PSComplex Structural, Lithological and Subtle Gas Traps, Upper Rotliegend, Polish Permian Basin*

Hubert Kiersnowski[1], Krzysztof Wolanski[2], Krzysztof Kwolek[2], Wojciech Zarudzki[3], and Maciej Tomaszczyk[2]

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Abstract

Current discoveries of gas traps in the Polish Rotliegend Basin show diversity and complex structure. Most of the traps are found in aeolian sandstones, and less often in fluvial sandstones. Most often traps are sealed with Zechstein Sea evaporates: salt and anhydrite. Less frequent are lithological seals represented by playa claystones or impermeable clayey sandstones as sand sheet beds. A separate category is diagenetic or capillary seal. This kind of internal seal is formed as thick units of impermeable, tight or porous sandstones.

The search for gas deposits is focused on the seismic deduction of subtle traps, both just below the Zechstein seal and within the Rotliegend sediments. The point is to emphasize the phenomenon of geomorphic traps created during the Zechstein Sea inundation over the existing morphology of aeolian sand seas within the Rotliegend Basin.

Sandstones, in most cases, have good reservoir properties. Improvements to these properties may result from the appearance of secondary porosity resulting from the dissolution of the feldspar lithic grains. Deterioration of these properties results from diagenetic processes: the development of clay minerals (mostly illite and chlorite), and the appearance of carbonate and sulfate cements, especially in proximity to Zechstein Sea deposits. The patchy cementation areas are a challenge for finding the most favorable reservoir conditions.

Many gas fields have a complex structure. They are divided into compartments, separated by tight faults. In some cases, faults are associated with a dense network of impermeable deformation bands. This results in different gas-water levels in individual segments. The challenge is also to search for hidden faults that are not visible on the Sub-Zechstein structural surface. Such faults can be impermeable barriers and thus formed subtle traps for gas accumulations. In some cases, multistory or hybrid traps have been distinguished, for example Carboniferous s.st. - Rotliegend s.st; Rotliegend s.st - Zechstein limestone - Z. Carbonate (Ca1); Carboniferous s.st. - Zechstein limestone - Z. Carbonate (Ca1).

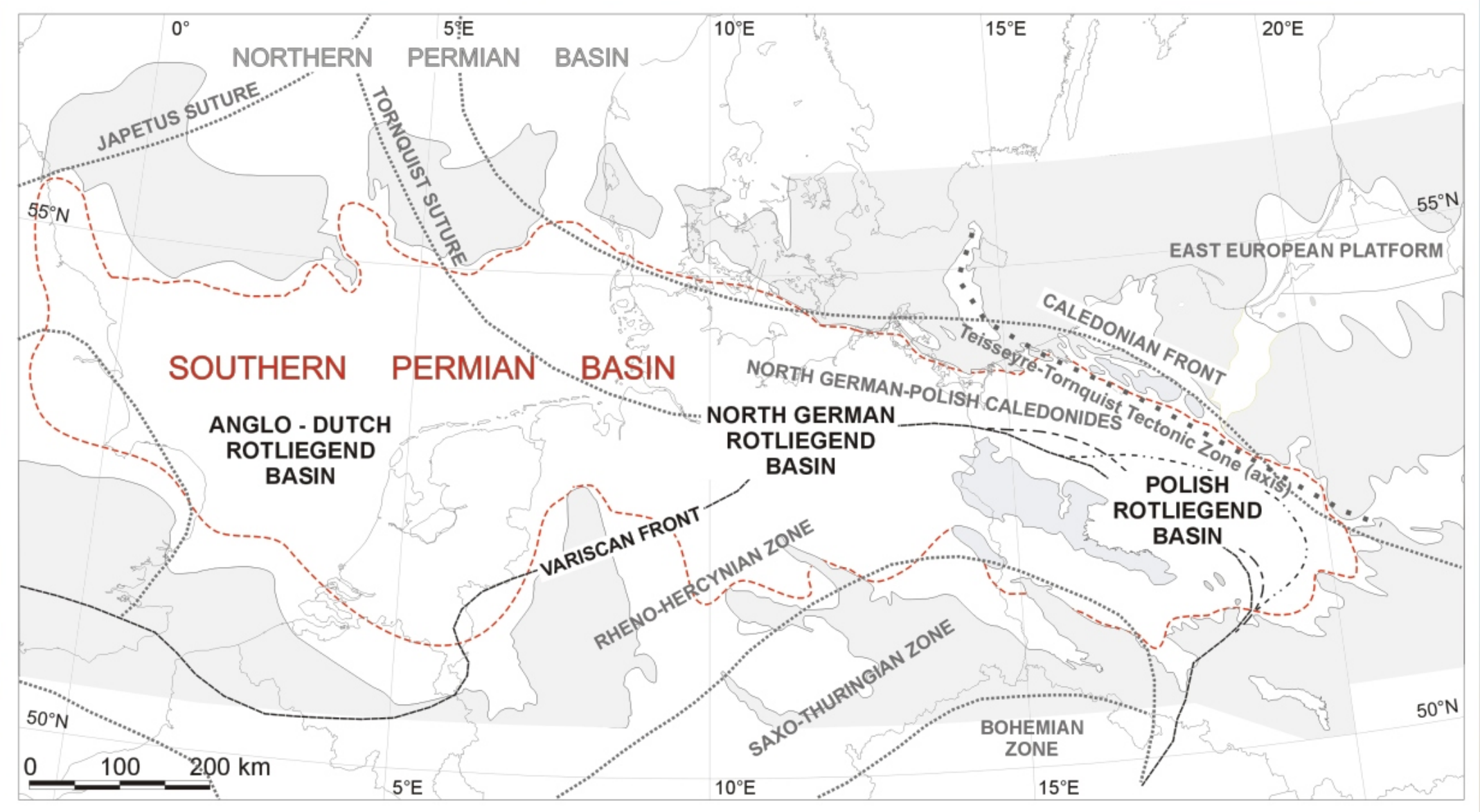
Tight gas was found in structural traps. The deep tight gas is interpreted as bound with a Basin Centered Gas System (BCGS) and is still considered as probable. In some wells, overpressure was measured in the Rotliegend deposits. Locally it is interpreted as related to BCGS.

Gas in Rotliegend traps is from more than 80% methane to high nitrogen content. Locally, a specific feature is the high proportion of helium in the gas composition.

Gas production is carried out using conventional methods, and by means of more complex methods such as hydraulic fracturing or perforation in horizontal sections. The last method is particularly effective when applied to extensive, low amplitude gas traps. Progress in three-dimensional seismic technology and interpretation methods yield measurable results, especially for subtle traps. Searching for the next subtle trap in the Polish Rotliegend Basin is still necessary.

COMPLEX STRUCTURAL, LITHOLOGICAL AND SUBTLE GAS TRAPS, UPPER ROTLIEGEND, POLISH PERMIAN BASIN

"FIVE (NOT) EASY PIECES"

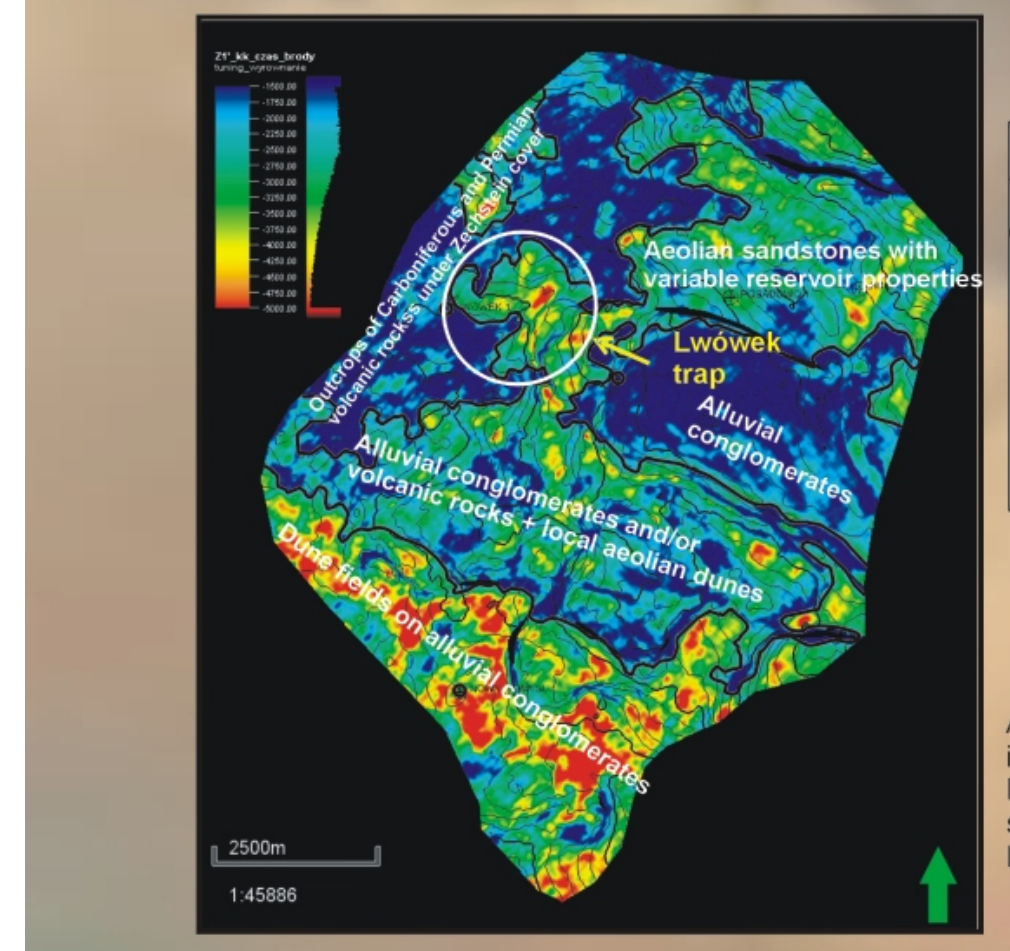


Kiersnowski H., 2013. Late Permian aeolian sand seas from the Polish Upper Rotliegend Basin in the context of palaeoclimatic periodicity. In: Palaeozoic climate cycles: their evolutionary and sedimentological impact. Gąsiewicz A. & Słowakiewicz M., (Eds.). Geological Society, London, Special Publications, No 376, p. 431-456.

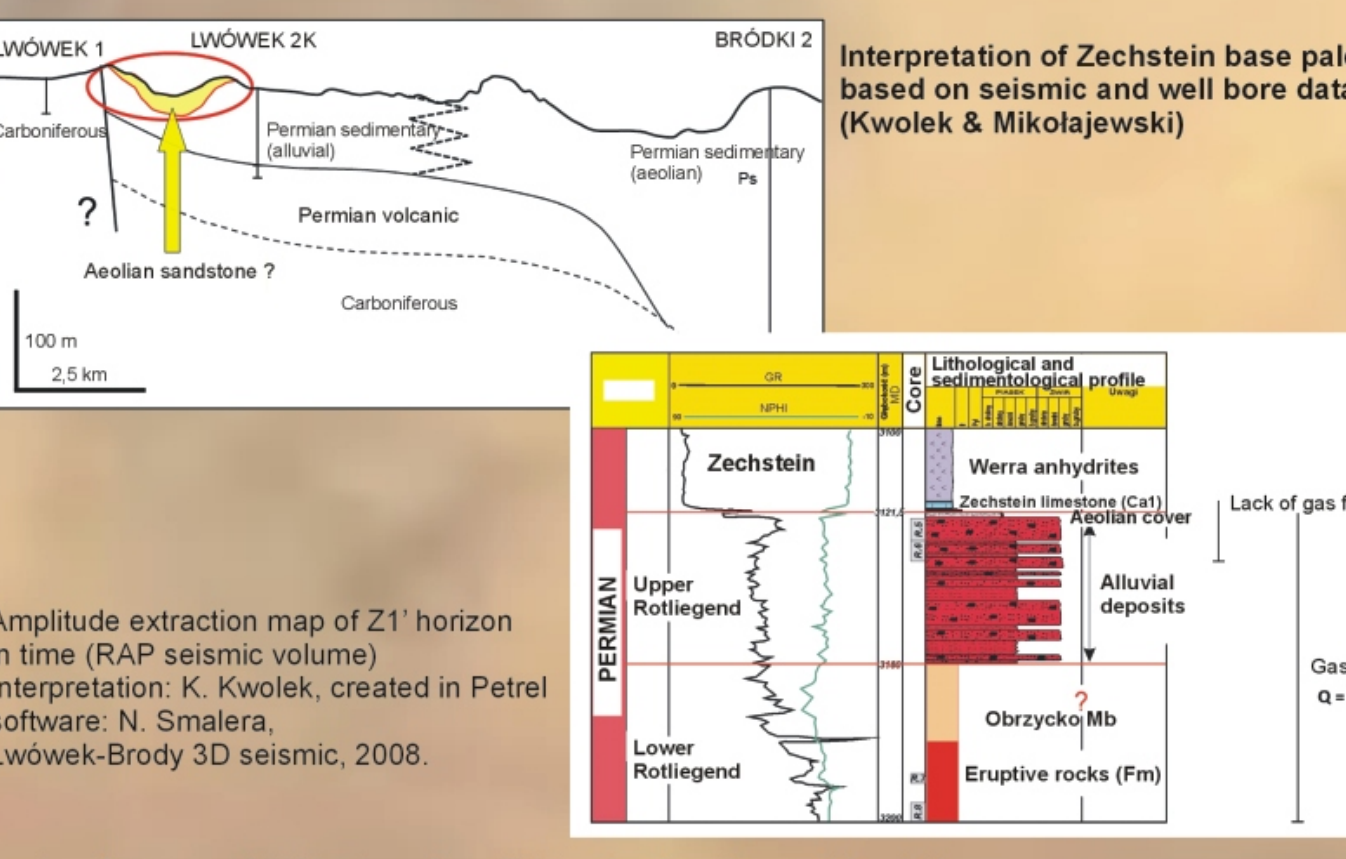
Krzysztof Kwolek, POGC

LWÓWEK GAS FIELD DISCOVERY?

Upper Rotliegend: subtle trap dedection

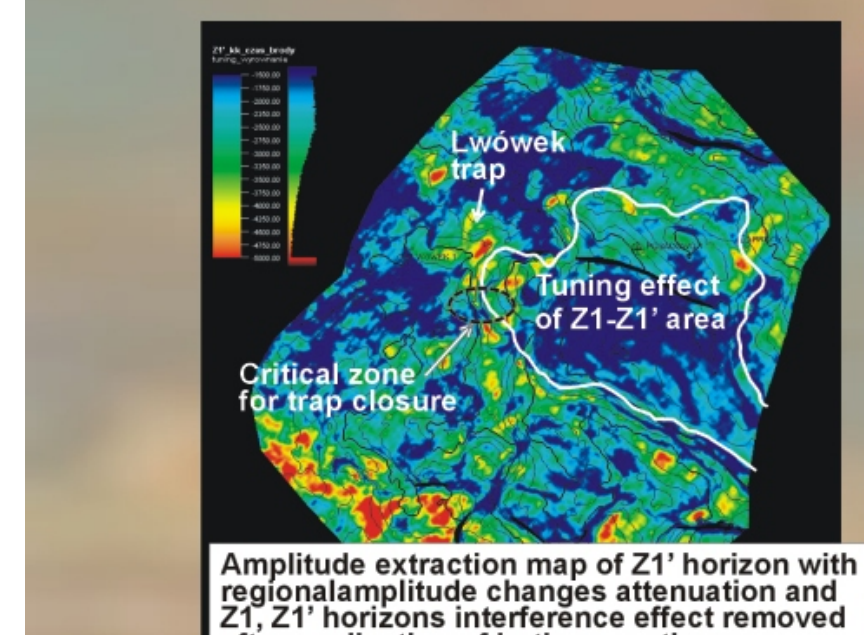


Amplitude extraction map of Z1' horizon in time (RAP seismic volume)
Interpretation: K. Kwolek, created in Petrel software: N. Smalera,
Lwówek-Brody 3D seismic, 2008.



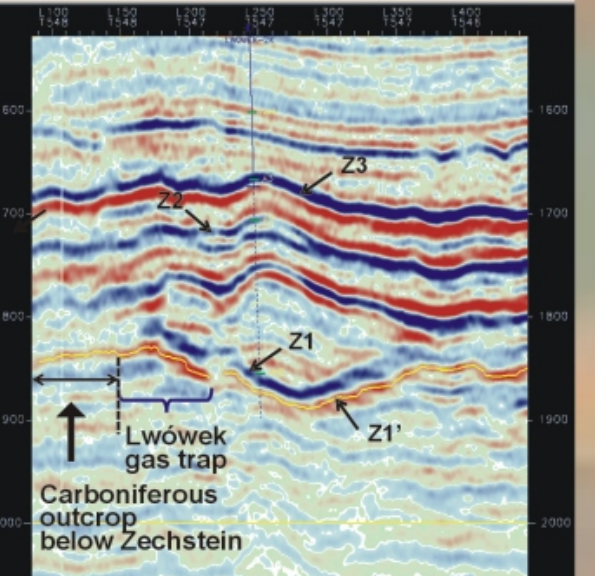
Interpretation of Zechstein base paleogeography based on seismic and well bore data (Kwolek & Mikołajewski)

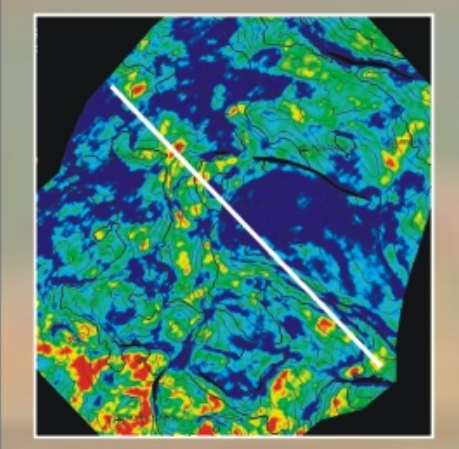
Amplitude extraction map of Z1' horizon from RAP seismic volume with relative amplitude and anti-interference correction (linear) applied
Interpretation: K. Kwolek, Lwówek-Brody 3D seismic, 2008.



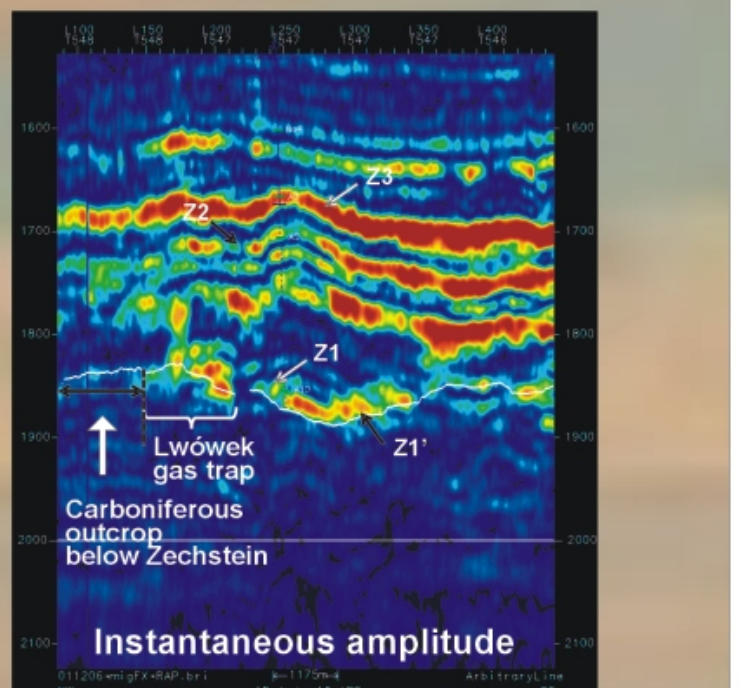
Amplitude extraction map of Z1' horizon with regionalamplitude changes attenuation and Z1, Z1' horizons interference effect removed after application of both corrections

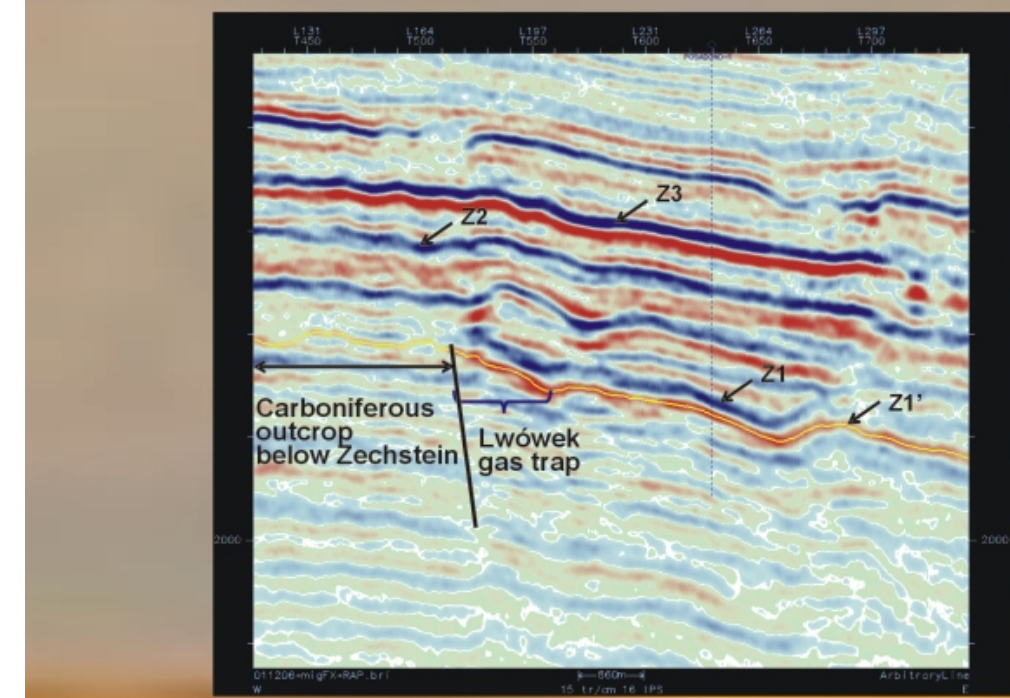
Seismic cross-section NW-SE

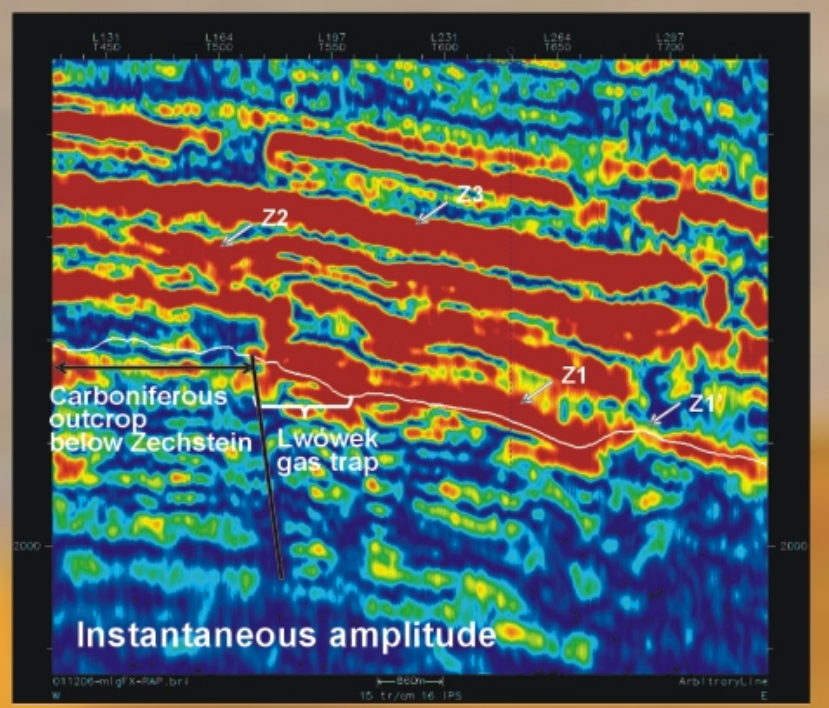




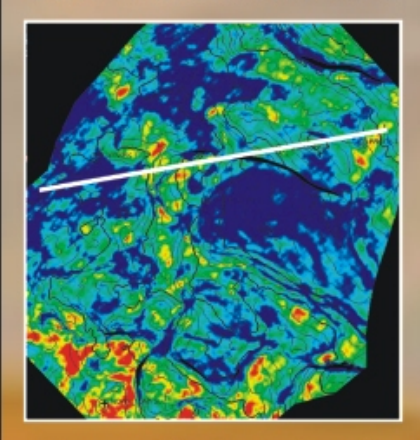
Z1' amplitude extraction





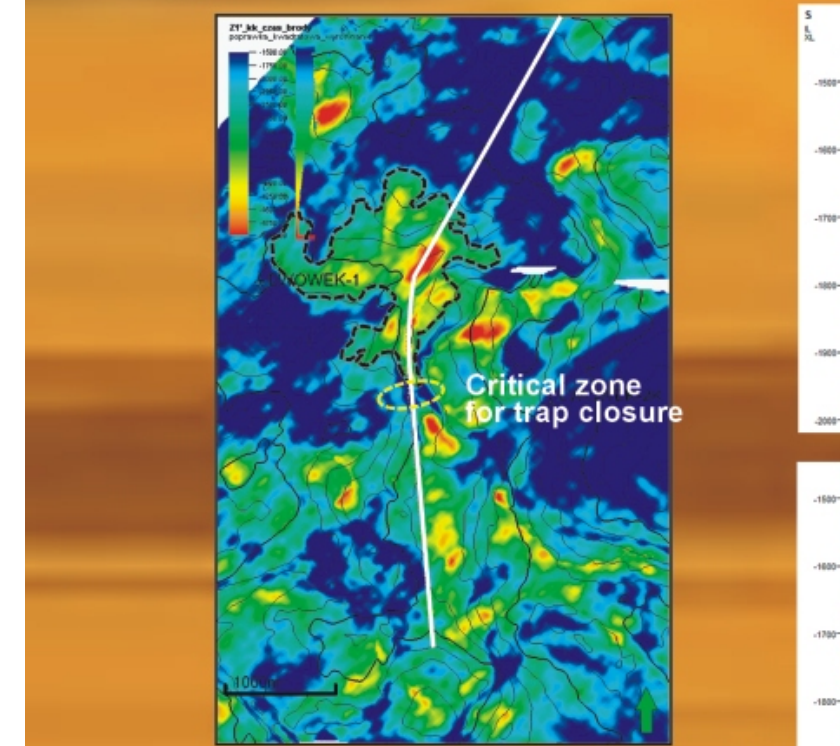


Seismic cross-section W-E



Z1' amplitude extraction

Final gas trap dedection



Amplitude extraction map of Z1' horizon in time (RAP seismic volume)
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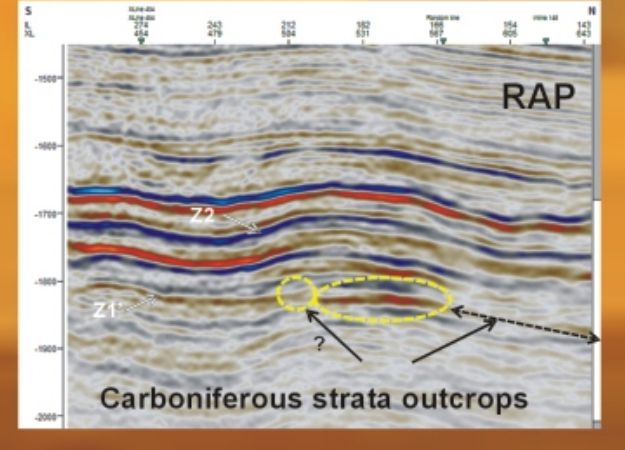
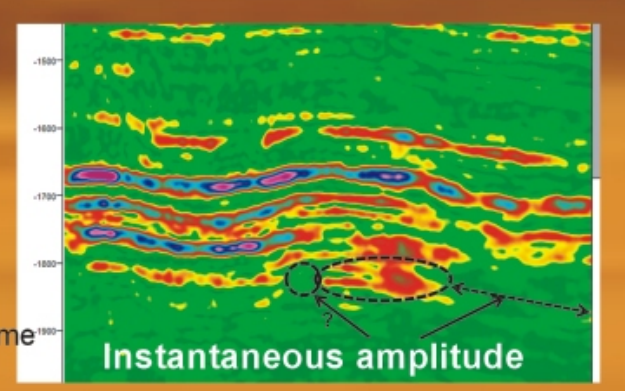
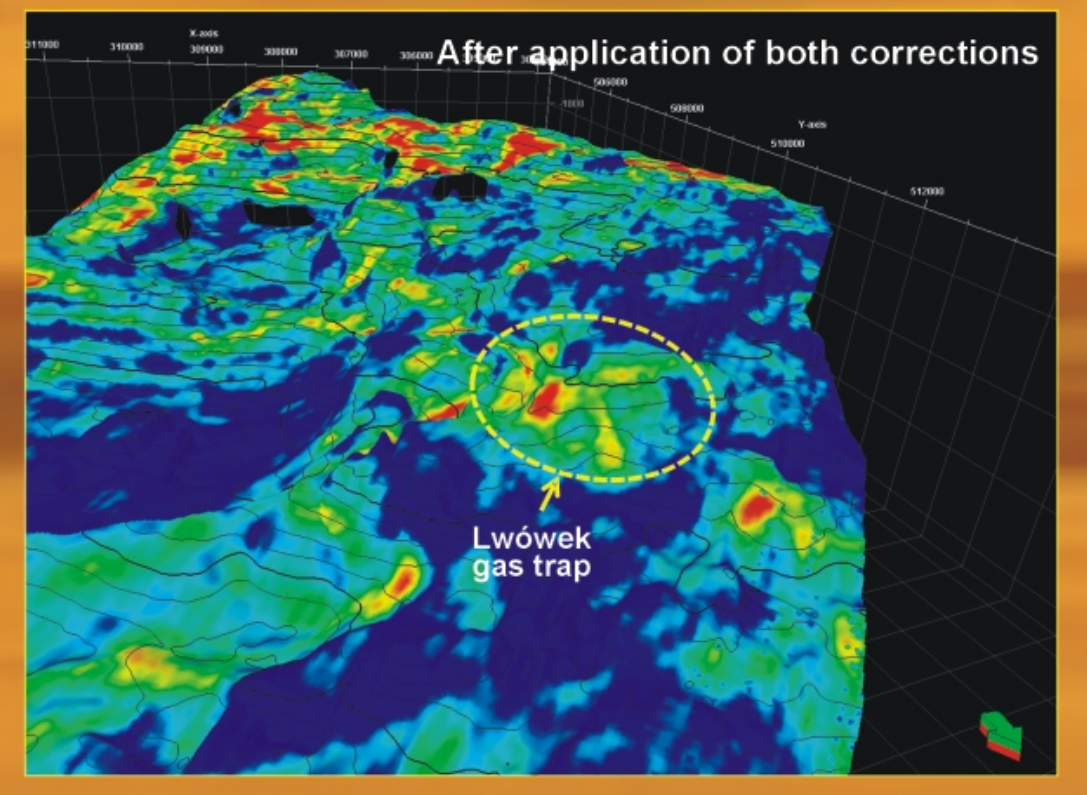




After relative amplitude preservation and tunning effect of Z1-Z1' corrections applied



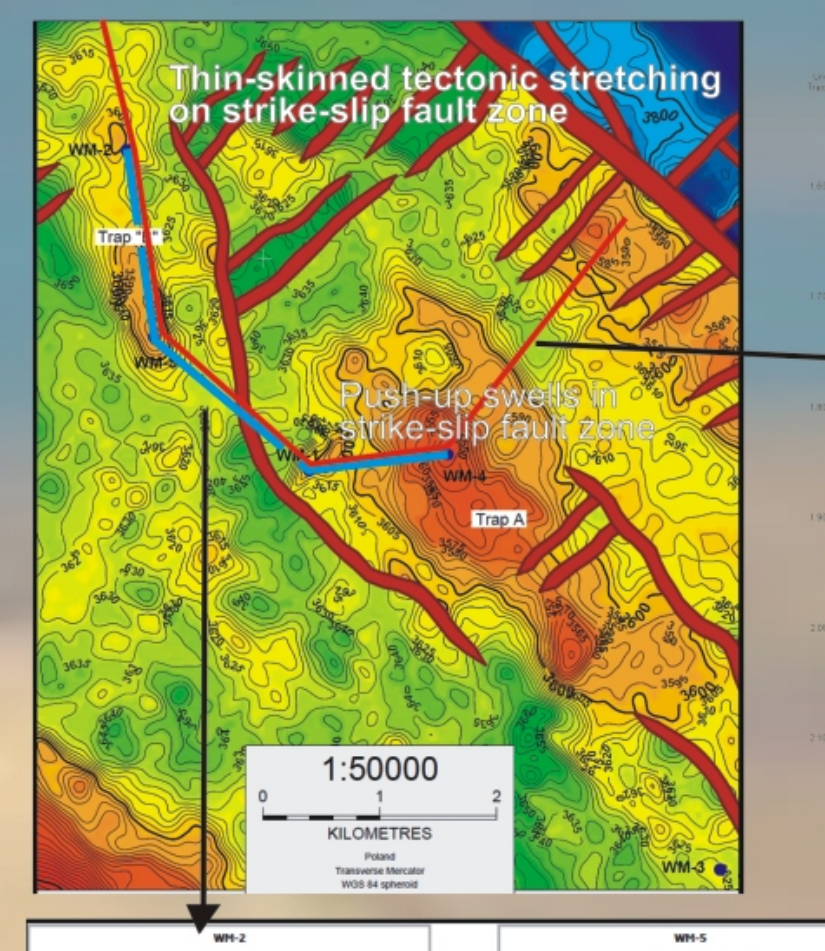
Amplitude extraction map of Z1' horizon in time (RAP migration) - 3D visualiation

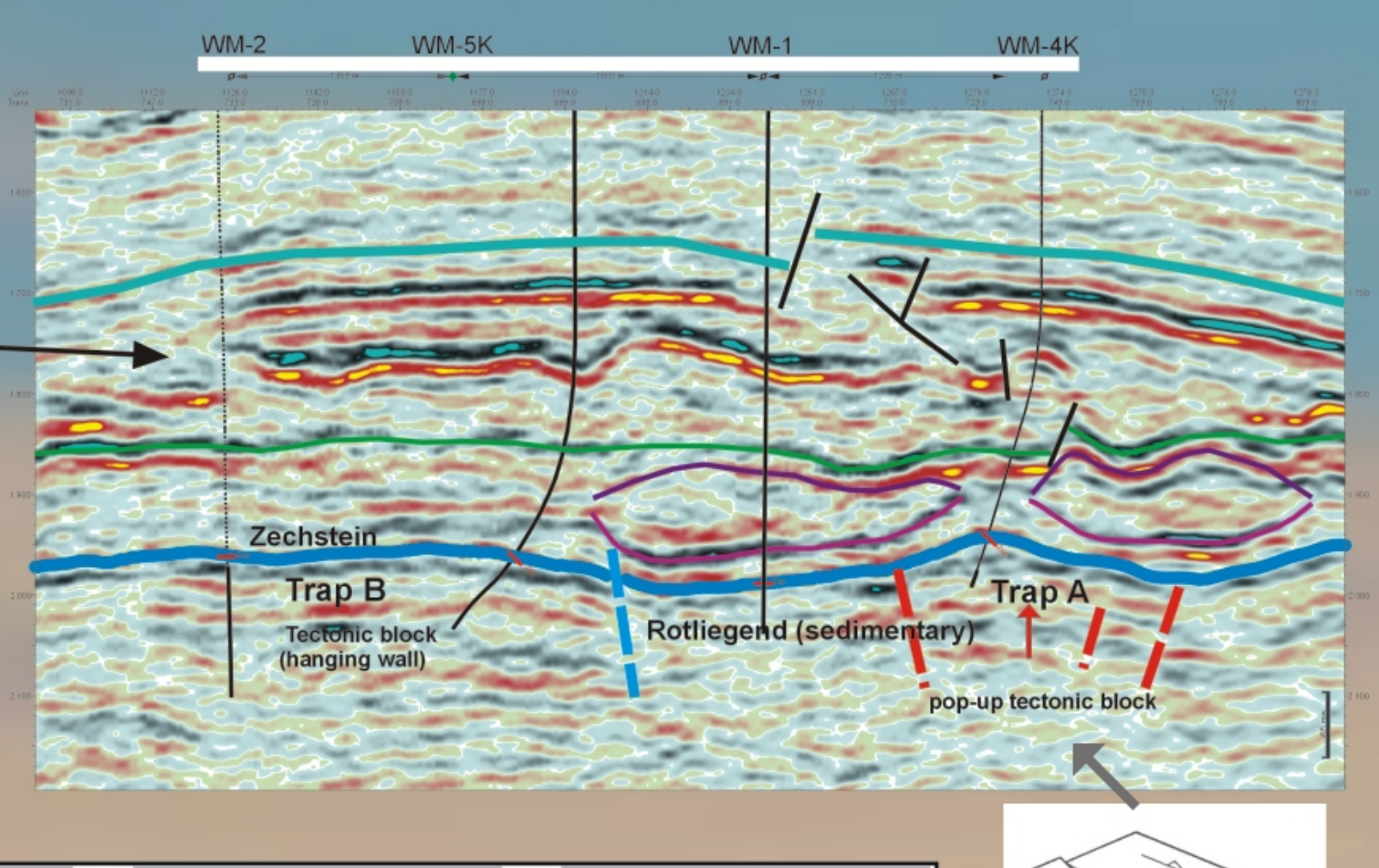
Wojciech Zarudzki, Orlen Upstream

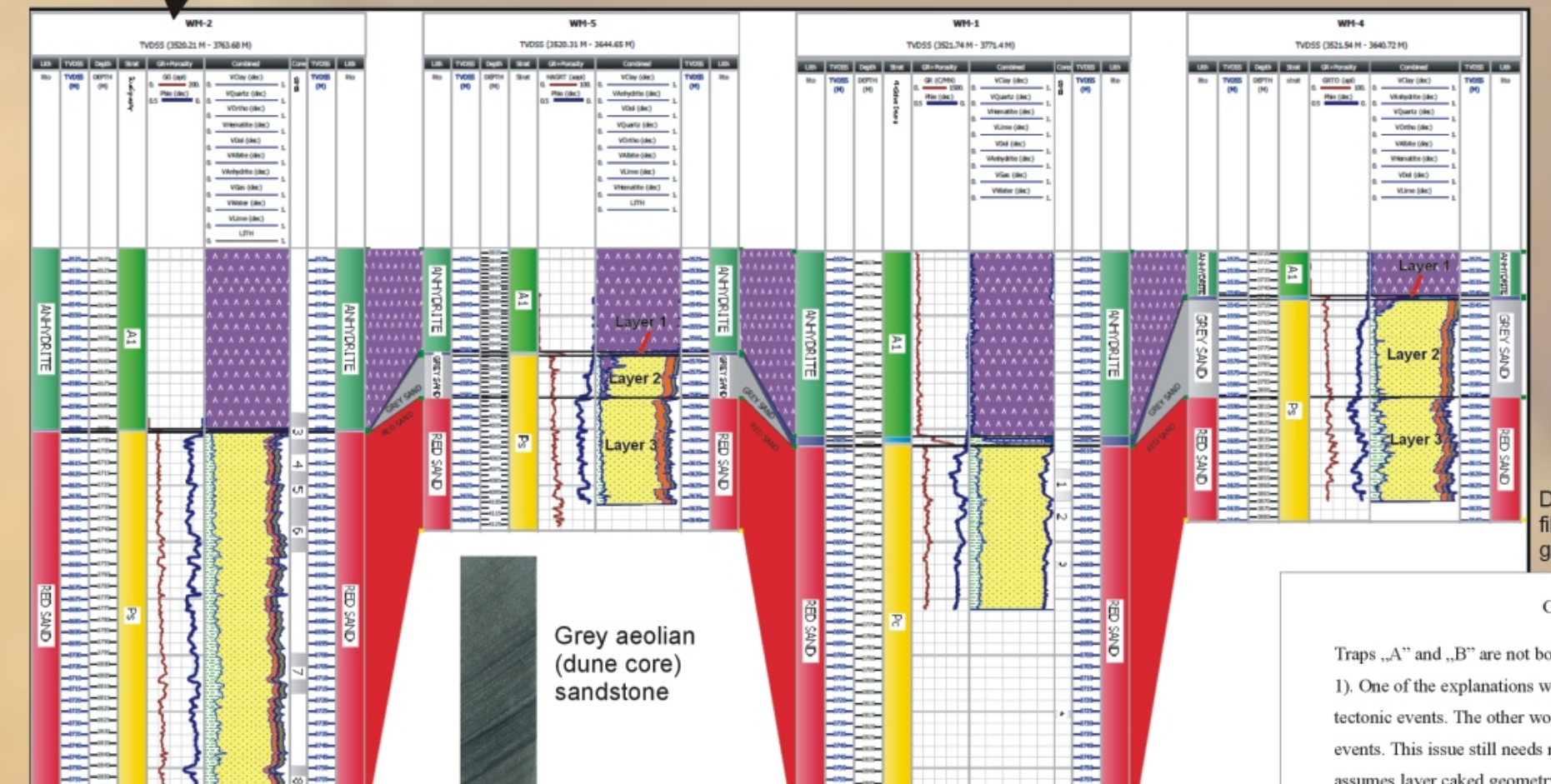
Hubert Kiersnowski, PGI-NRI

MIŁOSŁAW GAS FIELD DISCOVERY

Structural and geomorphological traps



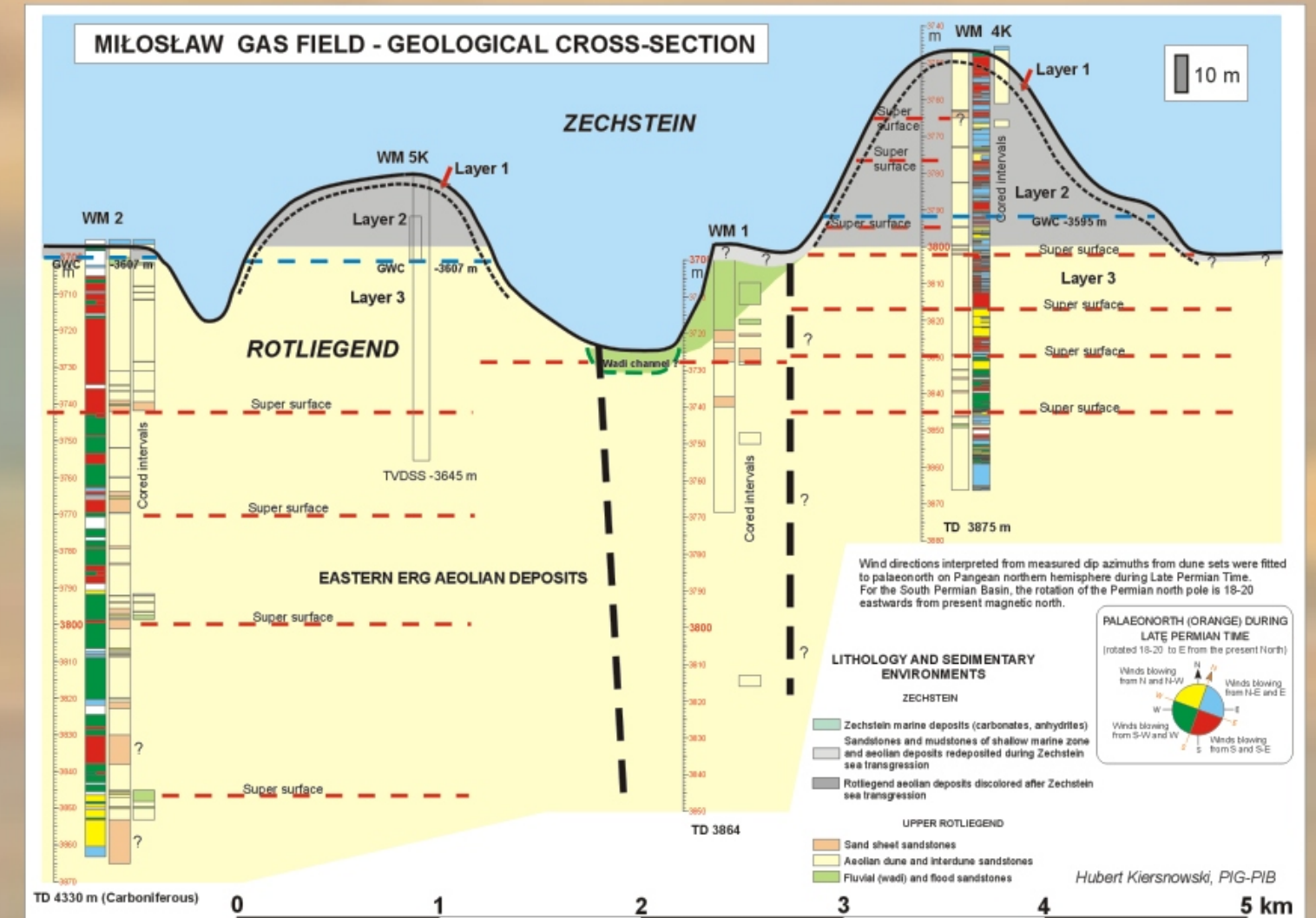




Grey aeolian (dune core) sandstone

Push-up swells in strike-slip fault zone

Dolomite cement: Dolomite cement (D) fills the pore space. The dolomite crystals grow on detrital quartz grains.



Wind directions interpreted from measured dip azimuths from dune sets were fitted to palaeonorth on Pangean northern hemisphere during Late Permian Time. For the South Permian Basin, the rotation of the Permian north pole is 18-20 eastwards from present magnetic north.

PALAEONORTH (ORANGE) DURING LATE PERMIAN TIME (rotated 18-20 to E from the present North)

LITHOLOGY AND SEDIMENTARY ENVIRONMENTS

ZECHSTEIN
- Zechstein marine deposits (carbonates, anhydrites)
- Sandstones and mudstones of shallow marine zone and aeolian deposits redeposited during Zechstein sea transgression
- Rotliegend aeolian deposits discolored after Zechstein sea transgression

UPPER ROTLIEGEND
- Sand sheet sandstones
- Aeolian dune and interdune sandstones
- Fluvial (wadi) and flood sandstones

GEOLOGICAL MODEL OF TRAPS

Traps „A" and „B" are not bounded to the fault as most of structures found in the area (Fig. 1). One of the explanations would be that these traps are paleodunes which did not undergo tectonic events. The other would be the structures formed during transpressional tectonic events. This issue still needs more detailed analysis. Plausible geological model of the traps assumes layer caked geometry which is shown on Figures X and Z (correlation and geological model). Short description of particular layers is shown below.

A. **LAYER 1**: Top 5m to 7m thick layer is non-reservoir sandstone. The extent of this layer in the geological model mimics bottom of Zechstein. The diagenetic processes destroyed porosity. Anhydrite, dolomite and quartz cement fill the pore space (Figure VV. SEM). This layer may also include reworked sandstone, but it's thickness is very limited.

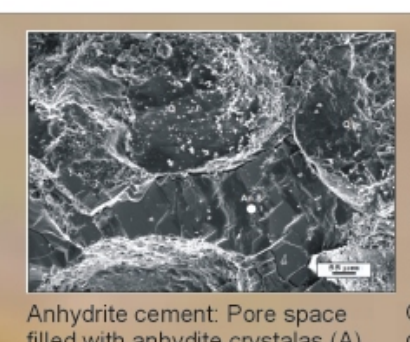
B. **LAYER 2**: The thickness of grey sandstone layer is 37m and 14m, respectively for trap "A" and "B". Diagenetic processes strongly influenced sandstone reservoir properties. Porosity loss caused by intensive quartz, anhydrite and dolomite cementation is clearly seen on presented well log correlation and SEM photo. On the other hand porosity was enhanced by feldspar dissoluton process (SEM photo).

Sandstone bleaching process has been identified in both structures. Chemically color change from red to white is actually reduction of iron (Fe3+) to mobile Fe2+ caused by agents like: heavier hydrocarbons migrating through the rock, hydrogen sulphide, organic acids, methane. In that particular case the details of geological process are still unknown.

C. **LAYER 3**: Diagenetic processes are less intensive in lower part of reservoir. No bleaching is reported, the sandstones are red with better reservoir properties. Porosity reaches 15%, which is common at this depth.

CONCLUSIONS

1. Proposed geological model of „Trap A" and „Trap B" can be used for predicting reservoir rock quality of future prospects.
2. Traps "A" and "B" are not bounded to the fault which may suggest different tectonic history.
3. Intensive cementation reduces reservoir properties, especially Layer 1 and Layer 2.
4. Sandstone bleaching process present in both structures.



Anhydrite cement: Pore space filled with anhydite crystalas (A). Detrital quartz grains are well rounded. Clay minerals are visible cover quartz grains.

Quartz cement: Pore space filled with quartz cement (Q) Detrital quartz grains are well rounded and appear to have long contacts

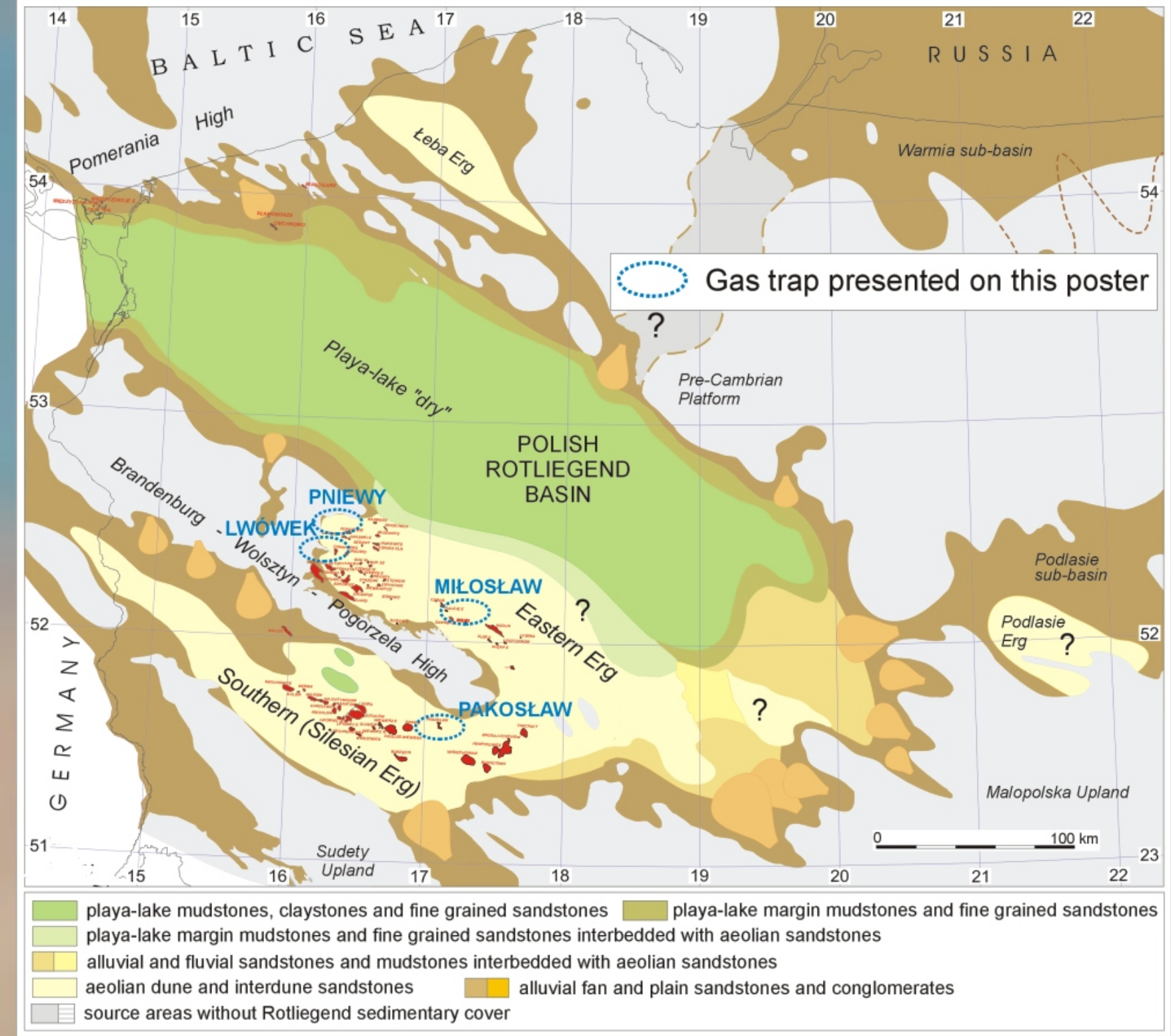
REFERENCES

Structural map of Zsp (base Zechstein) and seismic cross-section, FX Energy Poland, G&G Team, 2014.

Final Well Raport WM-4, PGNiG and FX Energy Poland (SEM-PetroGeo)

W.T. Parry, Marjorie A. Chan, and Brenda Beitler, Chemical bleaching indicates episodes of fluid flow in deformation bands in sandstone.

GAS FIELDS IN THE POLISH PERMIAN (ROTLIEGEND) BASIN



- playa-lake mudstones, claystones and fine grained sandstones
- playa-lake margin mudstones and fine grained sandstones
- playa-lake margin mudstones and fine grained sandstones interbedded with aeolian sandstones
- alluvial and fluvial sandstones and mudstones interbedded with aeolian sandstones
- aeolian dune and interdune sandstones
- alluvial fan and plain sandstones and conglomerates
- source areas without Rotliegend sedimentary cover

Kiersnowski H., 2013. Late Permian aeolian sand seas from the Polish Upper Rotliegend Basin in the context of palaeoclimatic periodicity. In: Palaeozoic climate cycles: their evolutionary and sedimentological impact. Gąsiewicz A. & Słowakiewicz M., (Eds.). Geological Society, London, Special Publications, No 376, p. 431-456.

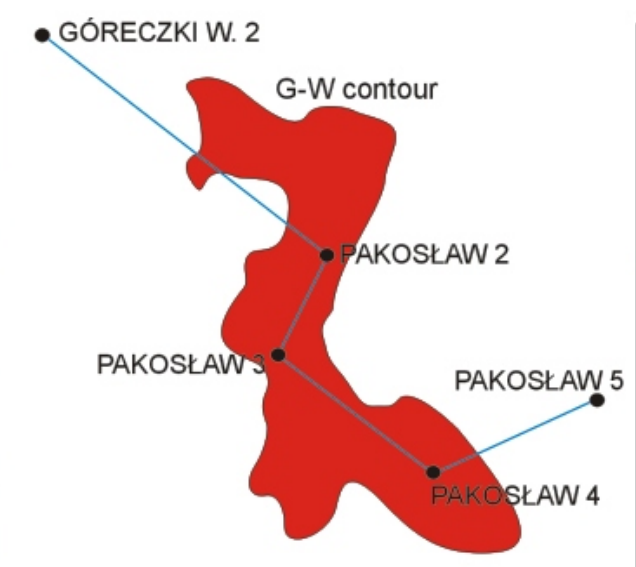
Hubert Kiersnowski, PGI-NRI

Maciej Tomaszczyk, POGC

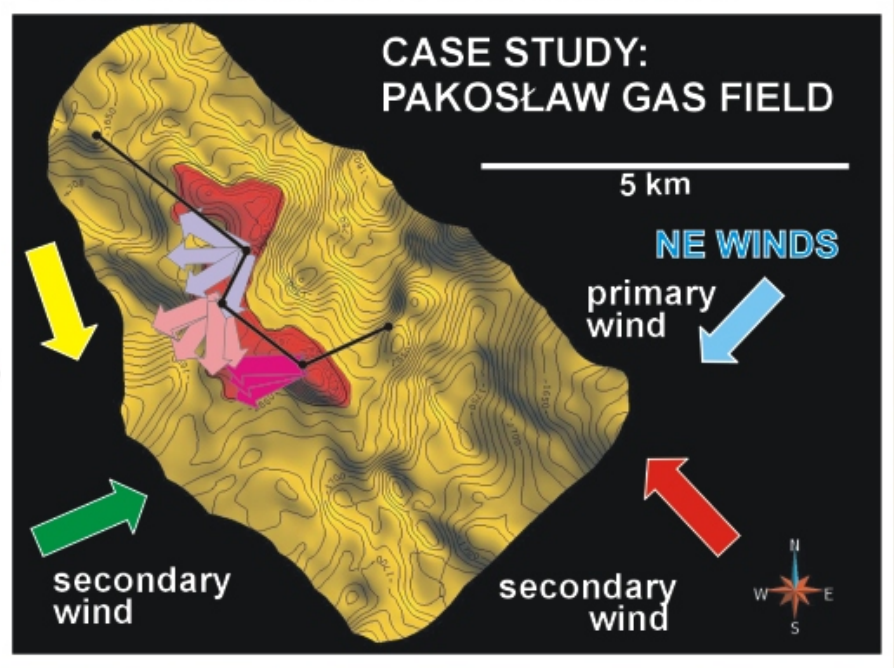
PAKOSŁAW GAS FIELD DISCOVERY

Upper Rotliegend: geomorphic (erosional) gas trap

PAKOSŁAW GAS FIELD



Interpreted as erosional form. Aeolian sandstones eroded by wind (yardangs) and flowing water, preserved (slightly eroded) under Zechstein cover



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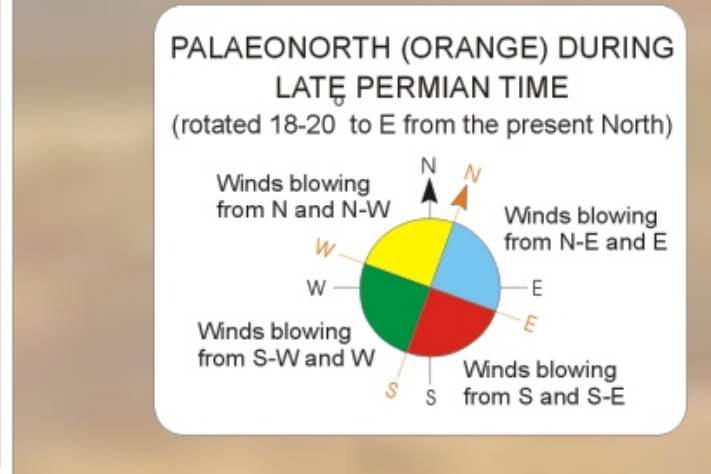
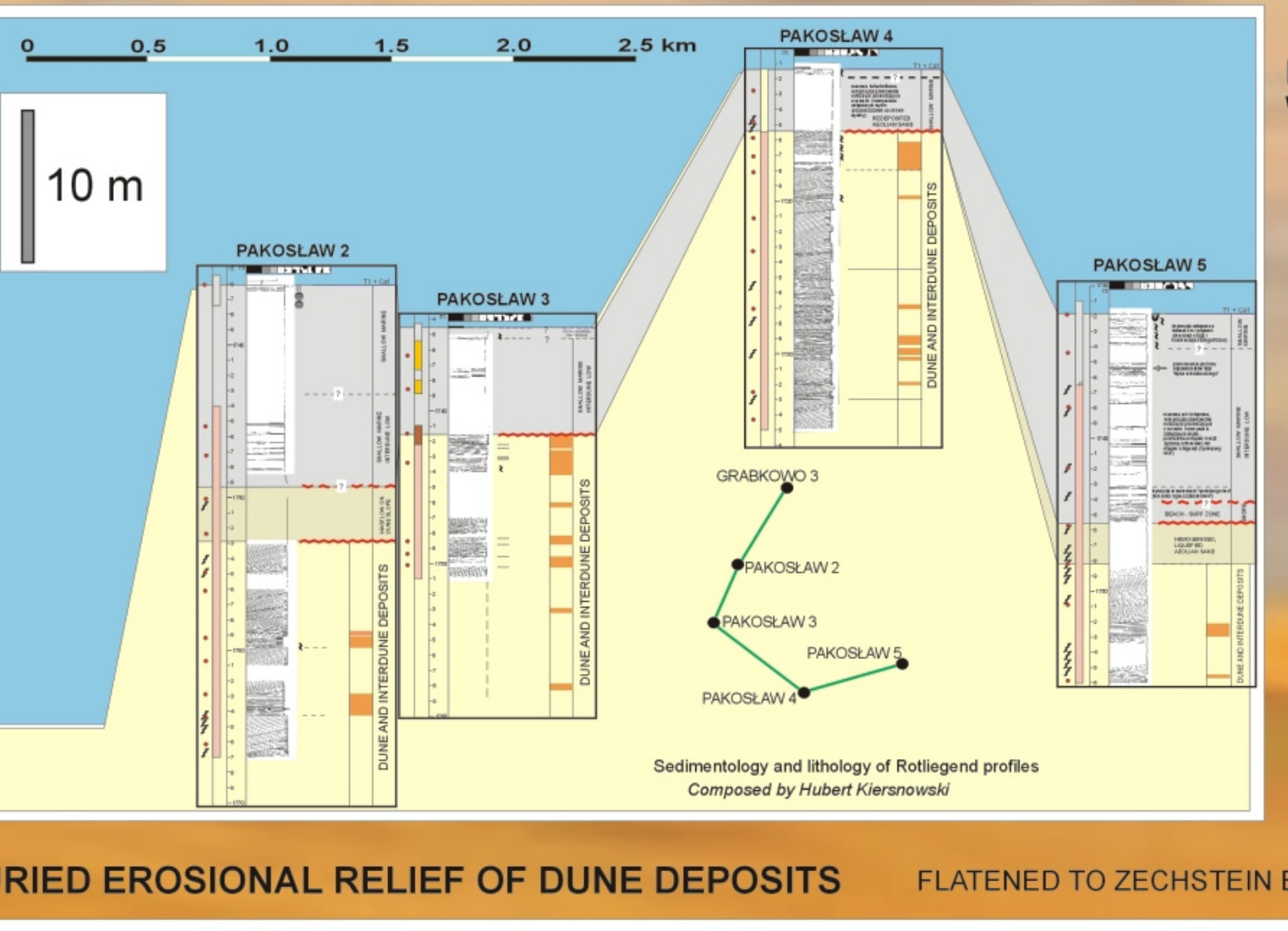


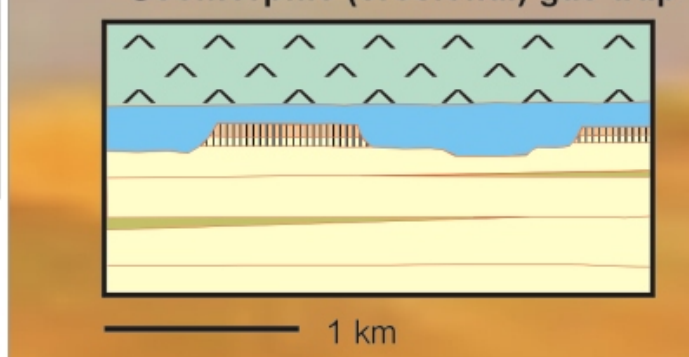


Sedimentology and lithology of Rotliegend profiles
Composed by Hubert Kiersnowski

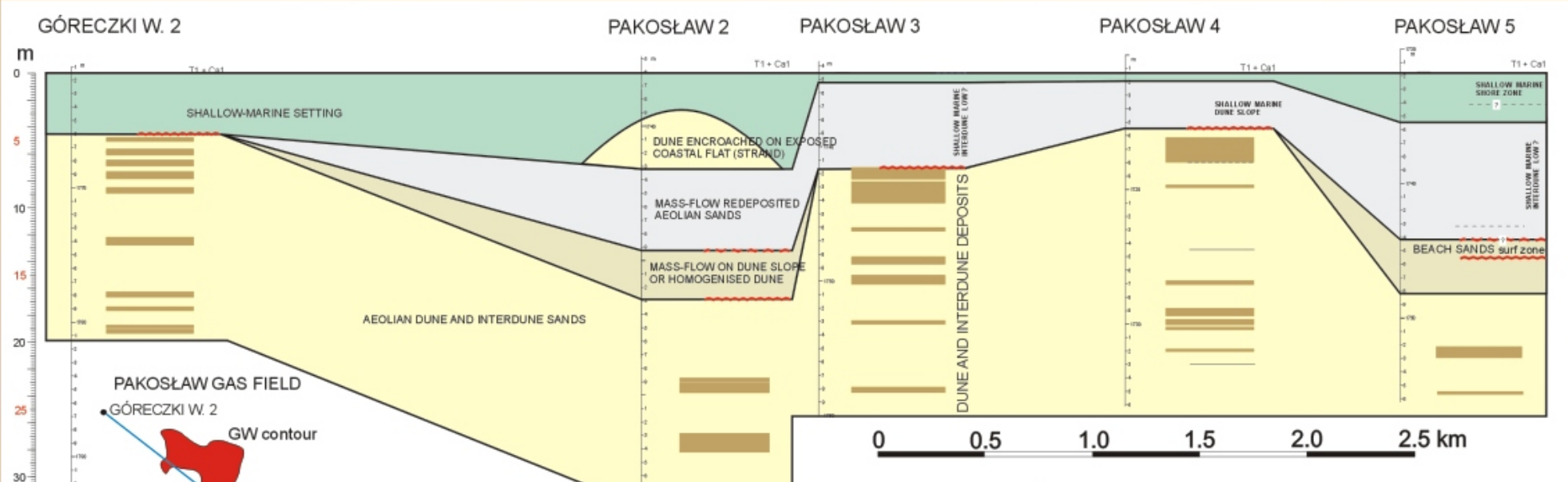
PAKOSŁAW GAS FIELD DISCOVERY WORKFLOW

1. Seismic recognition of Pakosław structure
2. Wells were drilled and gas field was discovered
3. Sedymentological description of core data
4. Regional model of Zechstein sea transgression
5. Determining the type of trap
6. Geomorphological trap of yardang type - Zechstein evaporates seal

Geomorphic (erosional) gas trap

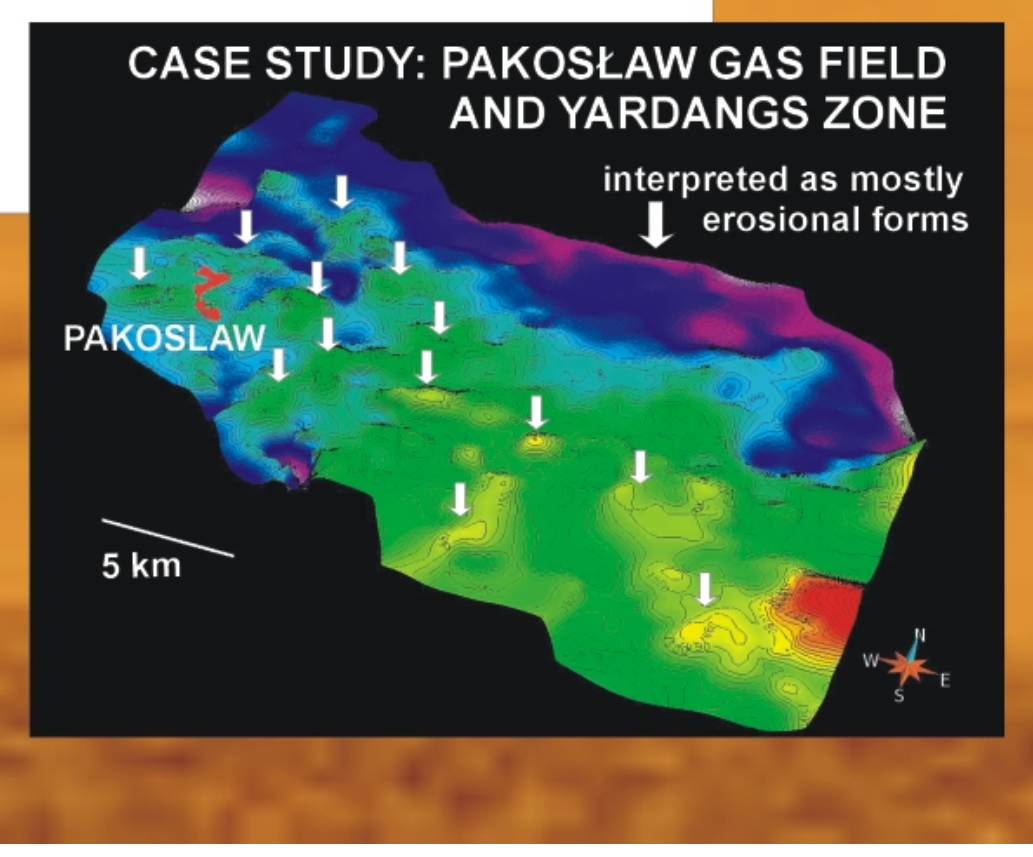


BURIED EROSIONAL RELIEF OF DUNE DEPOSITS FLATENED TO ZECHSTEIN BASE



PAKOSŁAW GAS FIELD
- Sand sheet sandstones
- Aeolian dune and interdune sandstones

Composed by Hubert Kiersnowski



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Hubert Kiersnowski*, Krzysztof Wolański**, Krzysztof Kwolek**, Wojciech Zarudzki***, Paweł Zwoliński****
* Polish Geological Institute – National Research Institute
** Polish Oil and Gas Co.
*** Orlen Upstream
**** Palomar Natural Resources

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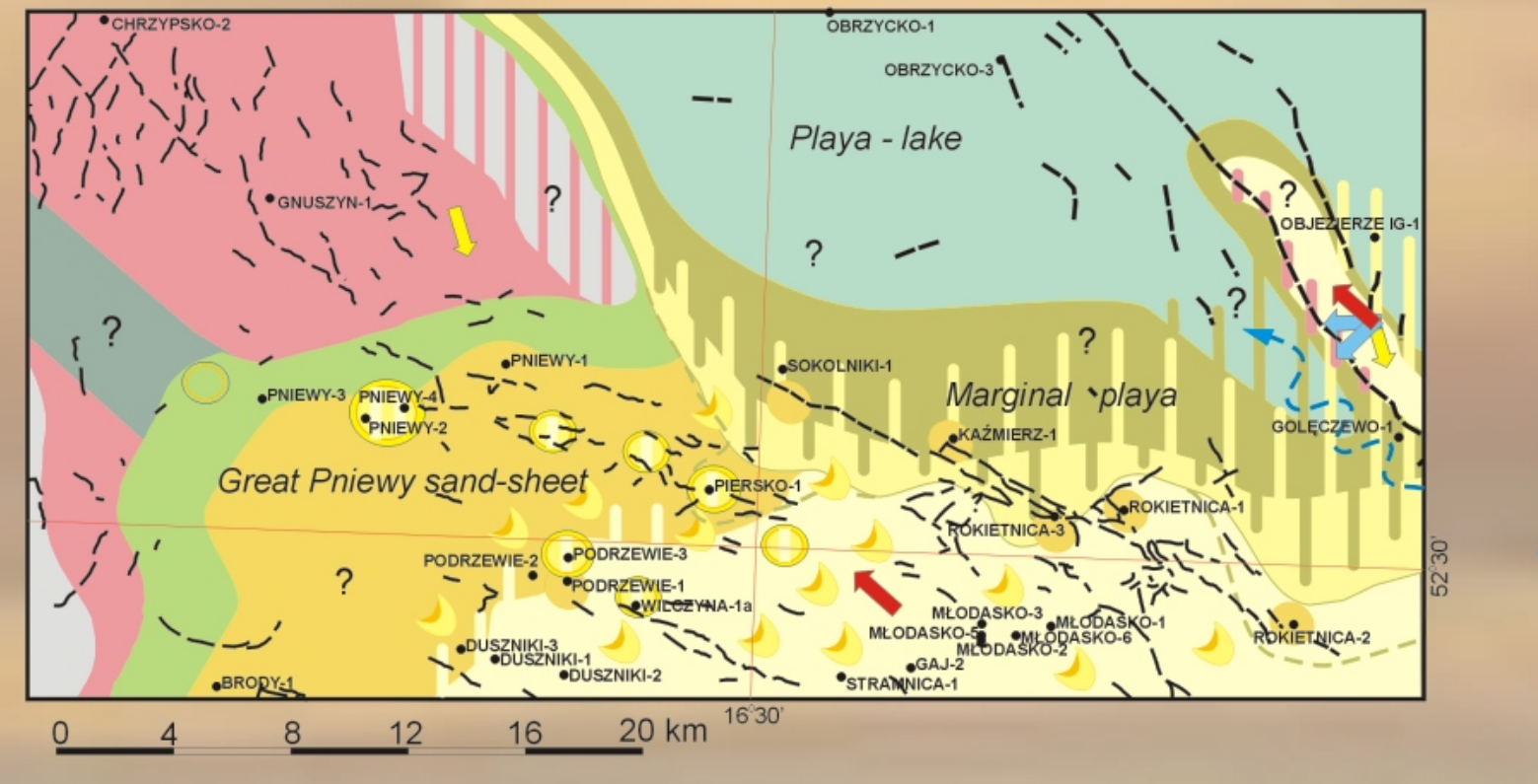
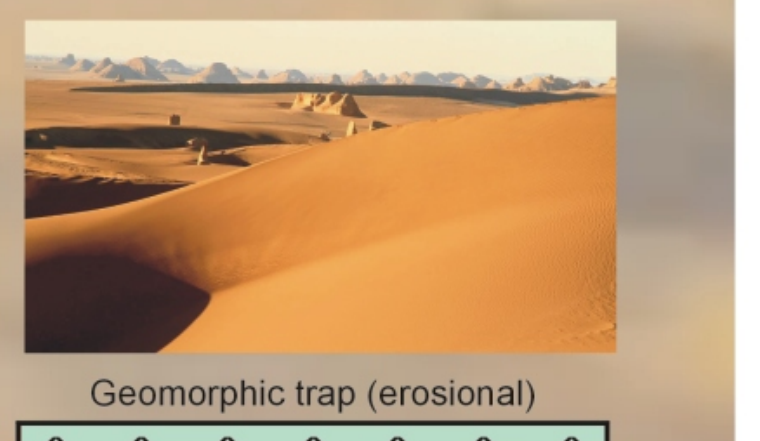
Krzysztof Wolański, POGC

PNIEWY GAS FIELD DISCOVERY

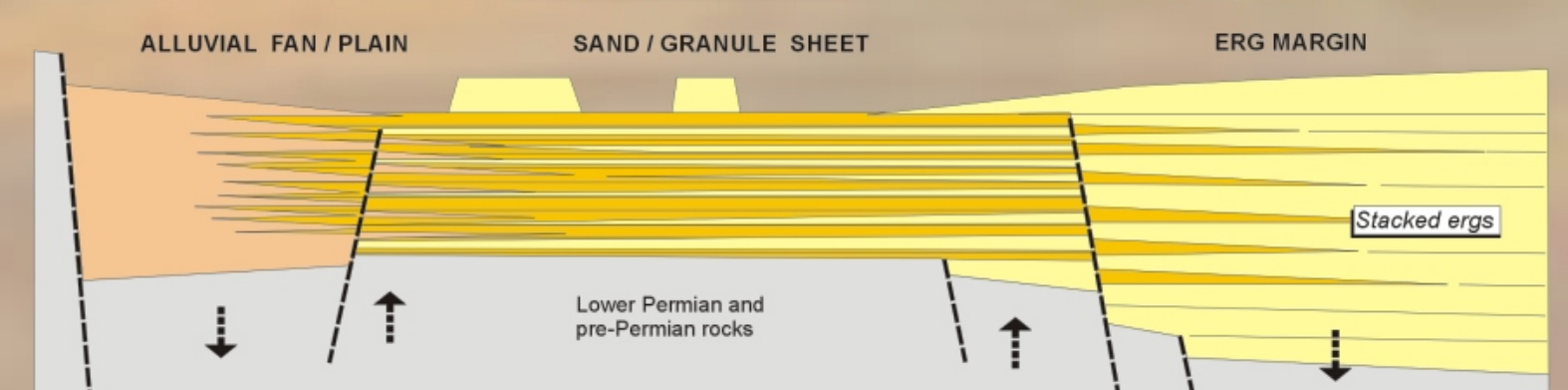
Upper Rotliegend: geomorphic (erosional) gas trap



- Remnants of eroded aeolian sand cover
- Open playa-lake mudstone, claystone and fine sandstone
- Marginal playa fine sandstone, mudstone and claystone
- Sand sheet sandstone and very fine gravel (granule) sheet
- Aeolian dune form sandstone
- Aeolian sandstone
- Alluvial and fluvial sandstone, mudstone and conglomerates
- Alluvial conglomerates
- Lower Rotliegend clastic and volcano-clastic rocks
- Carboniferous - Permian volcanic rocks
- Carboniferous clastis rocks
- Wind directions (based on averaged azimuths of aeolian dune laminae)

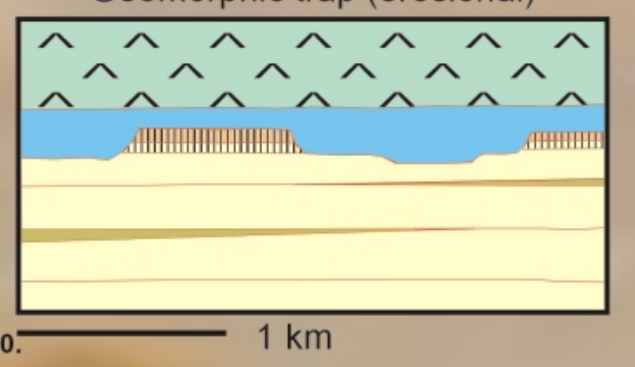


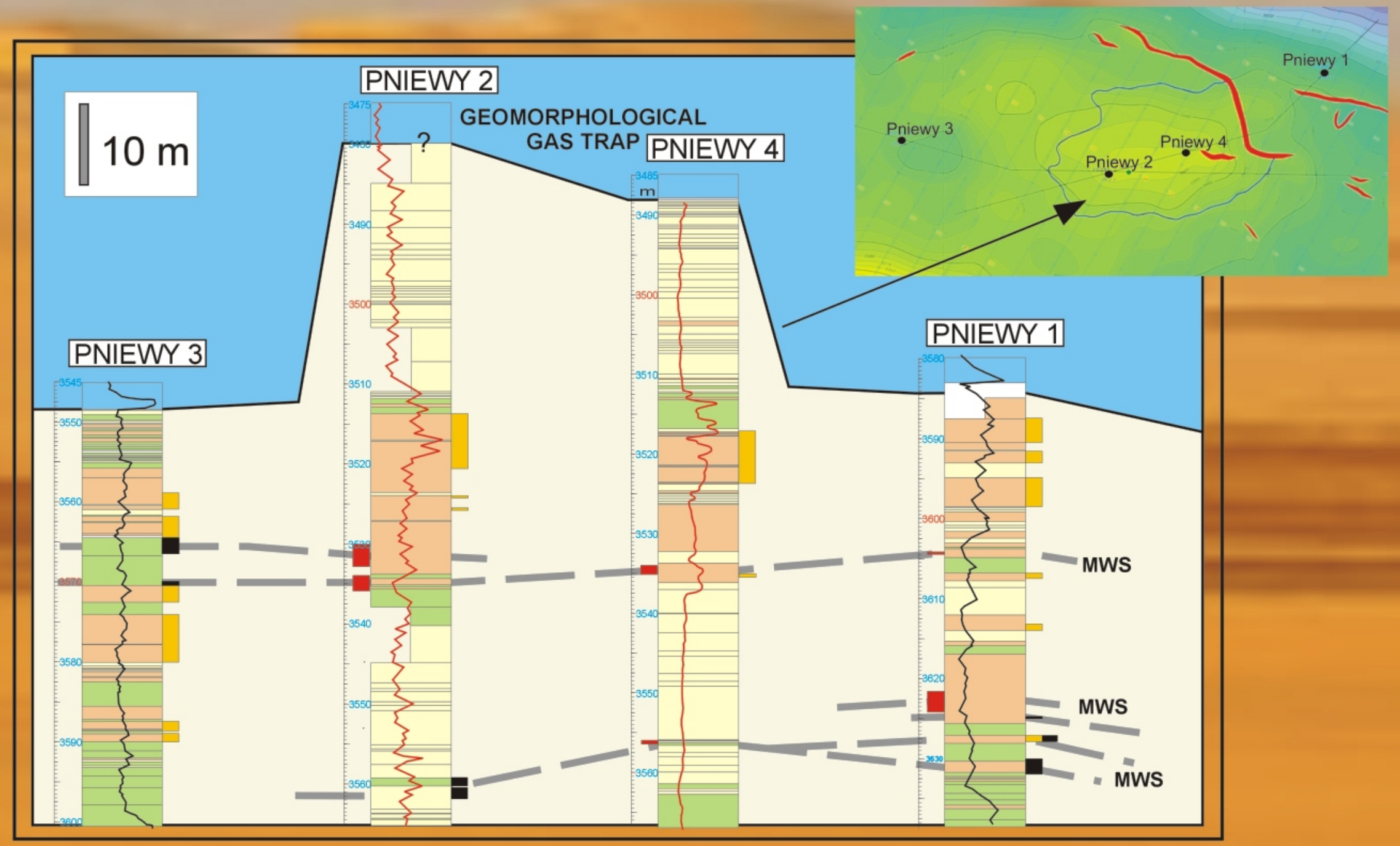
SIMPLIFIED DEPOSITIONAL ARCHITECTURE OF PNIEWY YARDANGS AREA

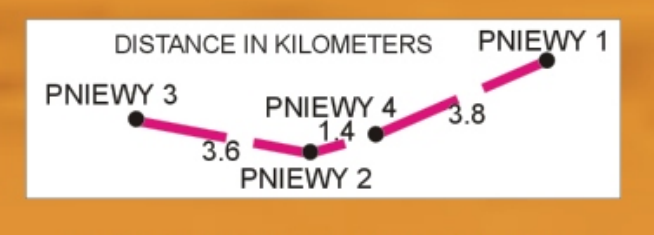


Kiersnowski H. & Buniak A., 2016. Sand sheets interaction with aeolian dune, alluvial and marginal playa beds in Late Permian Upper Rotliegend setting (western part of the Poznań Basin, Poland). Geological Quarterly, v. 60, numer 4, p. 771-800.

Geomorphic trap (erosional)







MWS - maximum wetting surface

LITHOLOGY AND SEDIMENTARY ENVIRONMENTS

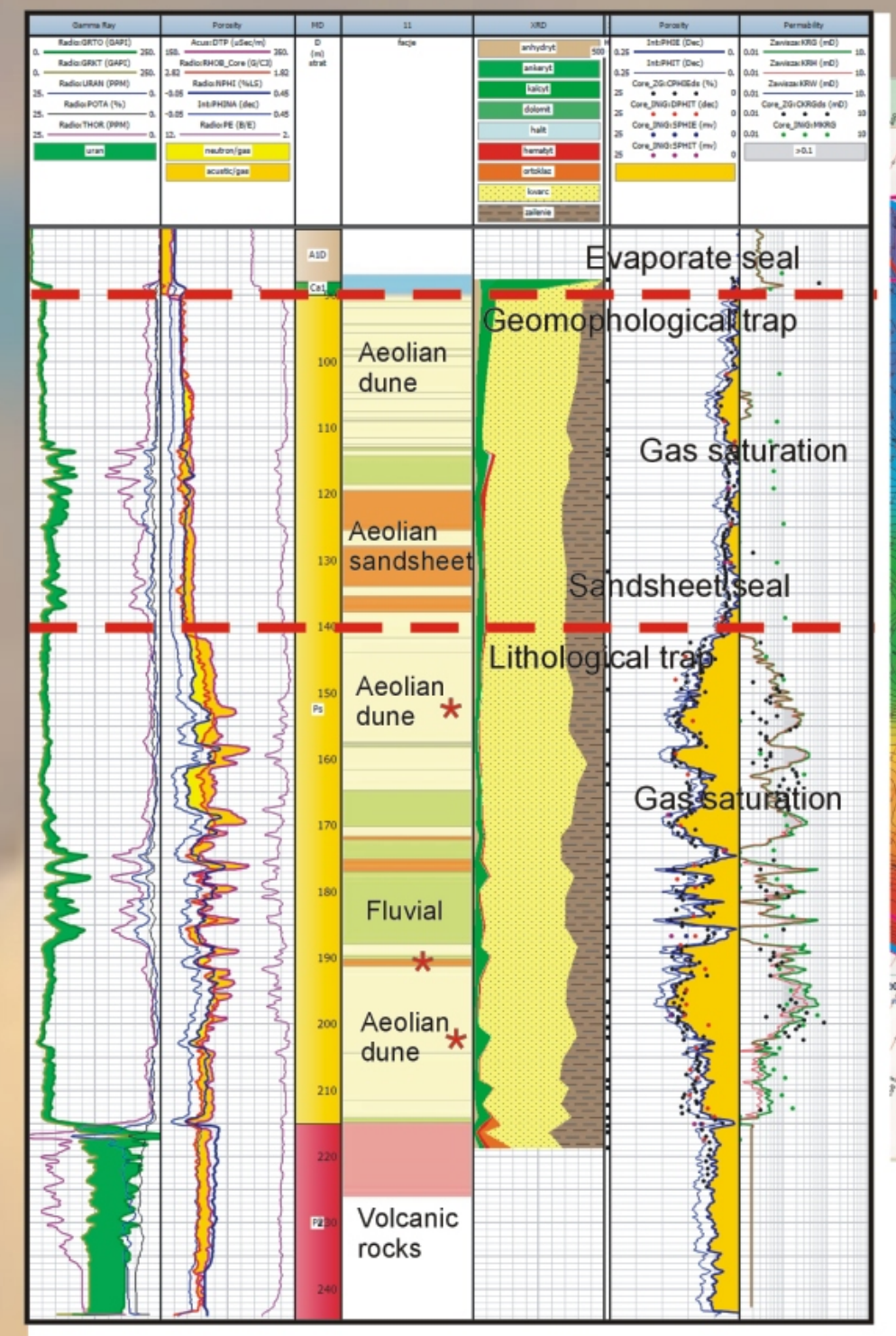
- Zechstein marine deposits
- Marginal playa fine sandstone, mudstone and claystone
- Sand & gravel sheet (sandstones and fine gravels)
- Sand sheet sandstones
- Aeolian dune and interdune sandstones
- Alluvial & fluvial sandstones, mudstones and conglomerates
- Alluvial conglomerates
- Lower Rotliegend clastic and volcano-clastic rocks
- Volcanic rocks
- Carboniferous siliciclastic rocks
- Erosional scours and chosen floods and fluvial channels
- Bioturbations

Krzysztof Wolański, POGC

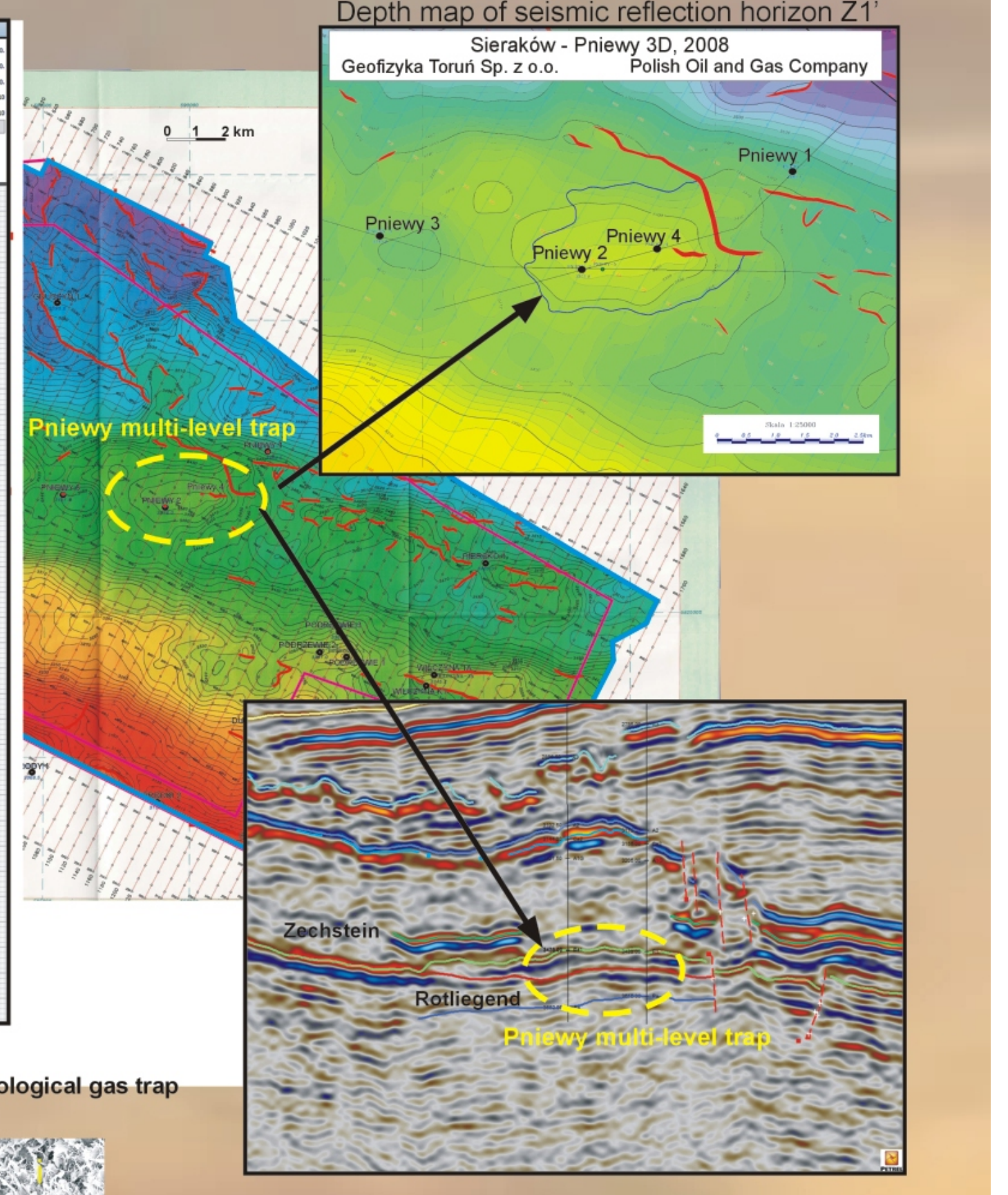
PNIEWY GAS FIELD DISCOVERY

Upper Rotliegend: Multi-level gas trap

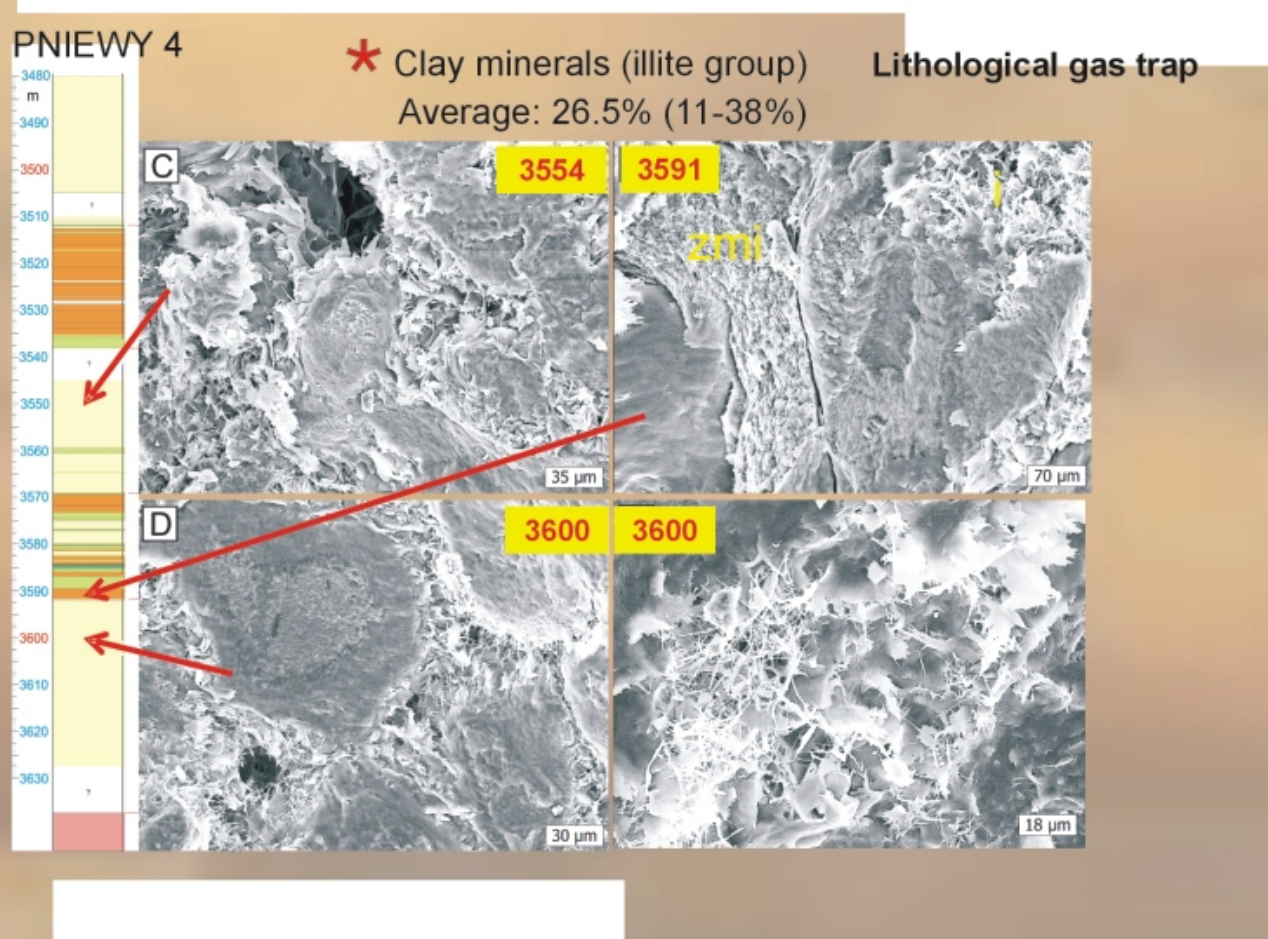
PNIEWY 4



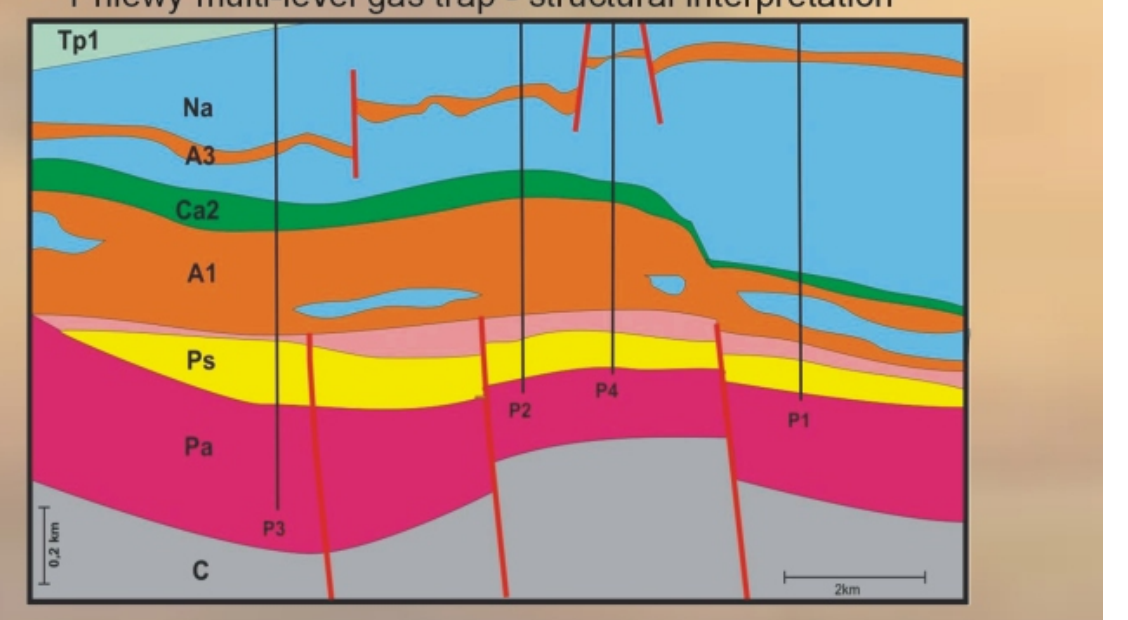
Depth map of seismic reflection horizon Z1'



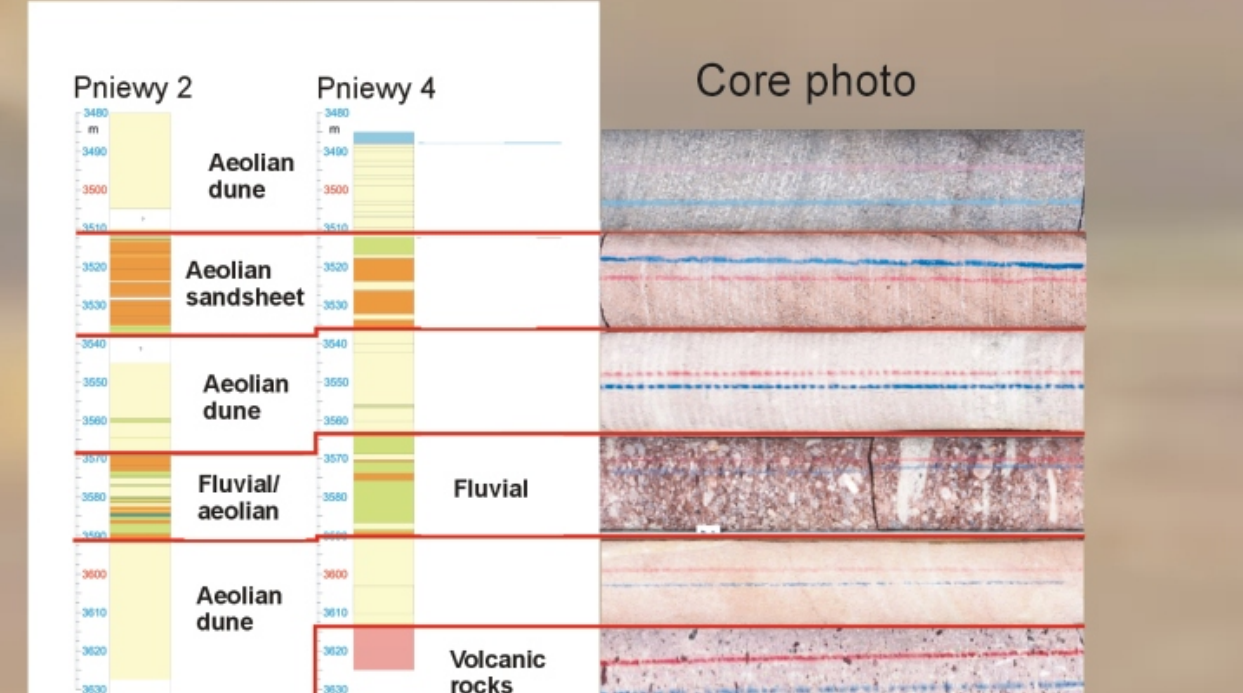
PNIEWY 4 * Clay minerals (illite group) Average: 26.5% (11-38%) **Lithological gas trap**



Pniewy multi-level gas trap - structural interpretation



Core photo



PNIEWY GAS FIELD DISCOVERY WORKFLOW

1. Seismic recognition of Pniewy structure
2. Wells were drilled and gas trap was discovered
3. Sandstones porosity and permeability analysis
4. Sedymentological description of core data
5. Regional model of Zechstein sea transgression
6. Determining the type of trap
7. Lithological trap - sandsheet seal
8. Geomorphological trap of yardang type - Zechstein evaporates seal