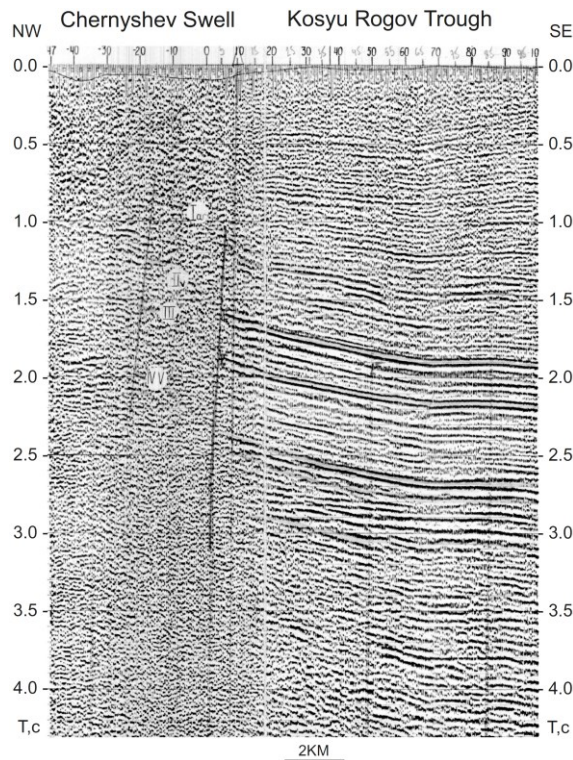
The Upper Ordovician salt was likely deposited at the end of the rifting stage



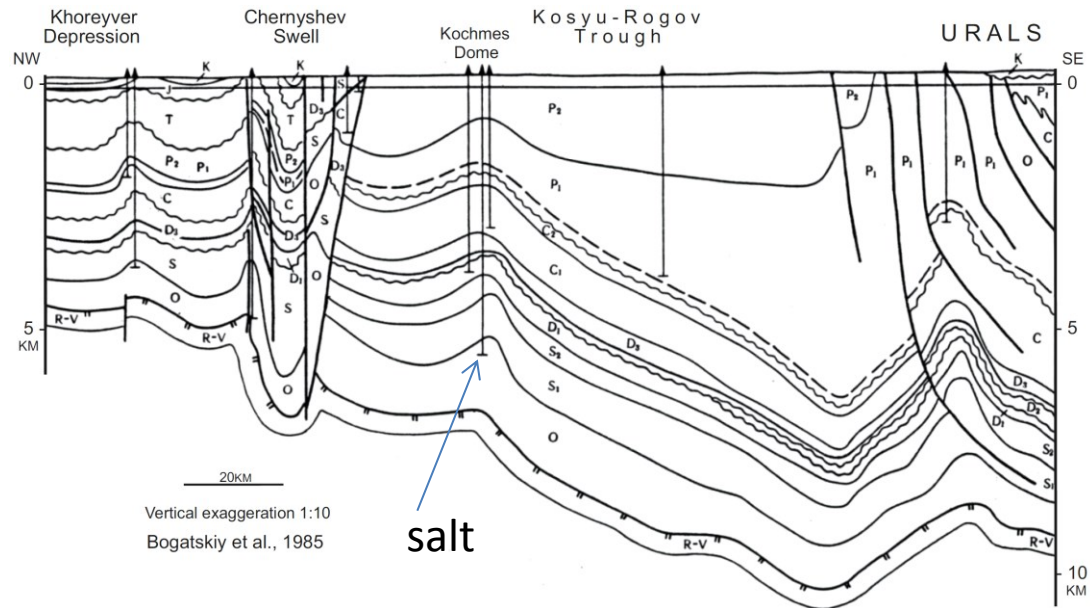


# Vintage interpretation

- ✓ Interpretation based on low-fold seismic data
- ✓ Several sub commercial oil and gas discoveries
- ✓ All fields were found in 4-way dip closures

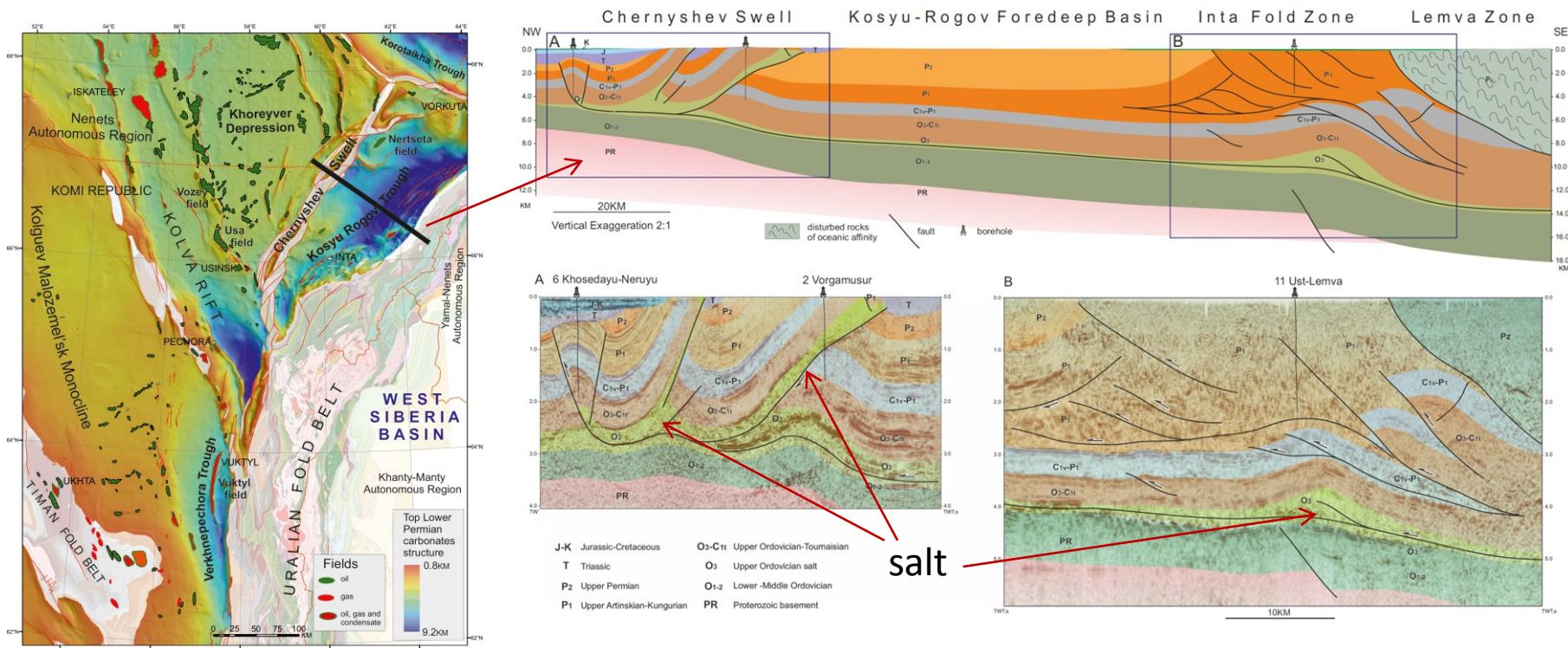


Data by Severageophizika



# Updated structural interpretation

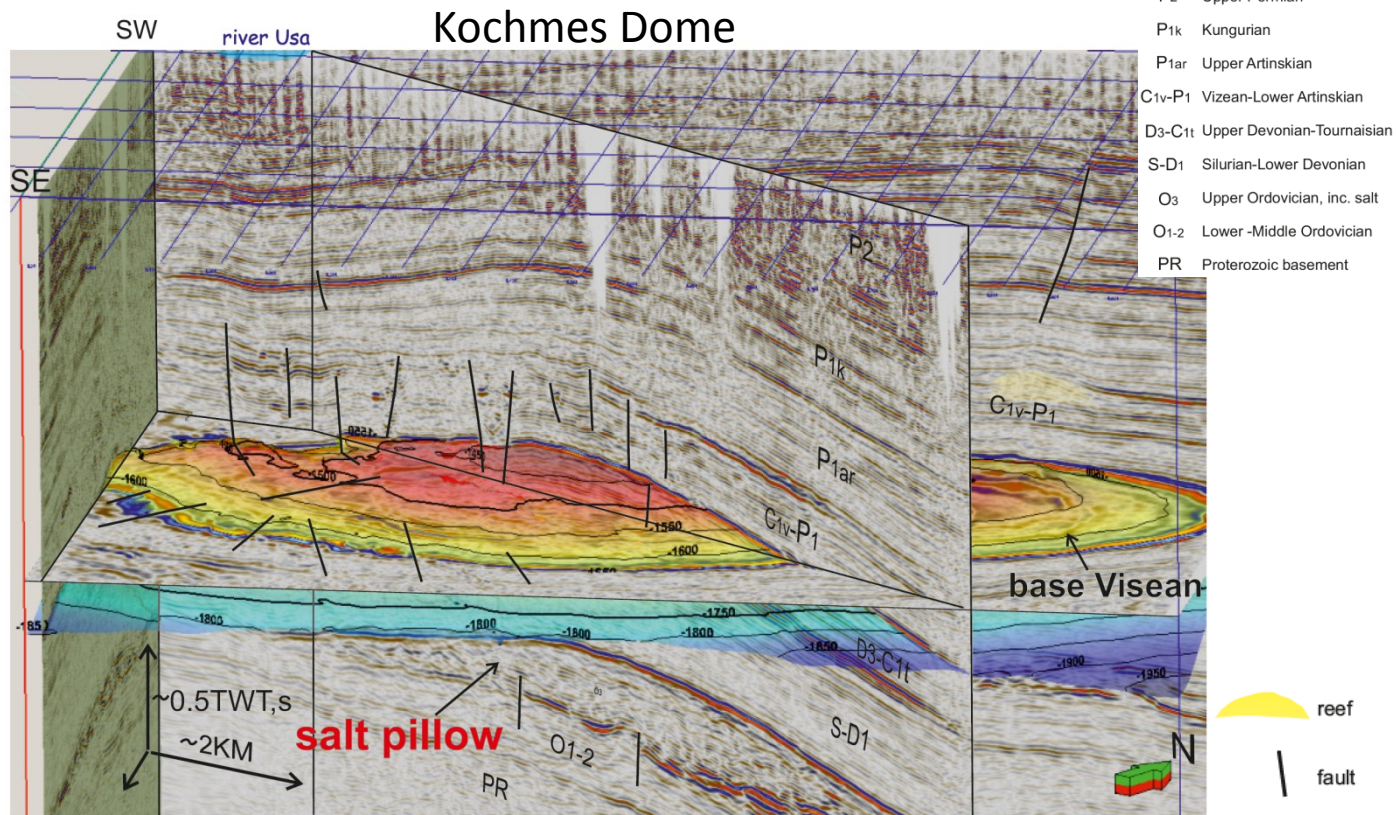
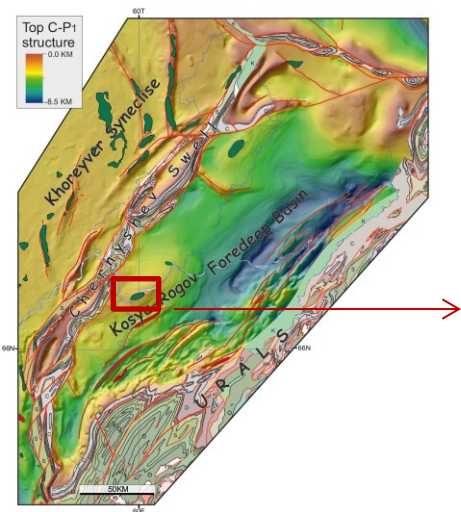
Re-interpretation based on the new subsurface data, identification of the wide occurrence of the detachment thrusting, disharmonic folding, various types of salt structures





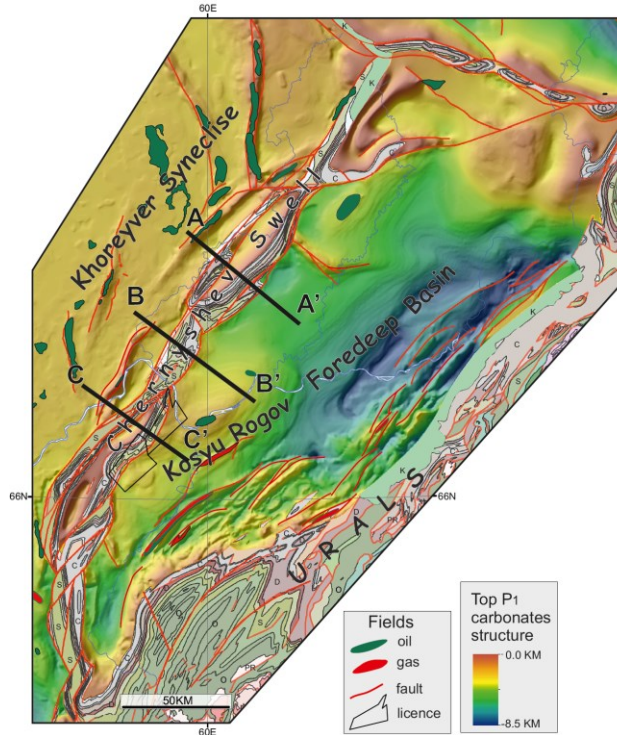
# New subsurface imaging, 3D seismic data

New seismic dataset:  
Improved subsurface  
imaging, revision of the  
past structural and  
depositional concepts

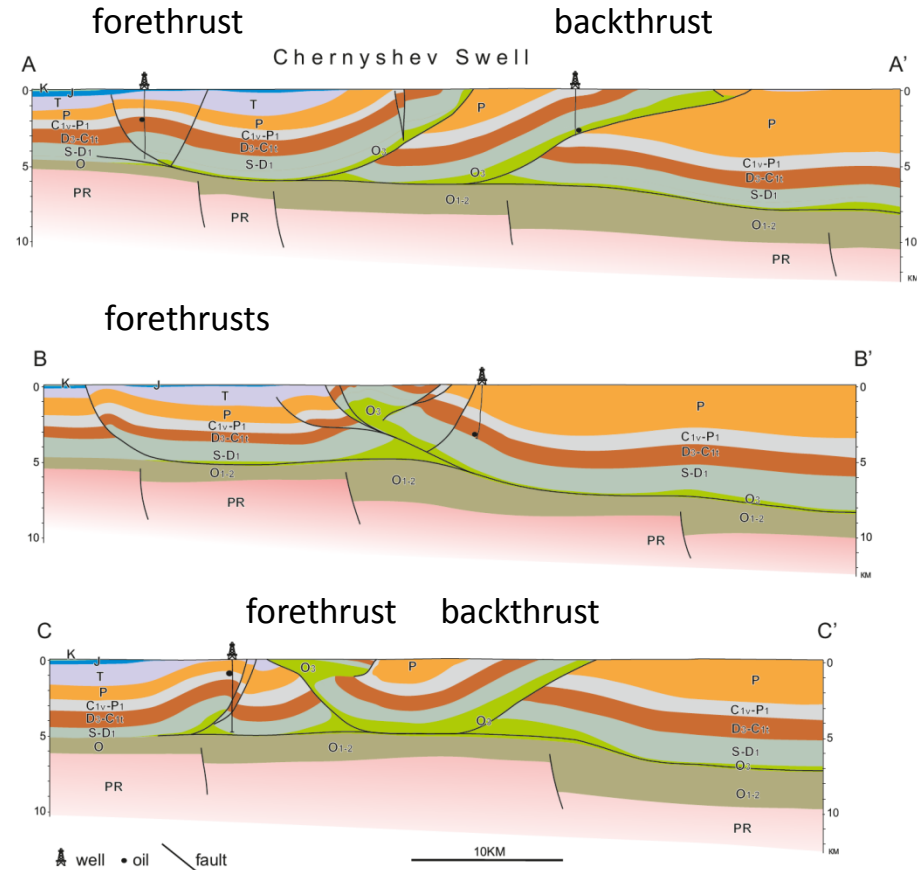


# Structural segmentation of the salt-and-thrust belt

Prominent structural changes across the Chernyshev Swell, squeezed diapires



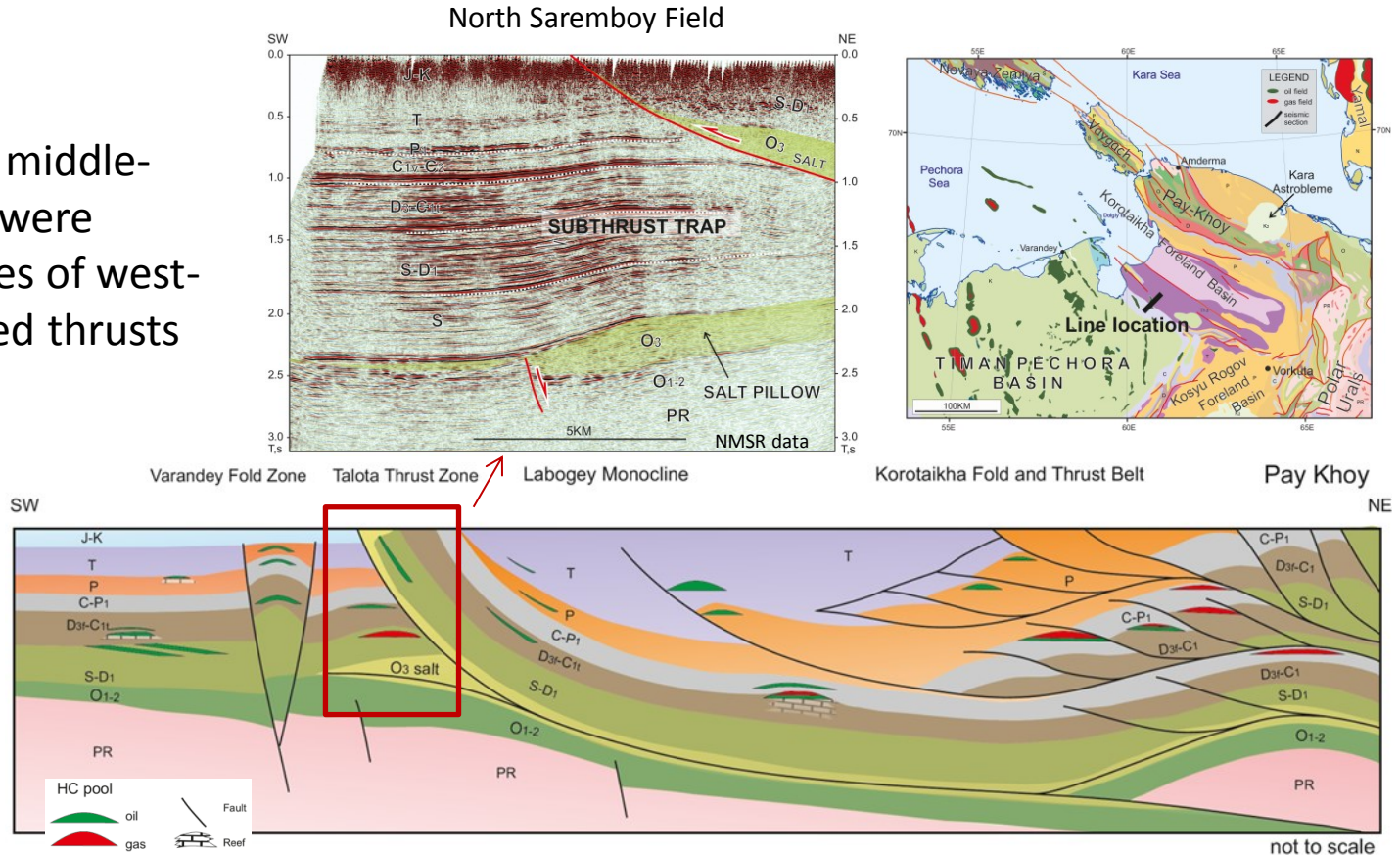
Geological sections are constrained by drilling, seismic data, potential fields, geological mapping





# Subthrust oil deposits

Several small and middle-sized oil deposits were discovered in zones of west-vergent salt-related thrusts



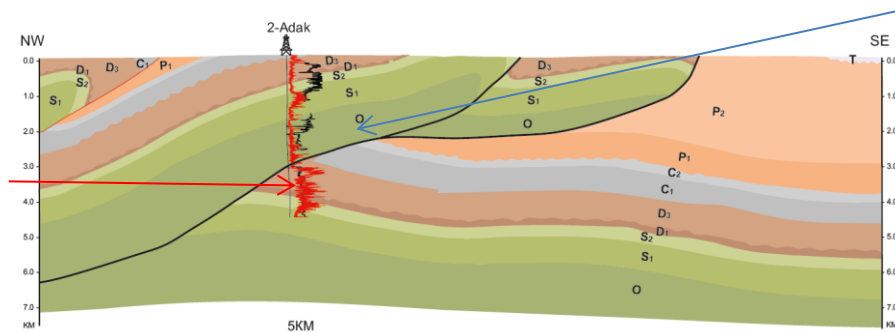
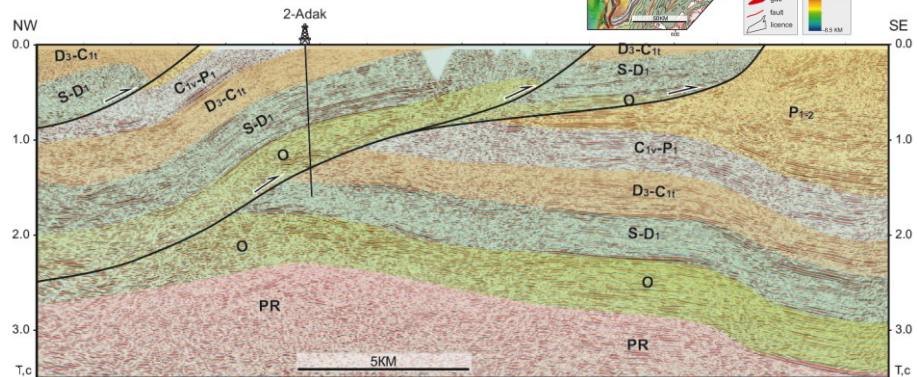
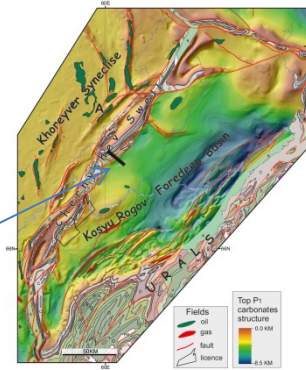
# Testing the backthrust play

- ✓ updip flank of the foredeep is juxtaposed against thrust sheets with the Upper Ordovician salt in the base
- ✓ significant oil flow in the first well plugged and abandoned due to technical reasons
- ✓ great expectations
- ✓ multiple shows, no commercial discovery
- ✓ post mortem study- there is no valid subthrust closure

Oil saturated dolomite, Lower Devonian, subthrust section



Line location



Seal - the Upper Ordovician evaporites



From Danilov, 2017 with modifications



# Revision of the backthrust play

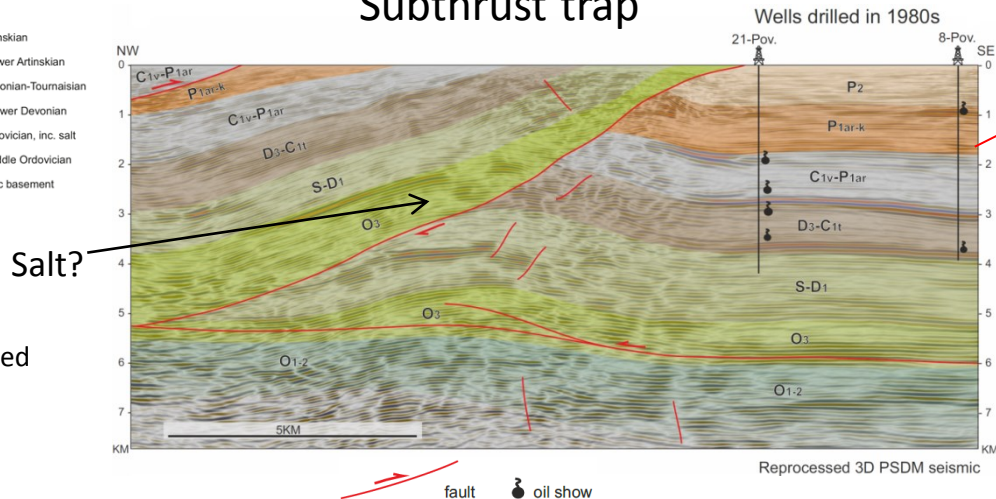
The post-drilling review:

- ✓ a regional study should precede drilling to understand structural and depositional context
- ✓ prospects must be delineated with the 3D seismic data accompanied by non-seismic methods to reduce uncertainty
- ✓ the major risk of a 3-way dip closure is the continuity of the salt seal

Stratigraphic nomenclature

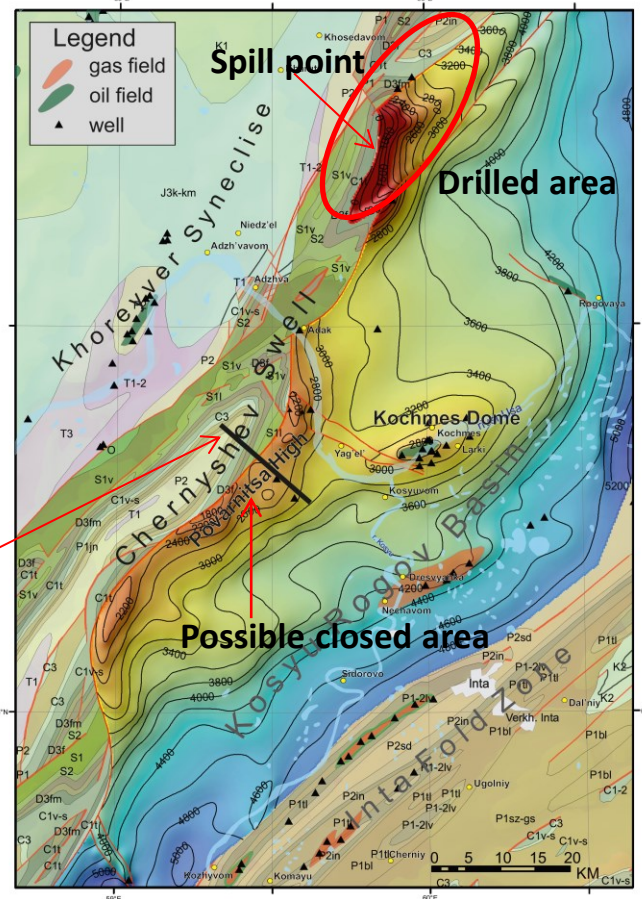
P2	Upper Permian
P1k	Kungurian
P1ar	Upper Artinskian
C1v-P1	Visean-Lower Artinskian
D3-C1t	Upper Devonian-Tournaisian
S-D1	Silurian-Lower Devonian
O3	Upper Ordovician, inc. salt
O1-2	Lower-Middle Ordovician
PR	Proterozoic basement

Subthrust trap



Depth converted seismic data

Base Visean autochthonous structure



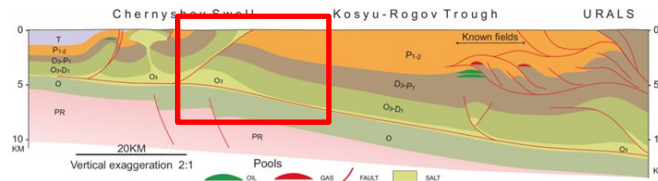
# Backthrust play, structure

Interpretation of newly acquired and vintage reprocessed data:

- ✓ The Povarnitsa High features a regional 3-way dip closure juxtaposed against a 40 km-long squeezed salt wall
- ✓ The areal footprint of the Povarnitsa High is c. 250 km<sup>2</sup>; its structural relief is about 1 km

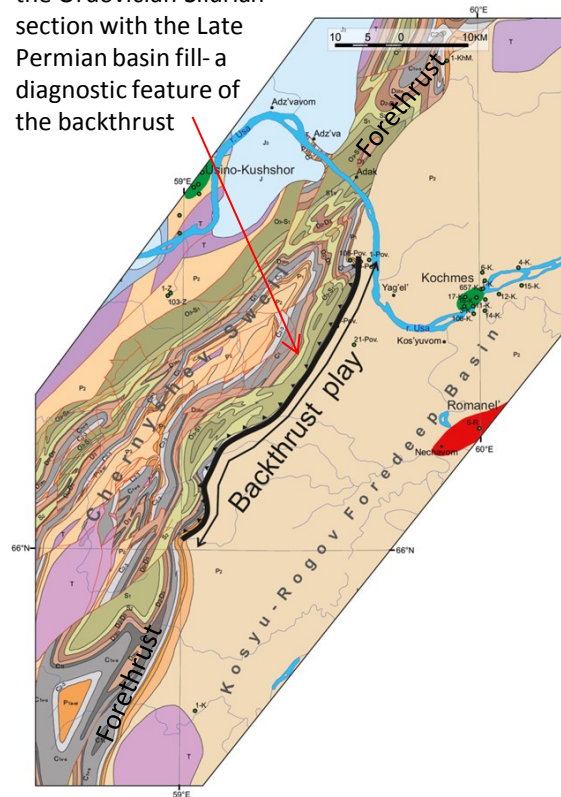
Regional geological cross-section

AOI

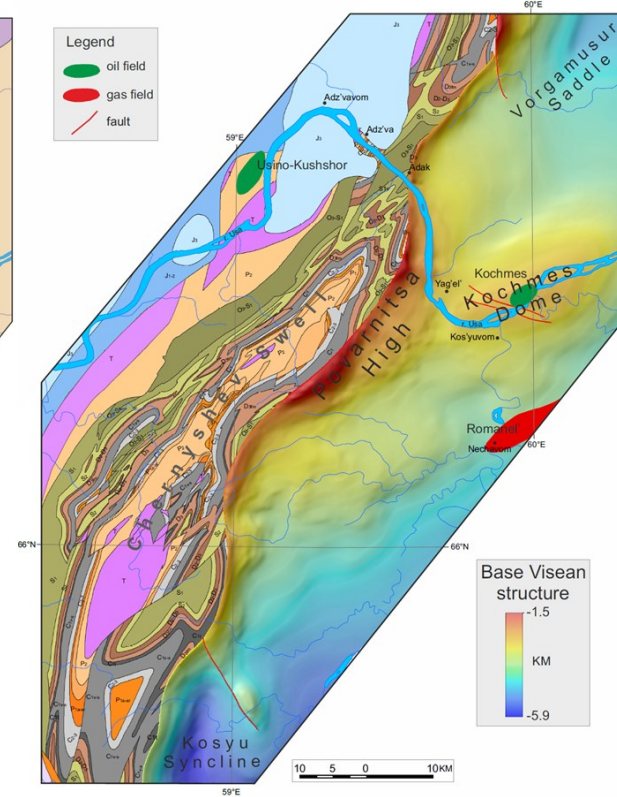


Tectonic contact of the Ordovician-Silurian section with the Late Permian basin fill—a diagnostic feature of the backthrust

Geological map



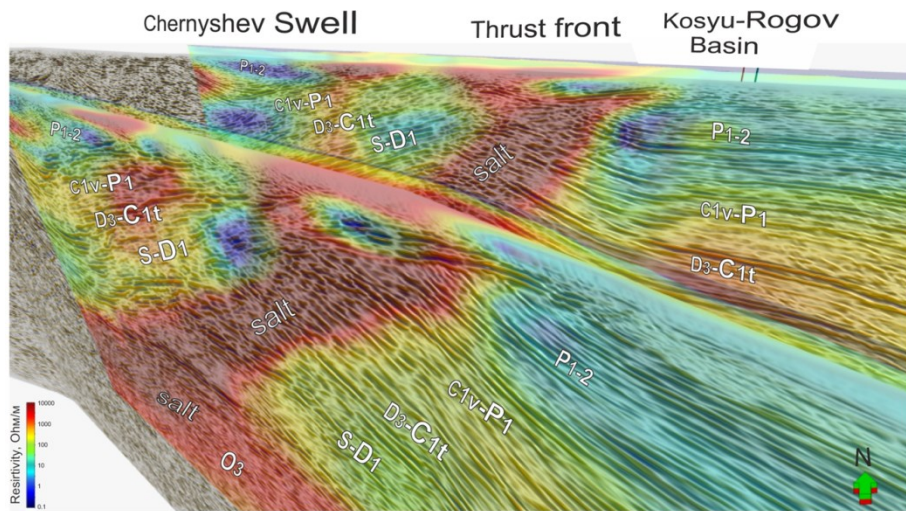
Autochthonous basin structure





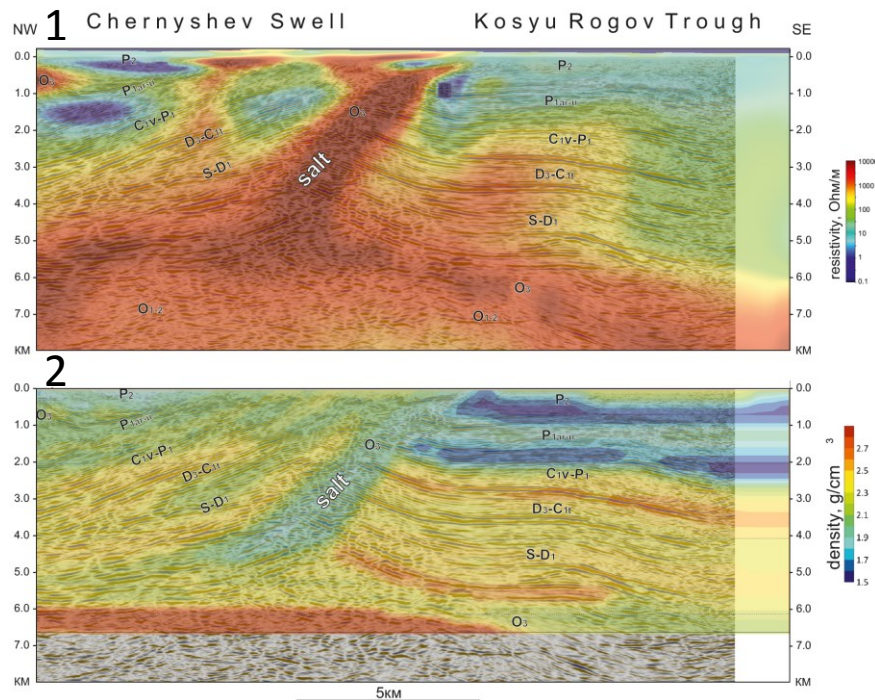
# Reducing uncertainty, salt seal

- ✓ Specially acquired seismic, magnetotelluric (MT), gravimetric and magnetometric data along with digital topography
- ✓ Main purposes: subthrust imaging and tracing of the salt wall



Composite 3D view of the seismic data with magnetotelluric (MT) resistivity overlay

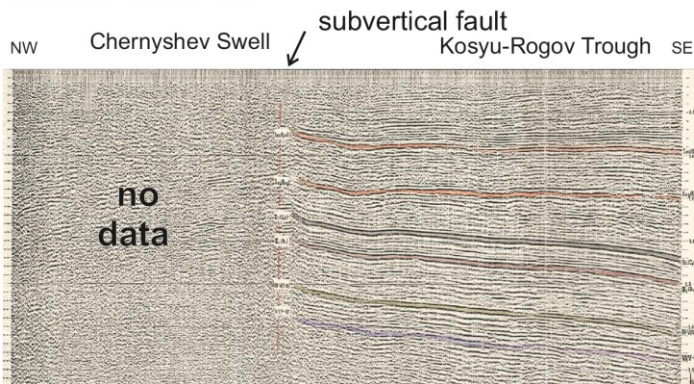
- 1 Seismic data with magnetotelluric (MT) resistivity overlay. High resistivity (red) corresponds to salt bodies.
- 2 Seismic data with results of gravity modeling.



# Salt-related exploration opportunity

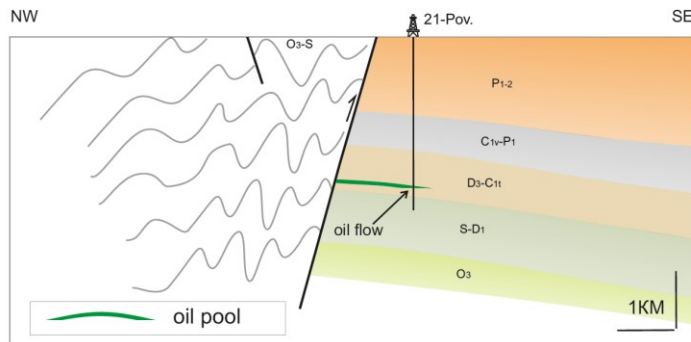
- ✓ New subsurface data permitted the identification of the large resource potential under the backthrust
- ✓ Prospective are stacked reservoirs in the Silurian-Lower Permian deposits
- ✓ Wells drilled in the 1980-ies are on the remote flank of the structure

Data of 1980-ies

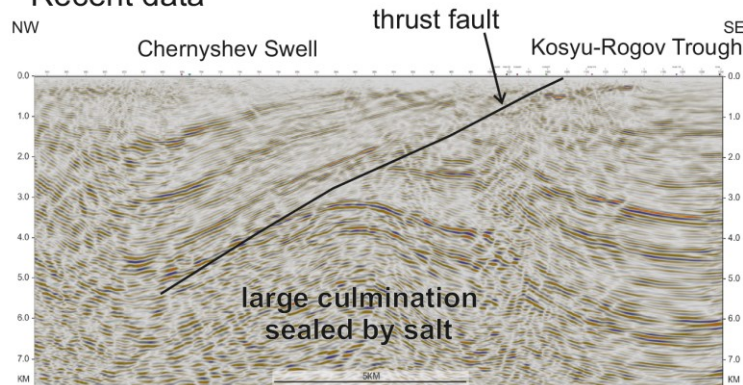


Time domain

Interpretation of 1980-ies

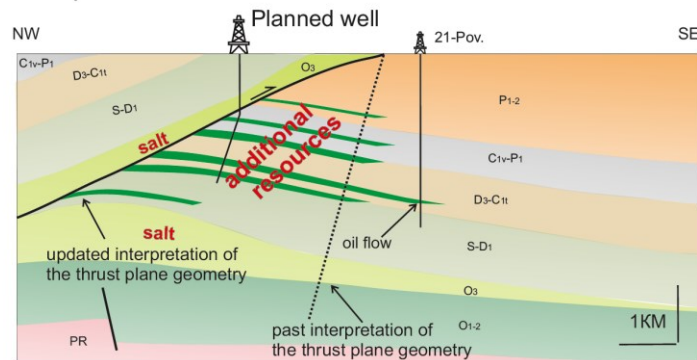


Recent data



Depth domain

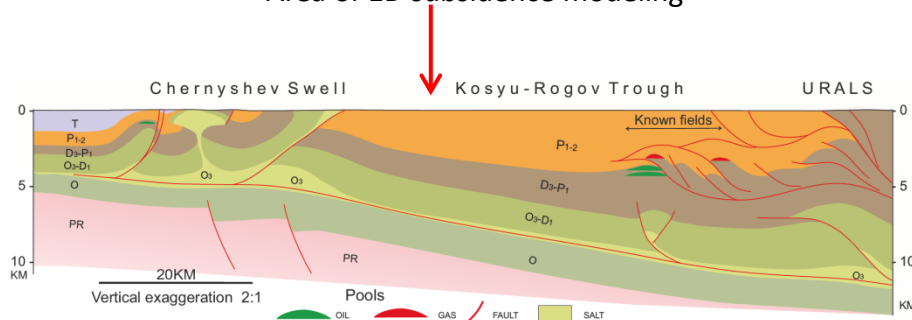
Interpretation of 2021



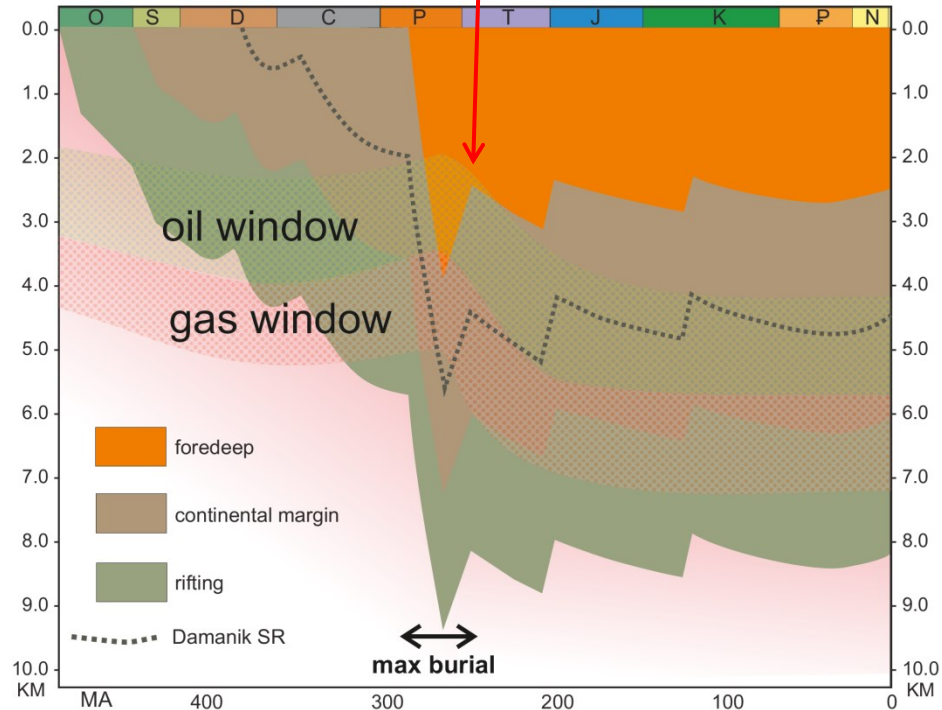
# Petroleum systems

- ✓ Many exploration wells failed due to the misinterpretation of the spatio-temporal relationship between trapping formation and hydrocarbon generation and expulsion.
- ✓ Many salt-related structures were created after the major stage of the oil migration.
- ✓ The development of the salt detachment resulted in the general uplift and cooling of the postsalt section

Area of 1D subsidence modeling



## Subsidence history



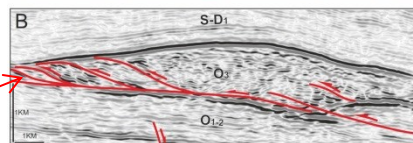
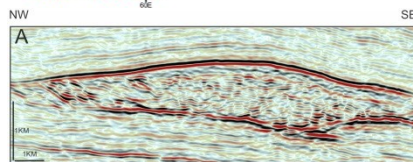
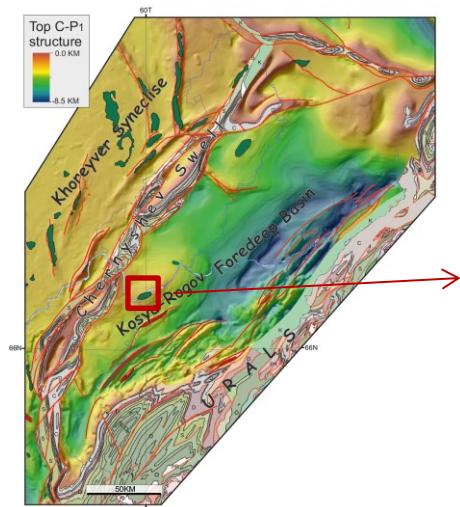


# Timing of the trap formation, internal zone

- ✓ Many salt-related anticlines in the inner part of the basin were created due to salt inflation during the latest episodes of the tectonic shortening.
- ✓ These late structures mainly postdated the major episode of the HC migration.
- ✓ Traps are undercharged with oil and gas.

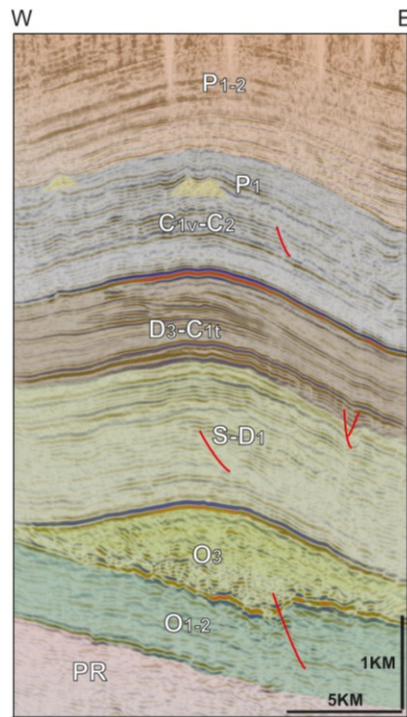
The internal structure of the salt pillow of the Kochmes Dome suggests the westward updip movement of the salt

Thrust duplexes within the salt pillow

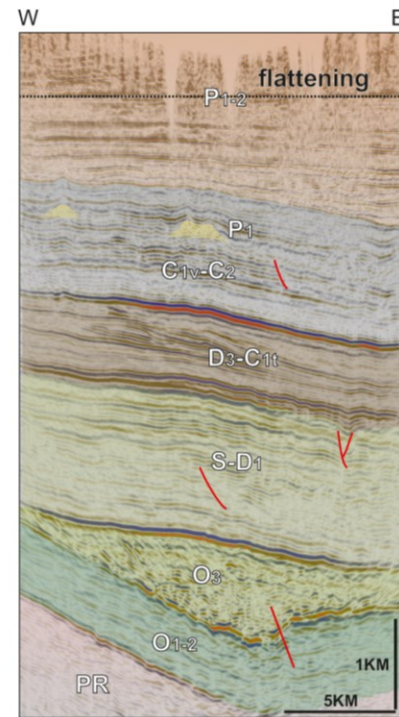


fault

An interpreted section through the Kochmes Dome



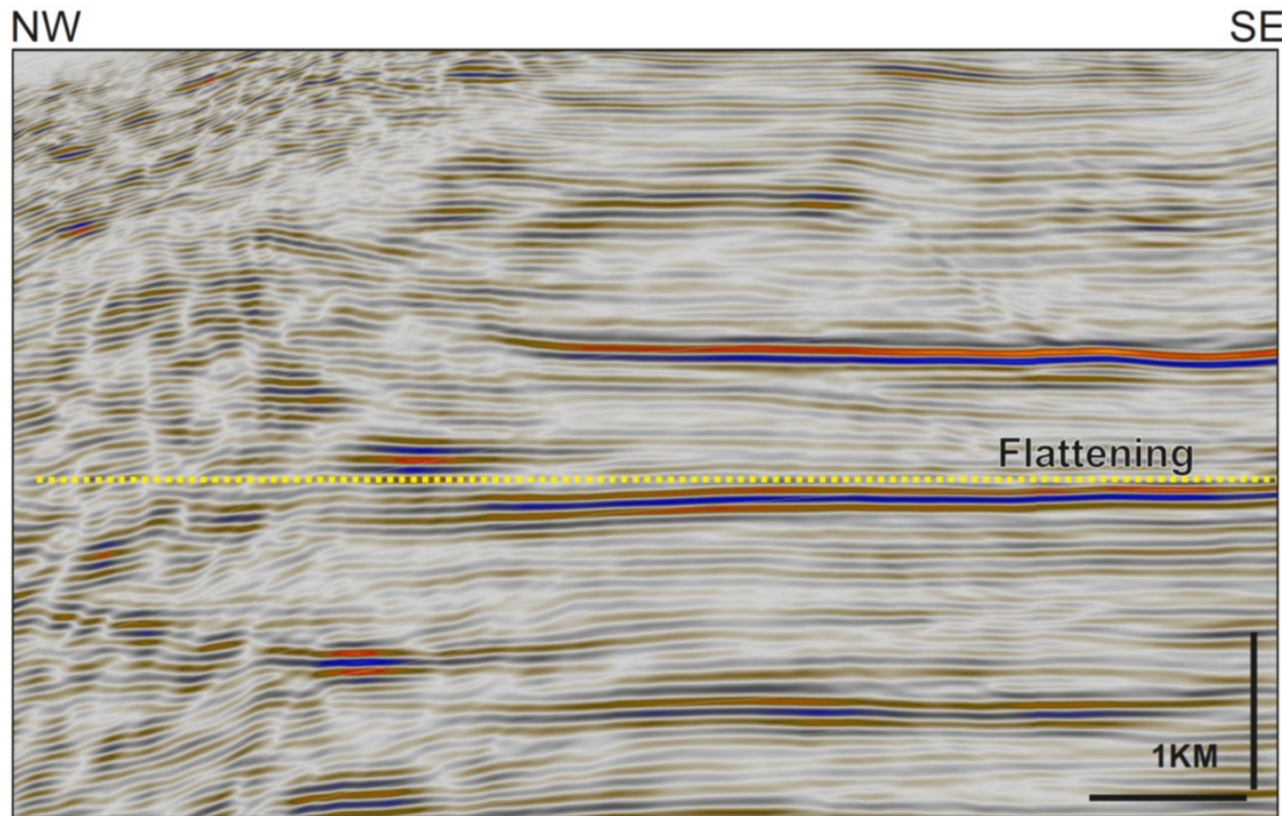
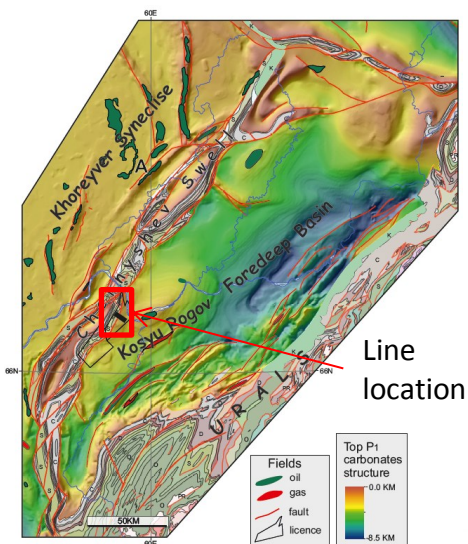
The same line flattened at the base of the Kungurian





# Timing of salt diapirism, external zone

Seismic line from a 3D survey flanking a salt wall flattened at the base of the Frasnian

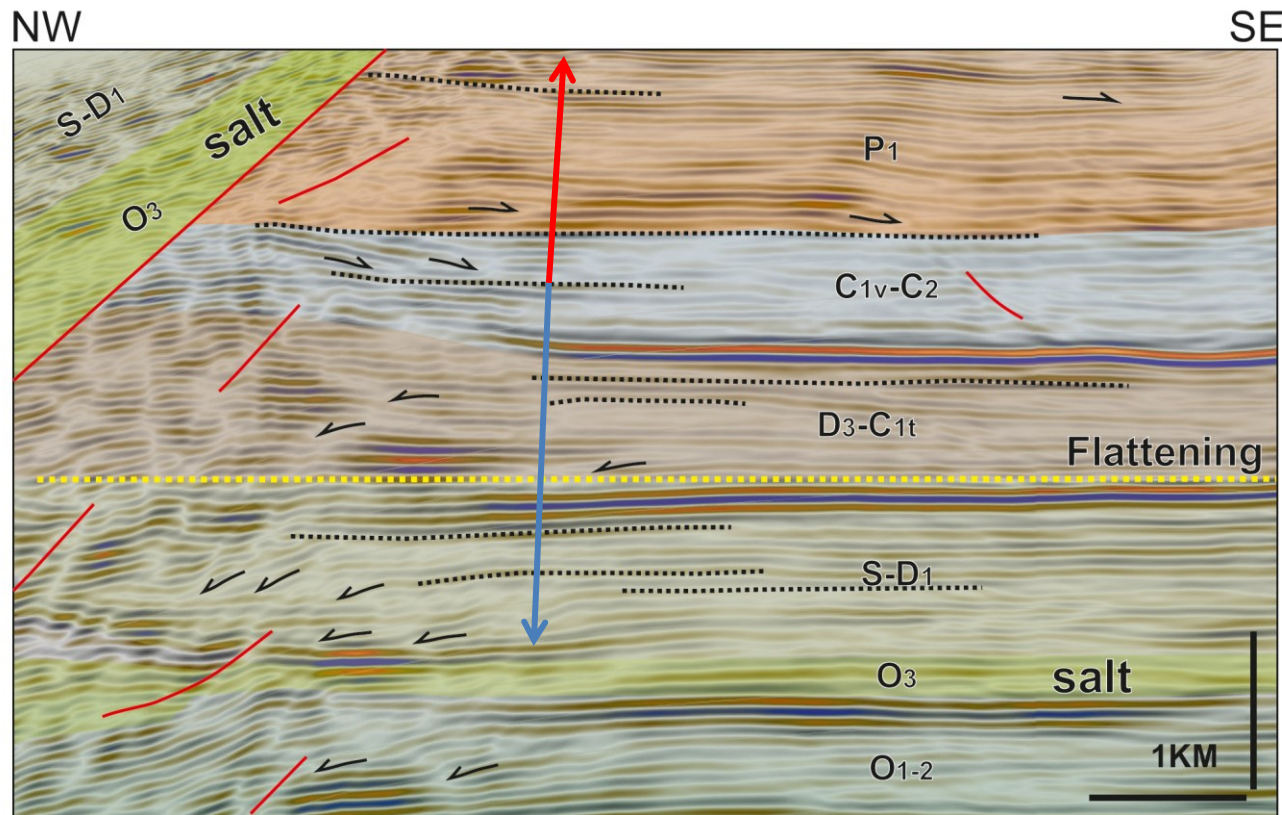


# Timing of salt diapirism, external zone

Interpretation of the seismic data near the salt squeezed wall suggests the major influence of the salt structure on the deposition

Two interpreted stages:

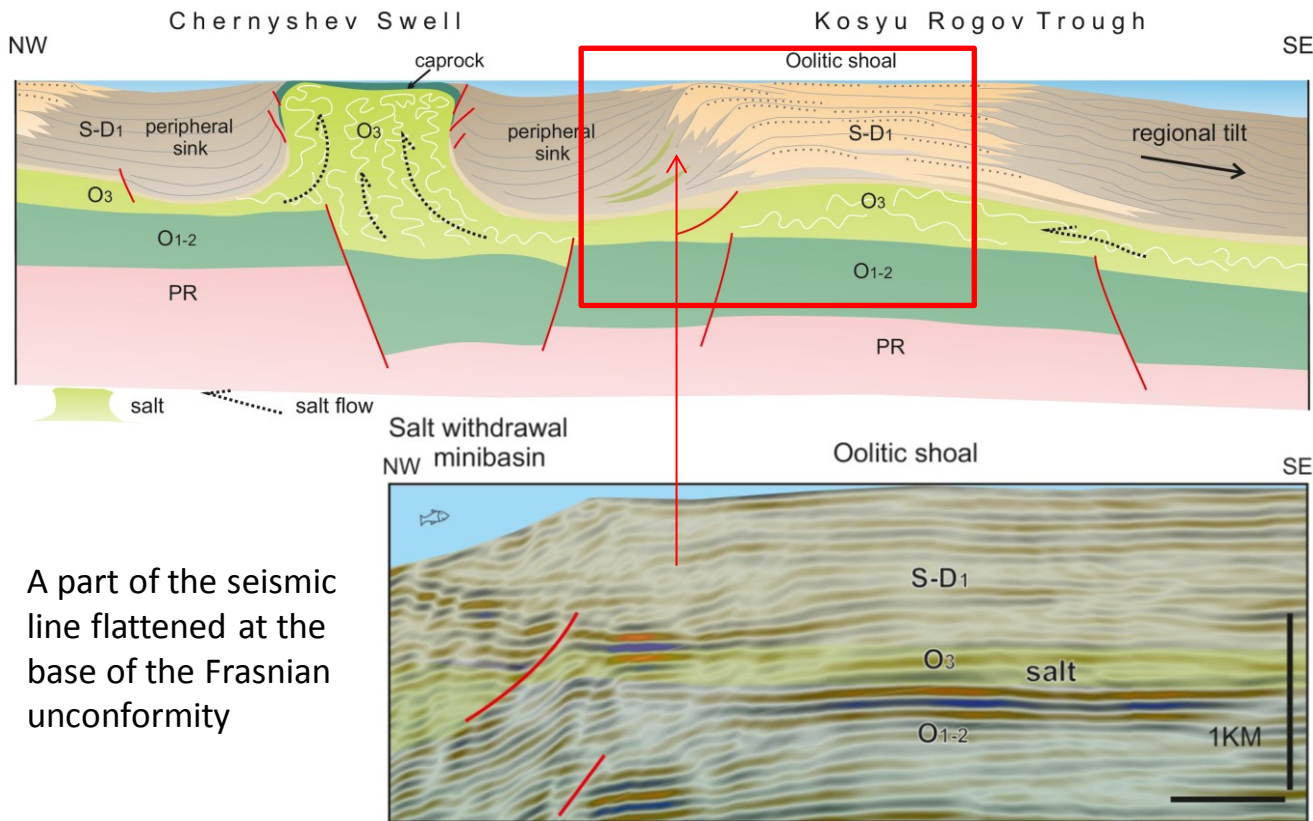
1. Silurian-Lower Carboniferous sink subsidence
2. Mid-Carboniferous-Permian uplift and squeezing of the salt wall



# Timing of salt diapirism, early phase

Interpreted depositional environment in the Silurian-Early Devonian

- ✓ Inflation of the salt diapir produced peripheral sinks, provided control on the formation of the carbonate bank
- ✓ Early diapirism created traps and reservoirs before the onset of the thrusting



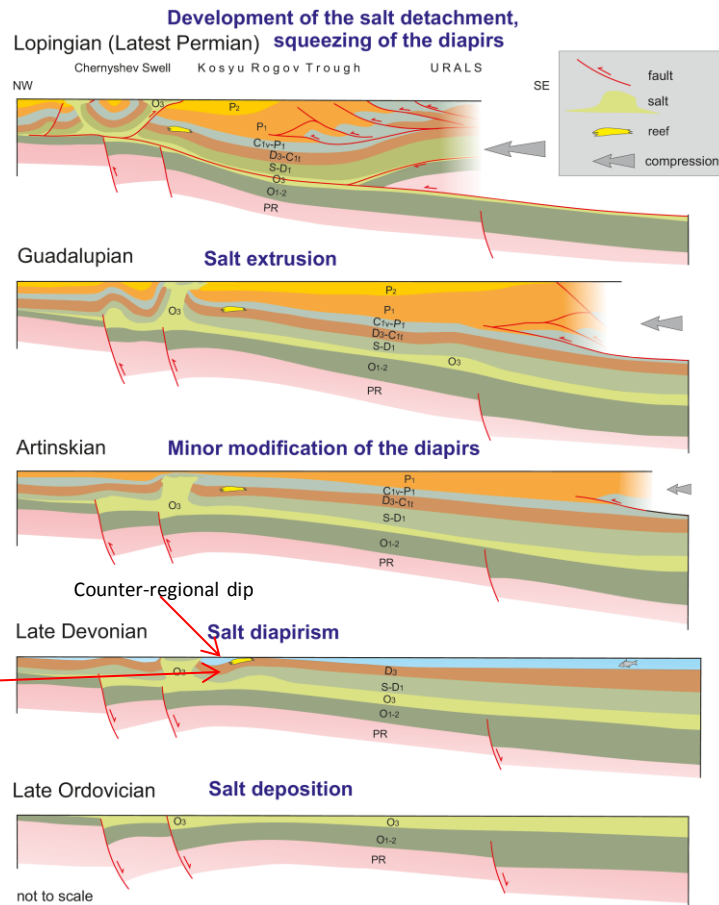
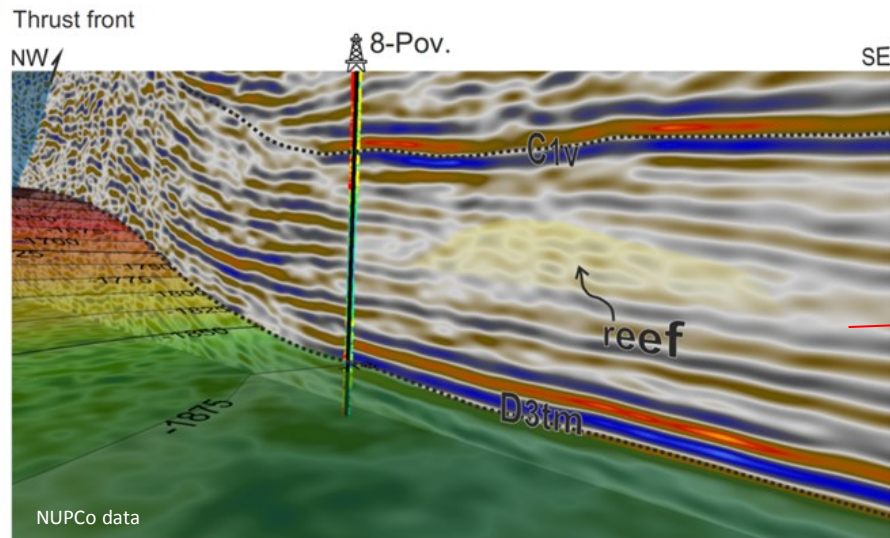
A part of the seismic line flattened at the base of the Frasnian unconformity



# Sequential restoration of the basin development

- ✓ The structural development of the basin includes early and late salt diapirism
- ✓ The early stage is likely related to the extension
- ✓ The later stage was governed by compression

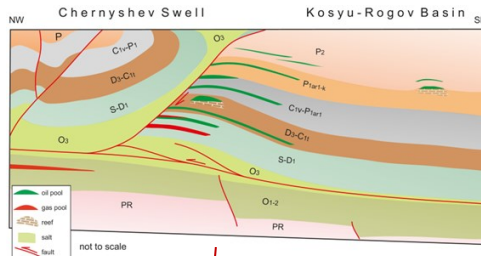
Combined view of seismic profile, time slice from the 3D seismic survey (processed with the use of the RTM migration), and an isochrones grid of the base Frasnian unconformity of the Povarnitsa High.



# Salt detachment, gas versus oil

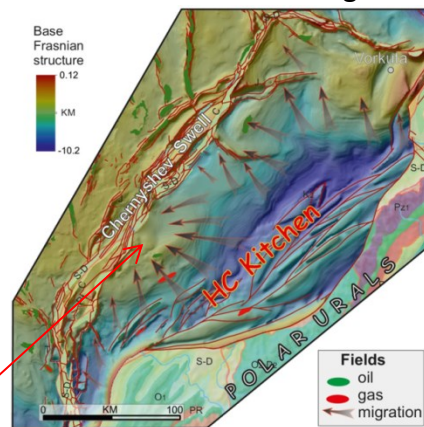
- ✓ The displacement of the post salt section on the tilted salt detachment resulted in the considerable (2-3 km) exhumation of the Kosyu Rogov Basin.
- ✓ Primary source rocks in the internal part of the basin are overcooked.
- ✓ Source rocks in the external part are oil mature.

Play types of the backthrust zone



Focus of oil migration

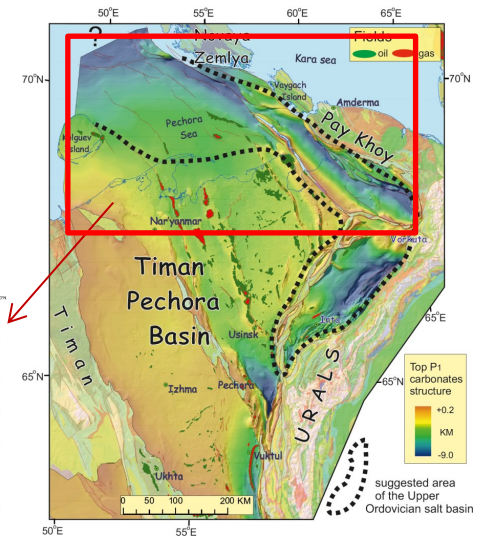
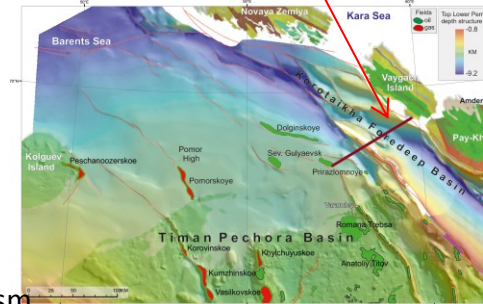
Domanik oil migration



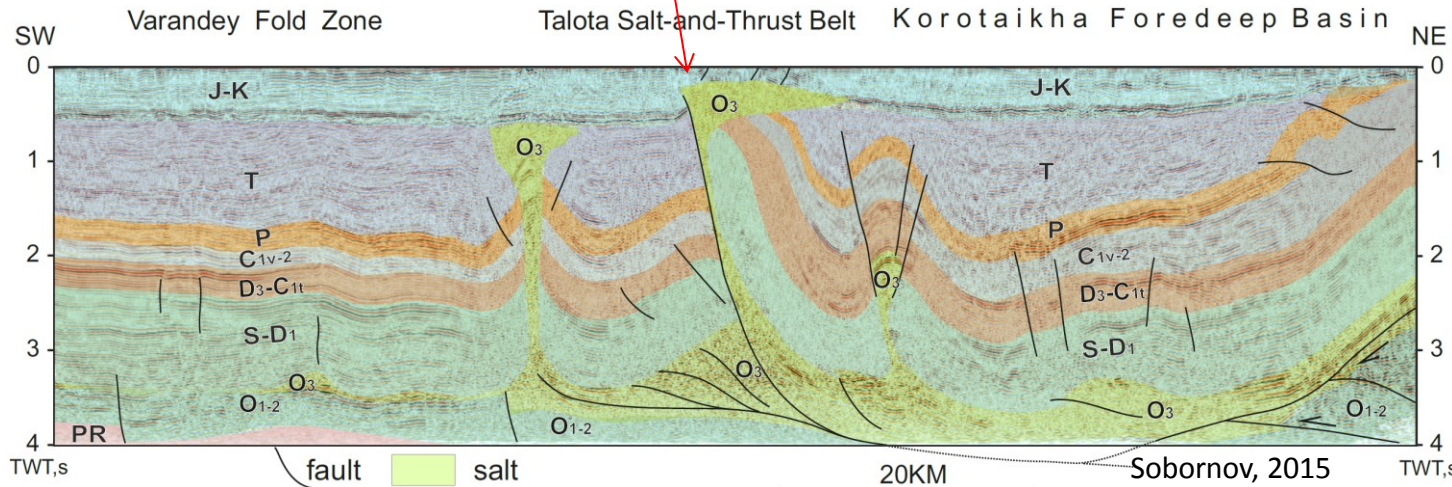
# Salt offshore

- ✓ Re-interpretation of the offshore extension of the salt-and-fold belt
- ✓ Numerous salt-related exploration opportunities

Line location



Post-orogenic diapirism

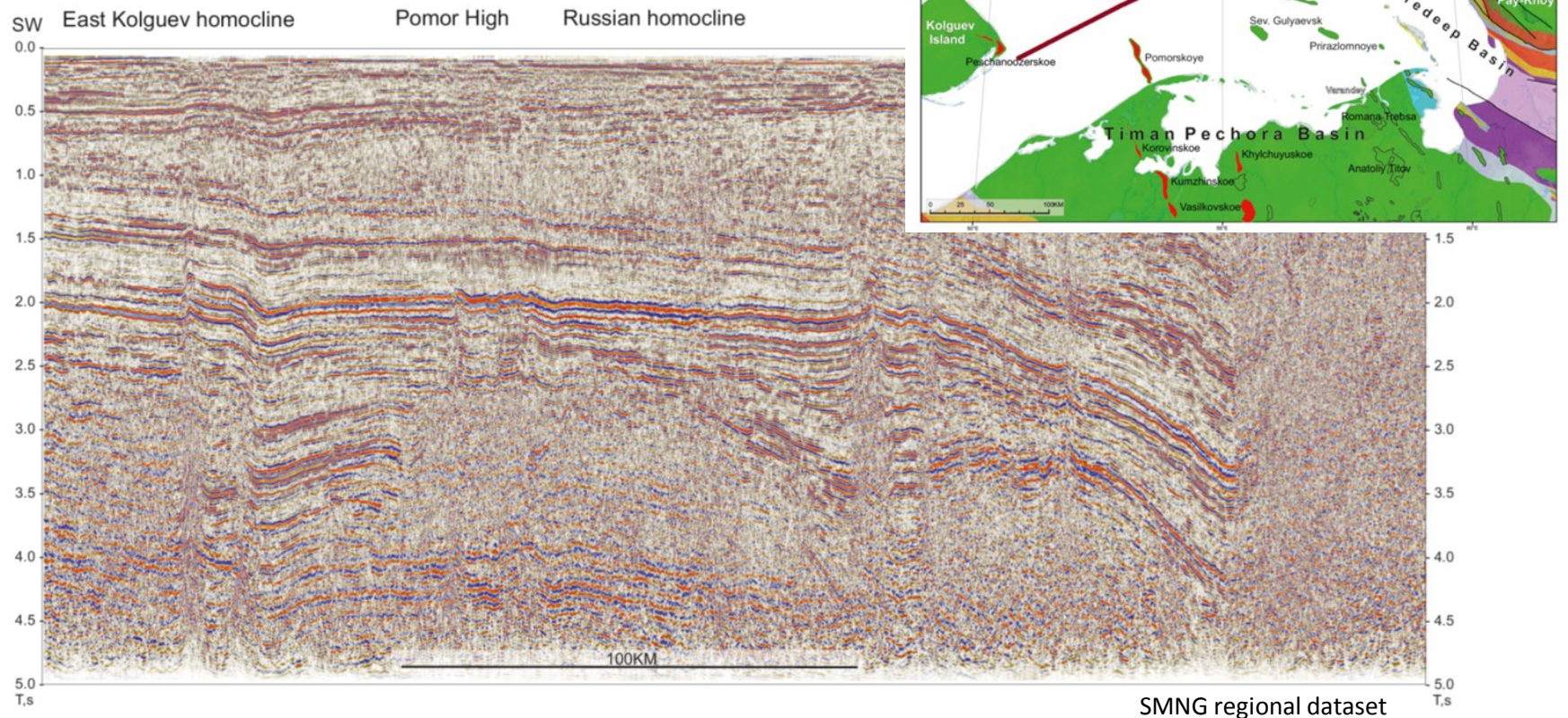


Stratigraphic nomenclature

J-K	Jurassic-Cretaceous
T	Triassic
P	Permian
C1v-2	Visean-Mid. Carboniferous
D3-C1t	Upper Devonian-Tournaisian
S-D1	Silurian-Lower Devonian
O3	Upper Ordovician
O1-2	Lower-Middle Ordovician
PR	Proterozoic



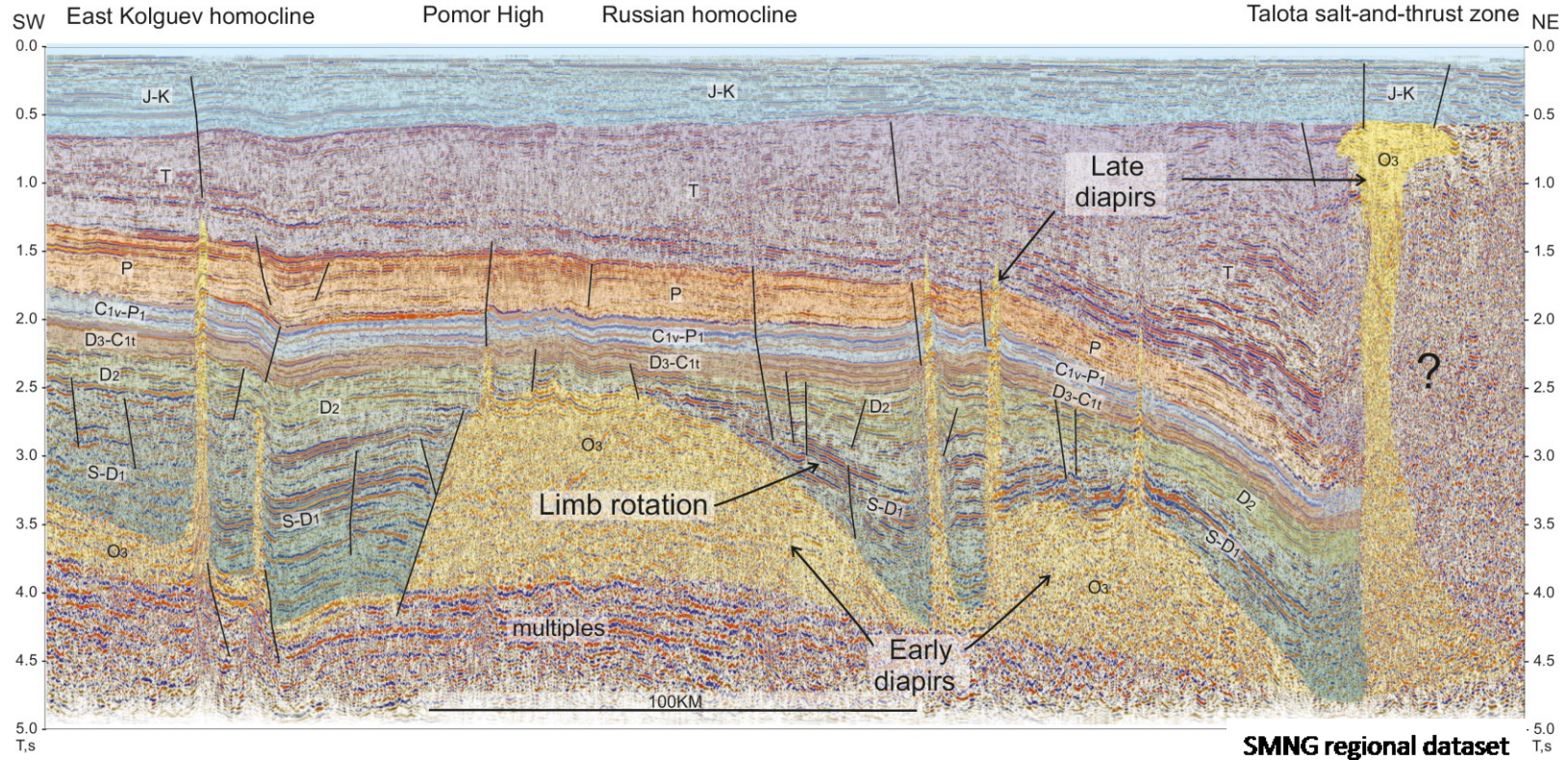
# Salt offshore





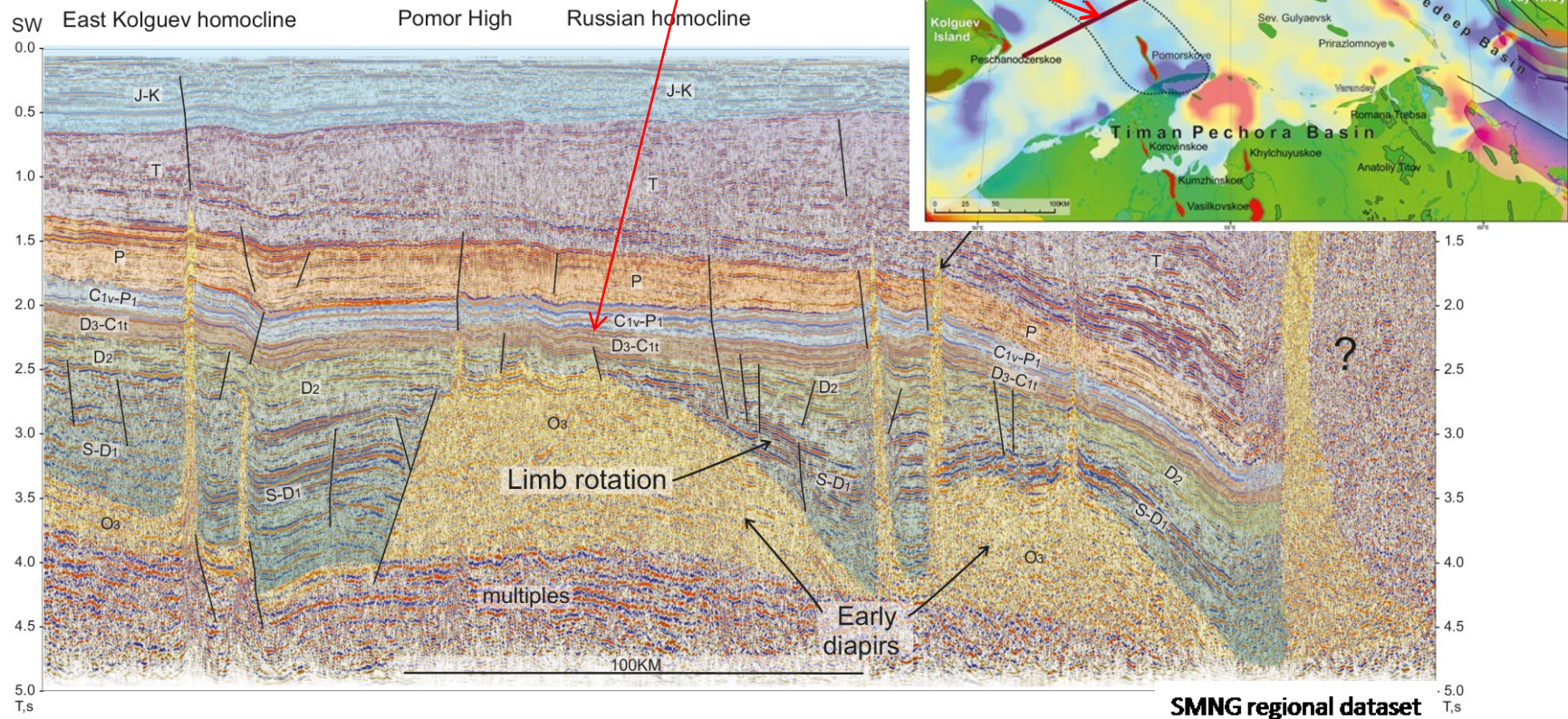
# Salt offshore

Two generations of diapirs are recognized based on seismic interpretation: extensional (early) and compressional (late)





# Salt offshore

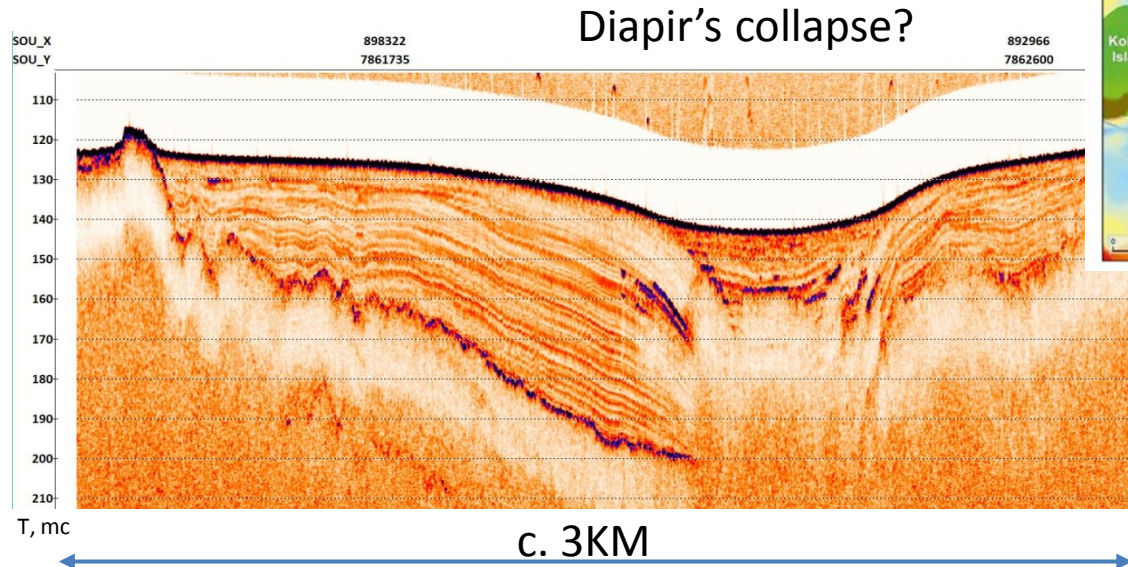




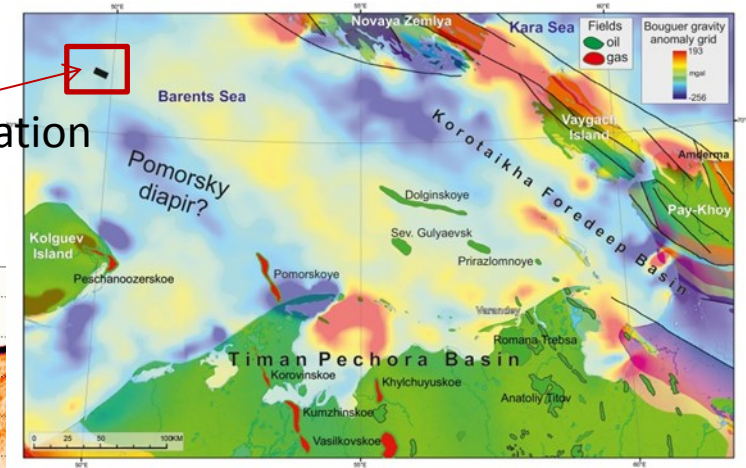
# Salt offshore

New evidence of the occurrence of the salt in the offshore part of the Timan Pechora Basin

Line location



From Sokolov et al., 2019



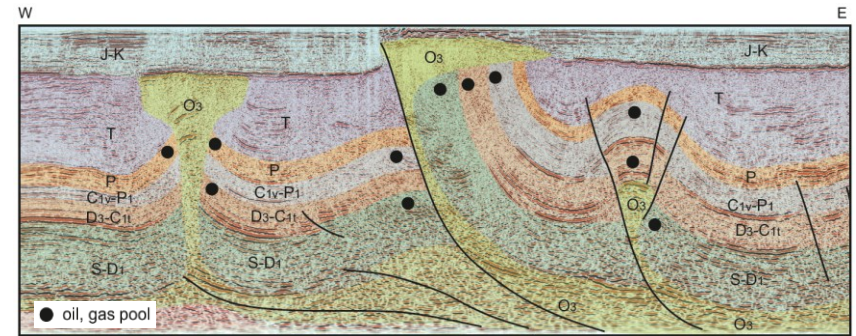
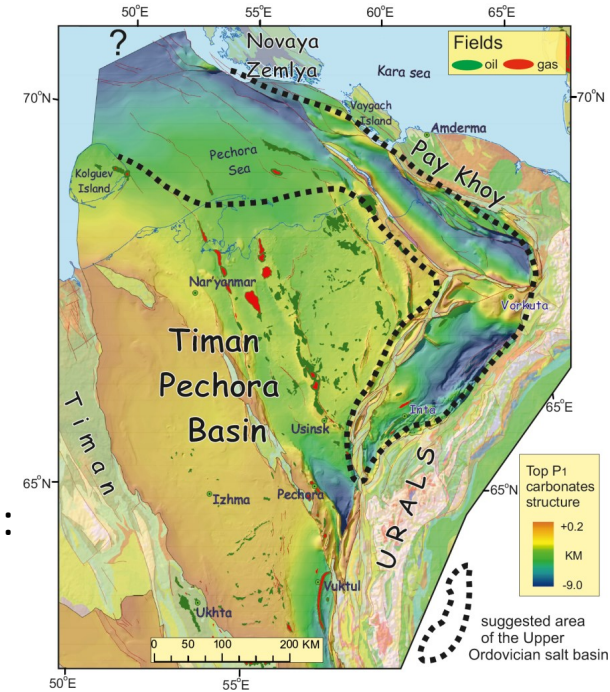
Kungurian salt karst, Perm region



<https://yandex.ru/images/search?from=tabbar&text=Пермь провалы соль>

# Conclusion

- The Upper Ordovician salt is broadly developed in the Timan Pechora Basin
- Salt tectonics provided a major control upon the structural and depositional development of the basin
- Two principal episodes of the salt diapirism are recognized: extensional (early) and compressional (late)
- There are new high-impact exploration opportunities related to alt diapirism





# Thank you!



Have you found  
salt in your basin?

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More information:

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