Polish Geological Institute
National Research Institute

Polish Geological Survey
Polish Hydrogeological Survey

# PGI-NRI OFFER

science & research

## HYDROCARBONS FROM UNCONVENTIONAL RESOURCES

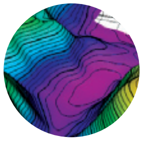
SHALE GAS AND OIL • TIGHT GAS
COAL BED METHANE

# Contents:

## HYDROGEOCHEMICAL LAB



## GEOLOGICAL MODELING & VISUALIZATION LAB

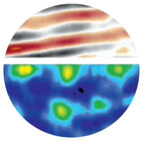




## TECTONIC & STRUCTURAL ANALYSIS LAB

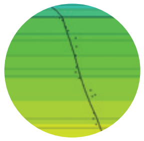


## GEOPHYSICAL LAB



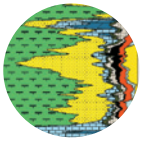


## PETROLEUM GEOLOGY LAB





## GEOPHYSICAL LAB





## GIS DATA & GEOLOGICAL MAPPING LAB



## ENVIRONMENT PROTECTION LAB

# 01 BIOSTRATIGRAPHY LAB

## GRAPTOLITE & ACRITARCH BIOSTRATIGRAPHY OF THE LOWER PALEOZOIC ROCKS

**The great interest in prospecting for unconventional hydrocarbons deposits has resulted in stratigraphic research, from biostratigraphy to high-resolution sequence stratigraphy, becoming an important field of activity in PGI-NRI.**

Lower Paleozoic fine-grained clastics, being a potential source of hydrocarbons, were deposited widely in Poland on the western margin of the East European Craton from the upper Cambrian-Tremadocian through the middle and upper Ordovician to the Silurian (Fig. 1). Dark mudstones are the dominant rock type in the thick Silurian series of the Polish part of the EEC. The fine-grained terrigenous clastic rocks form an essentially continuous sequence from the lower Llandovery to the Pridoli.

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**The main groups of fossils investigated in the Biostratigraphy Lab in PGI-NRI are graptolites and acritarch:**

- Planktonic graptolite faunas are abundant, well-preserved and continuous, allowing studies of the zonal division and chronostratigraphy (Fig. 2, 3). Due to their widespread distribution, graptolites are an excellent tool for regional correlations. Thanks to graptolites it is possible to "date" stratigraphic sequences and their boundaries, as well as the anoxic levels enriched in organic material which are the source of hydrocarbon in the rocks.
- Organic microfossil assemblages of an informal Acritarcha group are also successfully applied in stratigraphic subdivision of the Paleozoic, especially of the Lower Paleozoic rocks. Rich and determinable acritarch assemblages can be recovered from small rock samples, even of only a few grams in weight.
- The taphonomic investigation of fossils is used in practice for the exploration of zones enriched in organic matter and prospective levels for hydrocarbon accumulation.

The entire Ordovician and Silurian in Poland fits well into the current international chronostratigraphic subdivision and the graptolitic fauna are fully comparable with coeval rocks from other regions of the world.

Integrated stratigraphical, sedimentological and geochemical studies of the Lower Paleozoic fine-grained siliceous deposits of the Baltic basin allow us to reconstruct the sedimentary environment, create a depositional model of these deposits and predict prospective horizons for shale-gas exploration (Fig. 4).

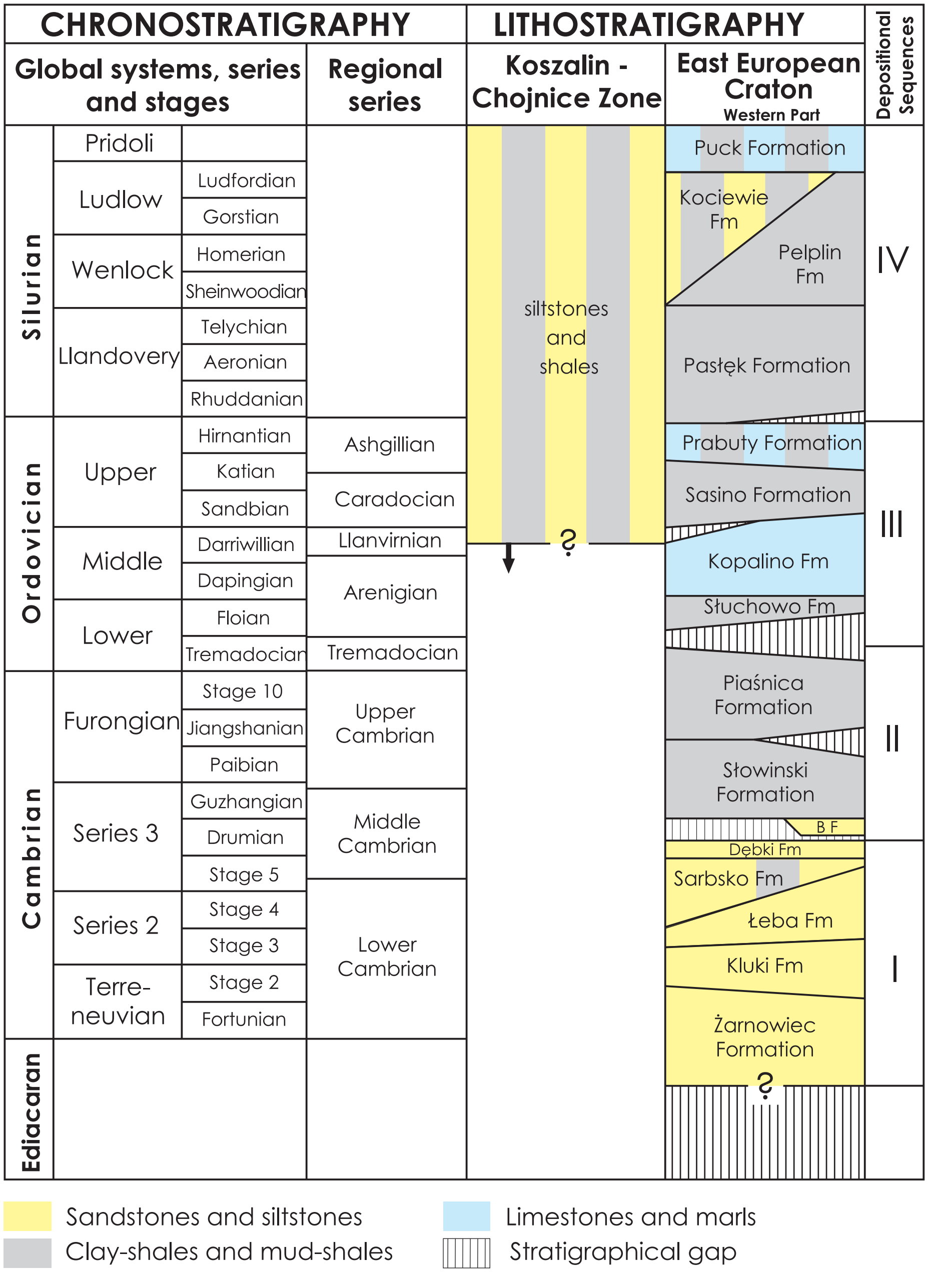



Fig. 1. Stratigraphic chart of the Lower Paleozoic in the Polish part of the Baltic region (Modliński, Podhalańska, 2010)

| SERIES | STAGE | Graptolite biozones (Melchin et al., 2012) | Graptolite biozones (EEC) (Urbanek & Teller, 1997, modified; Teller, 1969, modified) |
|---|---|---|---|
| PRIDOLI | | *Monograptus transgrediens* | *M. transgrediens* |
| | | *M. bouceki* | *M. perneri* |
| | | | *M. bouceki* |
| | | *Neocolonograptus lochkovensis* *N. branikensis* | *M. samsonowiczi* |
| | | | *M. chelmensis* |
| | | | *N. lochkovensis* |
| | | *N. ultimus* | *N. ultimus* |
| | | *N. parultimus* | *N. parultimus* |
| LUDLOW | LUDFORDIAN | *Formosograptus formosus* | *M. spineus* |
| | | | *M. protospineus* |
| | | | *M. acer* |
| | | | *Pseudomonocl. latilobus* |
| | | *Neocucullograptus kozlowskii* | *Neoc. kozlowskii* |
| | | *Polonograptus podoliensis* *Bohemograptus* | *Neoc. inexpectatus* |
| | | | *Neolob. auriculatus* |
| | | | *B. cornutus* |
| | | | *B. praecornutus* |
| | | *Saetograptus leintwardinensis* | *S. leintwardinensis* |
| | GORSTIAN | *Lobograptus scanicus* | *Cucullo. hemiaversus* |
| | | | *L. invertus* |
| | | | *L. scanicus* |
| | | *Neodiversograptus nilssoni* | *L. progenitor* |
| | | | *Neodiver. nilssoni* |
| WENLOCK | HOMERIAN | *Colonograptus ludensis* | *C. ludensis* |
| | | *C. deubeli* | *C. deubeli* |
| | | *C. praedeubeli* | *C. praedeubeli* |
| | | *Gothograptus nassa* | *G. nassa* |
| | | *Pristiograptus parvus* | *P. parvus* |
| | | *Cyrtograptus lundgreni* | *C. lundgreni* |
| | SHEINWOODIAN | *C. perneri* | *C. perneri* |
| | | *C. rigidus* | *C. rigidus* |
| | | *Monograptus belophorus* | *M. belophorus (= M. flexilis)* |
| | | *M. riccartonensis* | *M. antennularius* |
| | | | *M. riccartonensis* |
| | | *Cyrtograptus murchisoni* | *C. murchisoni* |
| | | *C. centrifugus* | *C. centrifugus* |
| LLANDOVERY | TELYCHIAN | *C. insectus* | *C. insectus* |
| | | *C. lapworthi* | *C. lapworthi* |
| | | *Oktavites spiralis* | *Oktavites spiralis* |
| | | *Monoclimacis crenulata–Monocl. griestoniensis* | *Monoclimacis crenulata–Monocl. griestoniensis* |
| | | *Monograptus crispus* | *Monograptus crispus* |
| | | *Spirograptus turriculatus* | *Spirograptus turriculatus* |
| | | *Spirograptus guerichi* | |
| | AERONIAN | *Stimulograptus sedgwickii* | *Stimulograptus sedgwickii* |
| | | *Lituigraptus convolutus* | |
| | | *Monograptus argenteus* | |
| | | *Demirastrites pectinatus–Demirastrites triangulatus* | *Demirastrites triangulatus* |
| | RHUDDANIAN | *Coronograptus cyphus* | *Coronograptus cyphus* |
| | | *Orthograptus vesiculosus* | *Orthograptus vesiculosus* |
| | | *Parakidograptus acuminatus* | *Parakidograptus acuminatus* |
| | | *Akidograptus ascensus* | *Akidograptus ascensus* |

*prospective deposits* ?

Fig. 3. Graptolite zonation of the Silurian

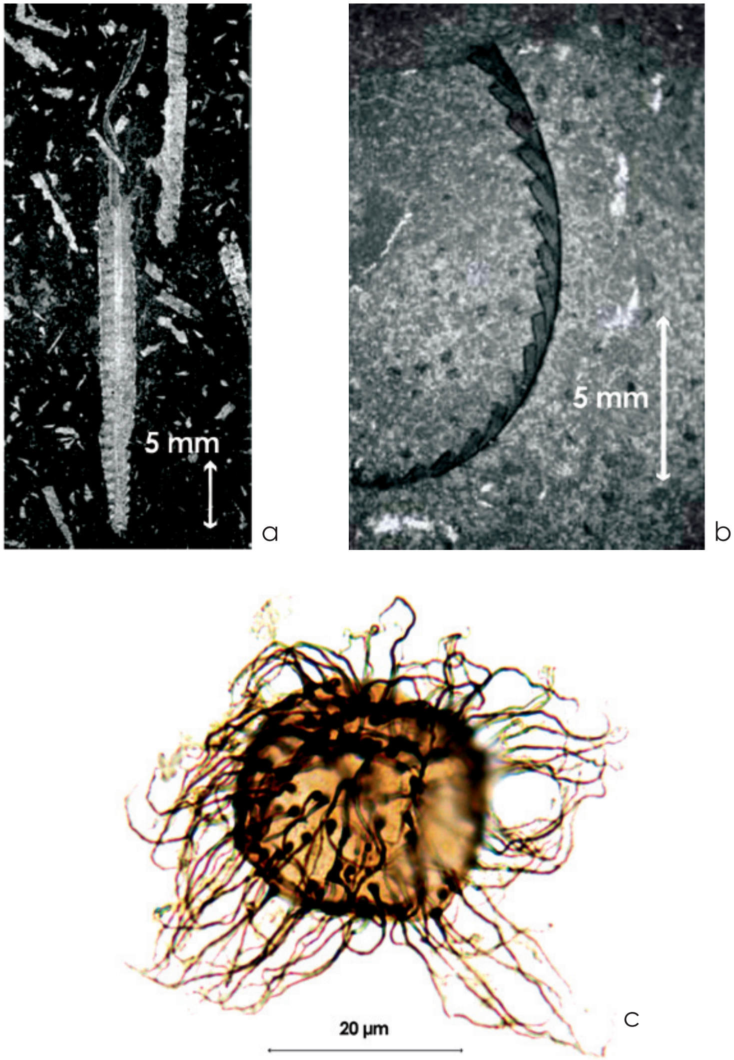



Fig. 2. Graptolites and *Acritarcha* from deep boreholes of the East European Craton
a. *Orthograptus vesiculosus* Nicholson, Łeba 8 section, depth 2,658.1 m, *vesiculosus* Biozone, Llandovery (Podhalańska, 2009)
b. *Bohemograptus bohemicus bohemicus* Barrande, Lębork IG 1 section, depth 2,634.5 m, Ludlow
c. *Ichnosphaera flexuosa* (Eklund, 1990), Lower Cambrian, Series 2, (Jachowicz-Zdanowska, 2013)

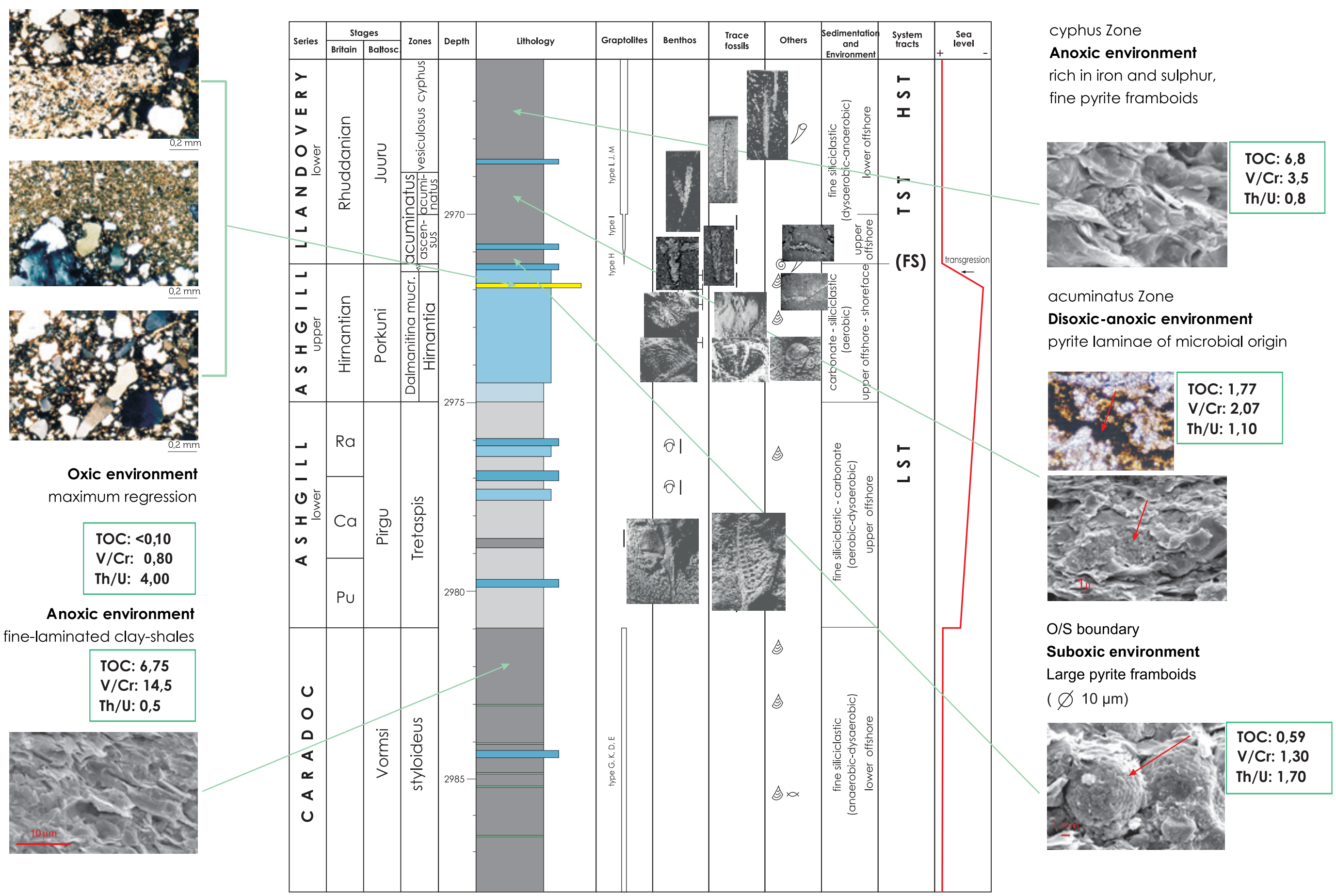
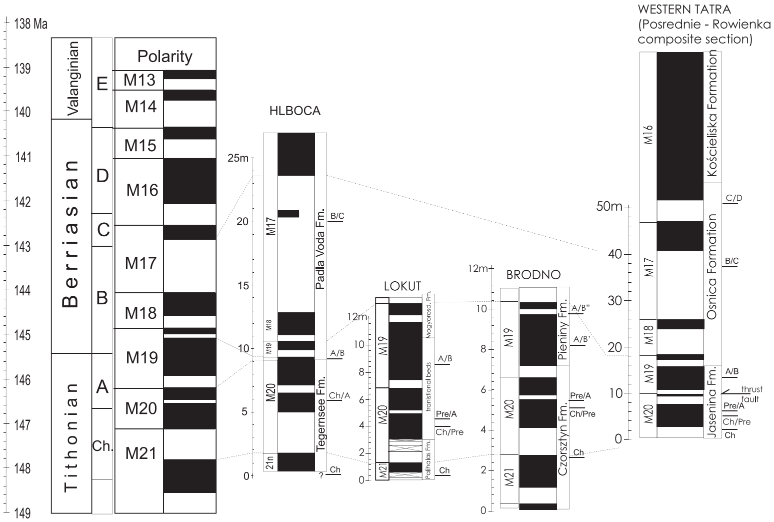



Fig. 4. Integration of stratigraphical, sedimentological and geochemical studies of the uppermost Ordovician--lowermost Silurian deposits, Hel IG 1 section, Łeba elevation, northern Poland (Podhalańska, 2009)

# 02 PALEOMAGNETIC LAB

## PALEOMAGNETIC PROPERITIES AS A TOOLS FOR STRATIGRAPHIC CORRELATION

**The paleomagnetic studies include the determination of the ancient geomagnetic field directions and their changes in stratigraphic successions (identification of normal and reversed polarity), as well as the determination and interpretation of magnetic susceptibility changes.**




Magnetostratigraphic correlation along the Jurassic/Cretaceous boundary interval within the Carpathian domain (Grabowski, 2011)

**Paleomagnetic data are used to:**

- Paleogeographic reconstructions of the position of continents and smaller tectonic units in various Phanerozoic epochs.
- Magnetostratigraphic correlation based on changes in polarity.
- Magnetic susceptibility correlation based on identification of characteristic fluctuations.
- Dating of diagenetic events based on secondary magnetization components.
- Determination of the orientation of drill cores, based on the viscous remanent magnetization.



Other paleomagnetic properities as ARM (Anhysteretic Remanent Magnetization) and IRM (Isothermal Remanent Magnetisation) are widely use to identification of magnetic particles in rock samples and to paleoenvironmental interpretations.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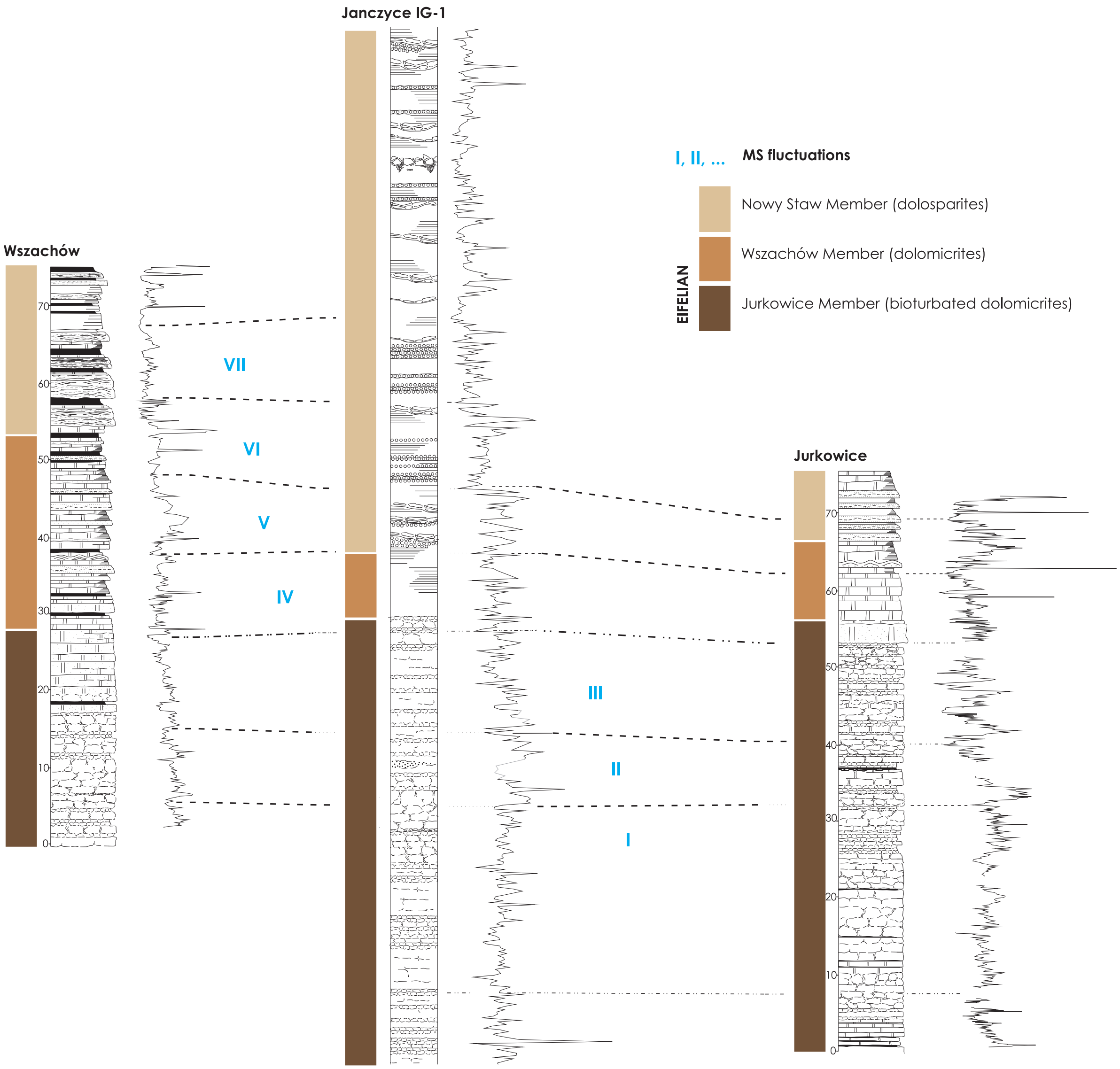


Magnetic susceptibility correlation of the Eifelian (Middle Devonian) succession in the Holy Cross Mountains. Wójcik, K. 2013. PhD Thesis, Archives of the Department of Geology, University of Warsaw, Poland, unpublished

03

# SHRIMP ION MICROPROBE FACILITY

## ISOTOPIC SURVEYING FOR HYDROCARBONS (I.A. SHALE GAS)

The SHRIMP (Sensitive High Resolution Ion Microprobe) is a secondary ion mass spectrometer designed for the analysis of geological materials. In the field of U-Pb geochronology and zircon dating, the SHRIMP has had its biggest impact on the geosciences and has revolutionized the geological time scale. **A relatively new aspect of the SHRIMP IIe exploitation is the *in situ* determination of stable isotopes of the light elements: oxygen (O), sulfur (S) and carbon (C), that enables us to detect isotopic fluctuations within different types of geological environments. High spatial resolution analysis of oxygen and carbon isotopes in biogenic materials has been used to reconstruct changes in temperature over geological timescales and to determine other geological factors.**

Shale gas exploration increasingly relies on modeling how, where and when these reservoir of a fine-grained and organic-rich, form and become trapped in rock structures. The SHRIMP IIe ion microprobe, that allows us to take a look back at millions of years can be applied to geological problems routinely encountered in petroleum exploration.

These include:

- Oxygen isotope ratios in biogenic and inorganic minerals.
- Stable isotopes and trace elements *in situ*.
- Isotope anomalies.
- Temporal and thermal evolution of hydrocarbon source rocks in sedimentary basins.
- Orogenic uplift/denudation rates in source regions.
- Rate of cooling and the age of cessation of hydrothermal or/and tectonic activity.
- Accurate geochronology, including detrital zircon study.
- Analyses of mounted grains or particles or *in situ* thin section in the context of the overall components /minerals assemblage.



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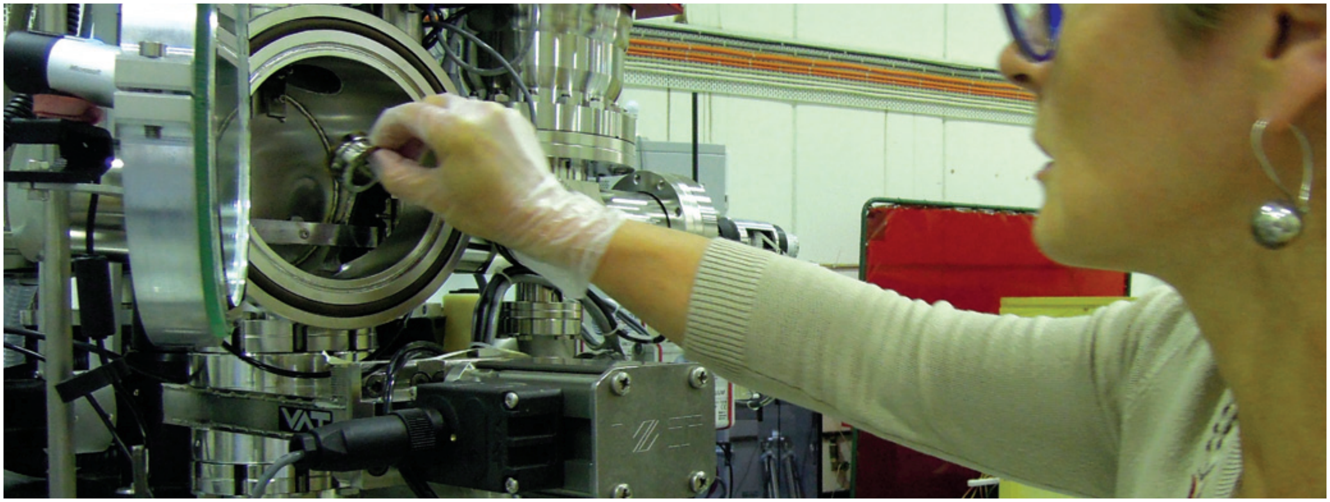


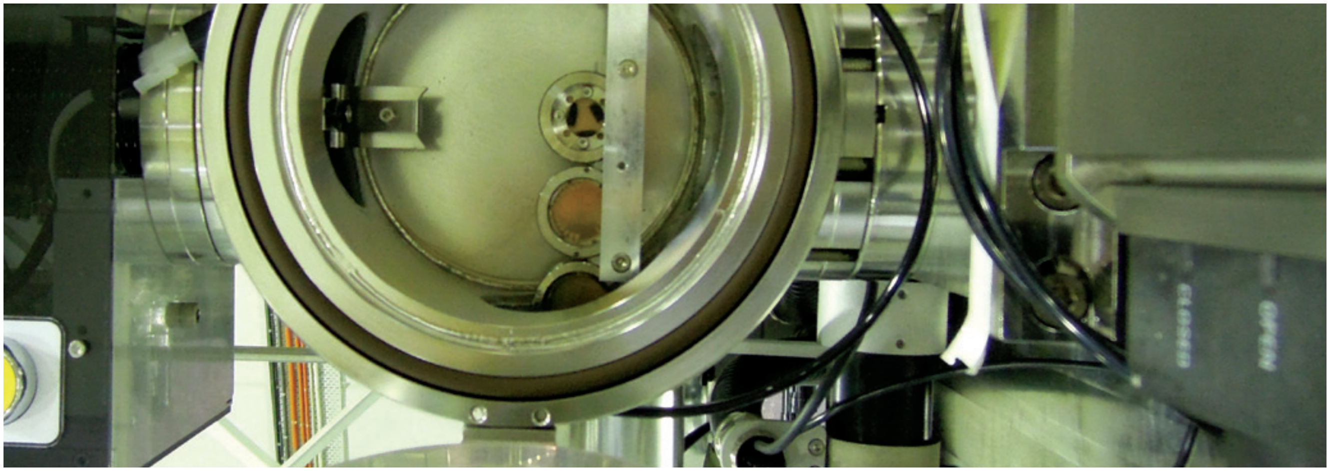

Elevation view of the Polish SHRIMP IIe/MC during acceptance tests in ASI Factory, Fyshwick, Canberra (March 2014)

# 03 SHRIMP ION MICROPROBE FACILITY

# 04 PETROLOGICAL LAB

## SHALE GAS

Lower Paleozoic fine-grained detrital rocks are represented by clay shales, mudstones and siltstones, often with a large admixture of carbonates. Identification of some rock types requires polarizing microscopes and other instruments. Cathodoluminescence (CL) is commonly used to determine the proportions of individual minerals in a given rock. Differences in luminescence properties make it possible to determine the contents of quartz, K-feldspar, plagioclase, carbonates or phosphates. In these analyses, we use CITL cathodoluminescence Mk3 and Mk5 stages with EDX and digital cameras.

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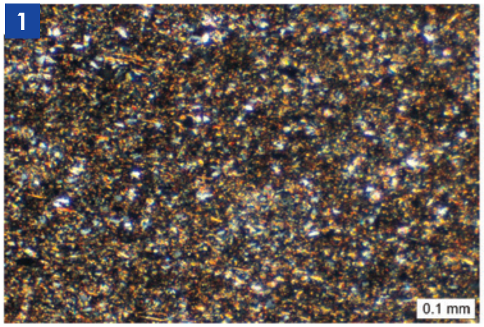
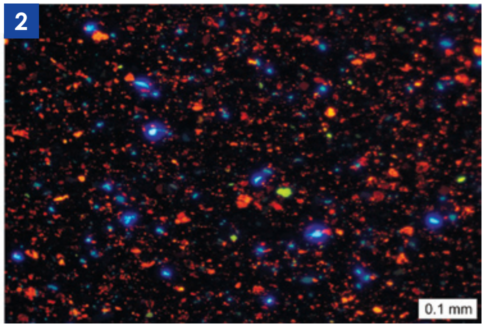
## TIGHT GAS

Core samples from drillings in tight gas reservoirs usually represent strongly cemented sandstones characterized by very low porosity. Standard microscopy makes it possible to determine the mineral composition of rock-forming grains and the types of cement. Moreover, cathodoluminescence is used in the analysis of quartz cement (regeneration rims), carbonate cement, textural features (granulation, roundness, mode of packing and types of grain-to-grain contacts) and tracing healed fractures in sandstones.

Porosity of sandstones (in volume %) is determined in thin sections saturated with blue resin by computer image analysis with the use of the NIS-Elements BR program. Analyses under polarizing microscope Eclipse E600 equipped with Nikon DS-Fi1 make it possible to determine the size and shape of pores and their distribution.

These petrographic studies are conducted in order to screen samples for detailed mineralogical and geochemical analyses (XRD, SEM, EDS, FI).

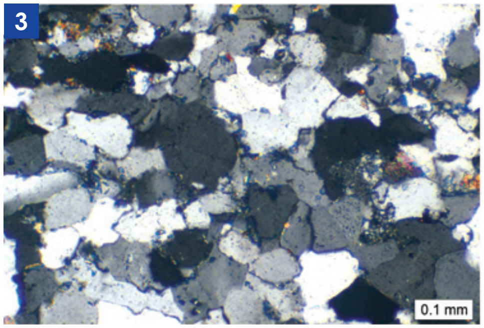


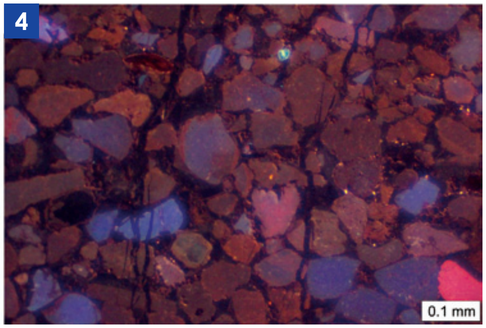




**Shale (Silurian)**

**1)** Crossed nicols image – silty grains in a clayey matrix

**2)** CL image – carbonates (orange CL), K-feldspar (blue CL) and plagioclase (green CL) are visible in a clayey matrix

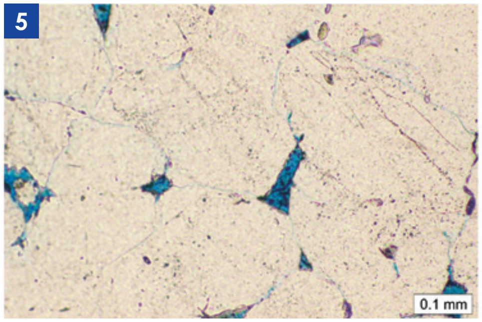


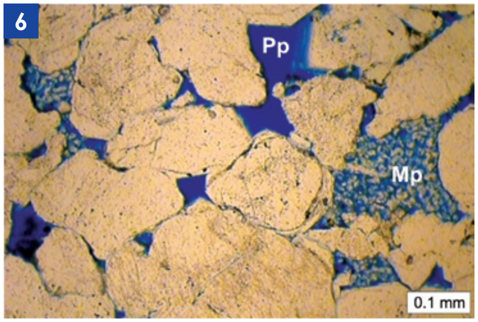




**Quartz arenite (Cambrian)**

**3)** Crossed nicols image – quartz grains cemented with regeneration quartz; microfractures are not visible

**4)** CL image – microfractures filled with diagenetic quartz and quartz overgrowths are visible




**5) Quartz arenite (Cambrian)**
– secluded primary pores

**6) Quartz arenite (Carboniferous)**
– primary pores (Pp) and intercry-stalline micropores (Mp)

Plane polarized light – pores filled with blue epoxy

05

# SEDIMENTOLOGY & CORE ANALYSIS LAB

## SEDIMENTOLOGICAL STUDIES OF FINE-GRAINED DEPOSITS, FACIES ANALYSIS (IN SEQUENCE STRATIGRAPHY FRAME)

Unconventional gas and oil exploration efforts in Poland focused especially on the investigation of Ordovician and Silurian shale rocks of the western margin of the East European Craton in Poland, which are dark and rich in organic material. The complete profile of the Lower Paleozoic rocks in this area consists of different fine-grained lithologies: shales, claystones, clayey mudstones, siltstones, marls and marly limestones.

**For a better understanding of organic-rich facies distribution and finding "sweet spot" areas, detailed, small-scale sedimentological analysis is necessary.**

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**A first step in the sedimentological investigation of fine-grained rocks is detailed core profiling. The Variety of primary sedimentological structures which characterize more precisely the sedimentary environments are carefully described bed by bed (in cm-scale):**

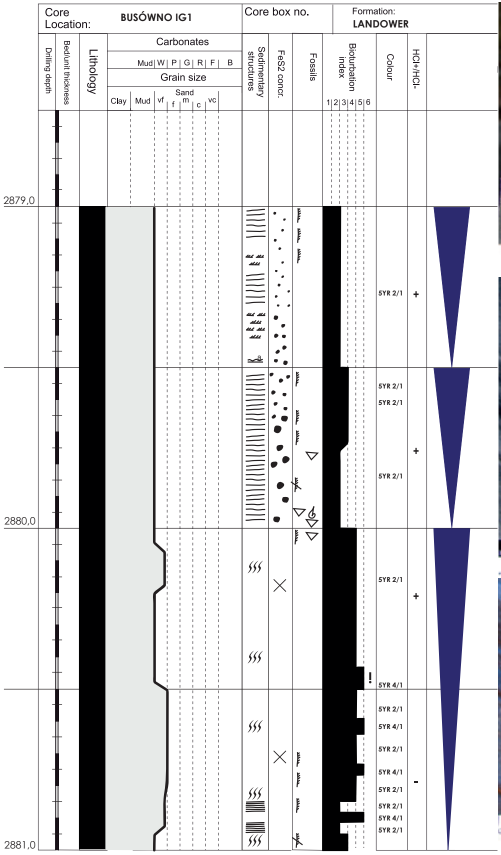
- Different types of bedding or lamination.
- Different types of base and top boundaries.
- Additional elements – pebbles, clasts, concretions, accessory minerals.
- Colour (unified and encoded).
- Thickness of complexes.
- Presence of fauna.
- Trace fossils: their types, abundance and tiering, index of bioturbation.

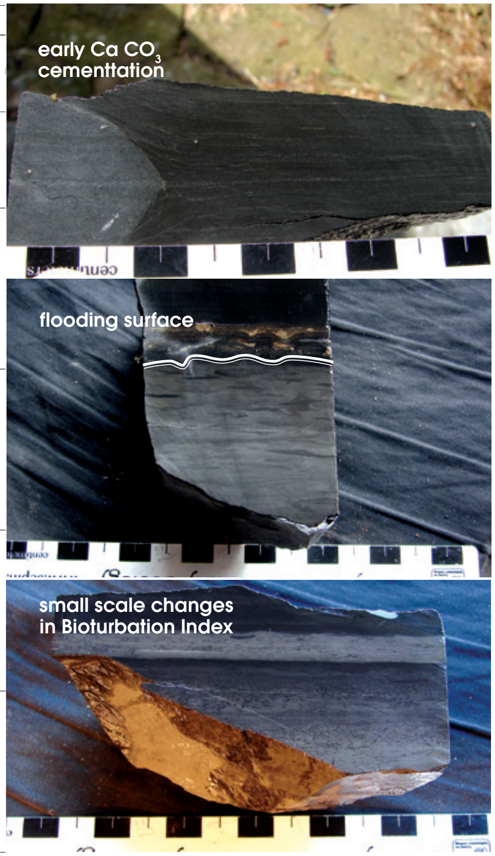
Data collected from cores supported by thin section petrography and diagenetic studies, laboratory measurements and scanning electron microscopy (SEM) results are used to build a vertical facies model.

Correlation of cores with geophysical logs and an analysis of the vertical alternation of facies interpreted from core material allow us to construct sedimentological profile and recognize cycles of different order (parasequences, sequences). Sequence stratigraphy techniques used in lateral correlation of cycles allow to construct spatial cyclicity model and trace development of sedimentary basin.

The Sedimentary Lab of PGI-NRI has experience in the complete sedimentological examination of the fine-grained material from cores and offers experts with considerable knowledge in the regional development of potential shale gas in the Lower Paleozoic basin.






Core logging
– from centimeter-scale structures to parasequences

# 06 GEOCHEMICAL LAB

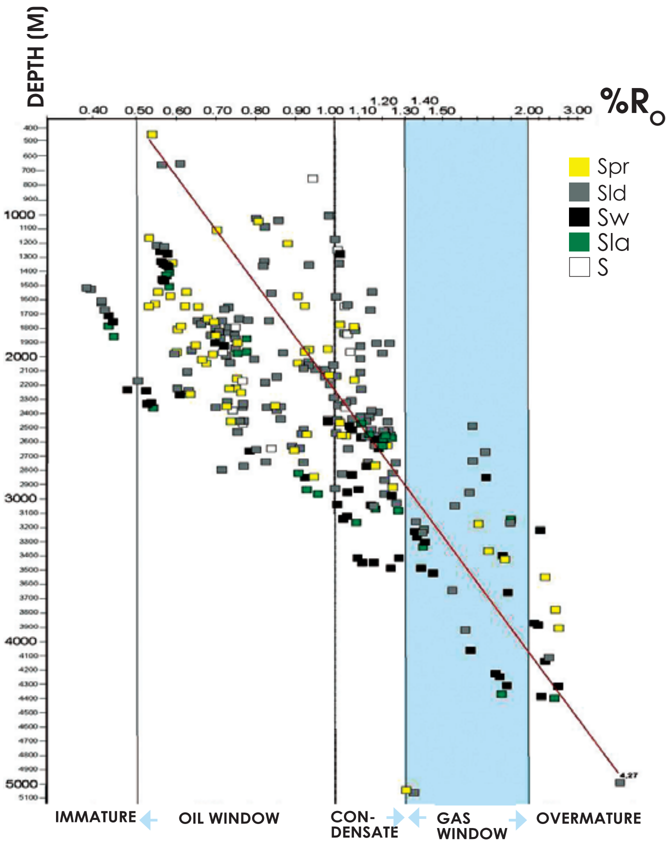
## ORGANIC MATTER REFLECTANCE

Our microscopic studies are made in white and ultraviolet (UV) reflected light to identify maceral components of the liptinite group. Analyses are performed on the Zeiss Axio Imager polarizing microscope equipped with a MSP 200 microphotometric device that allows the measurement of organic matter reflectance.

The studies allow us to determine the origin and level of thermal alteration of organic matter present in deposits of different age.

The reflectivity index (% Ro) of some syngenetic organic compounds represents the main parameter for the determination of the thermal maturity of organic matter. It plays a significant role in the reconstruction of the thermal history of sediment packages and the determination of petroleum / gas source rocks.

**Measurements are carried out in immersion on polished sections of sedimentary rocks containing vitrinite or vitrinite-like material. The tests are performed using: standards of optical glass of reflectivity 0.595% and 0.907%; monochrome filter with a wavelength of 546 nm; immersion oil, nD=1.515 at 20-25°C.**




Case study from Paleozoic shales on Precambrian platform



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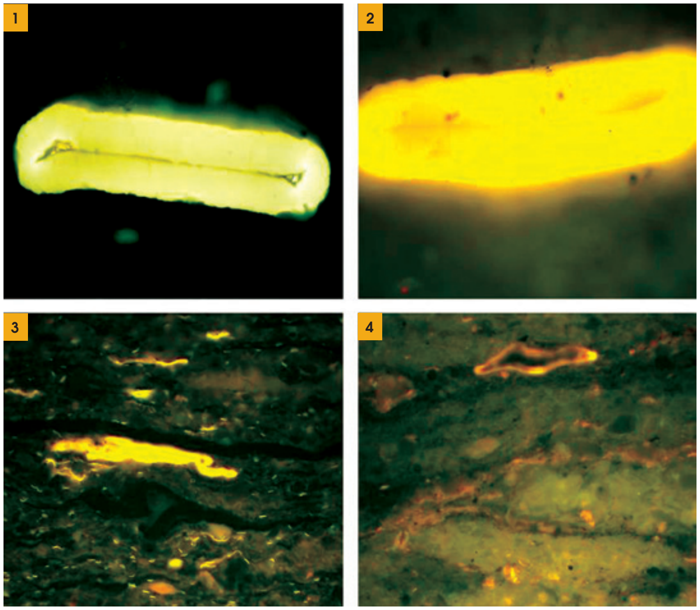
## Algae and bitumen impregnation – oil window



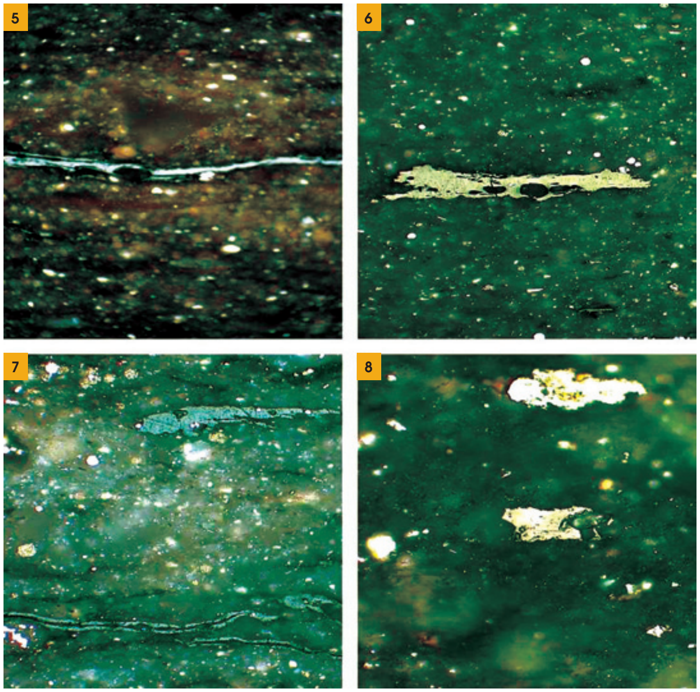

**1)** Algae immature
**Ro – 0,39%**

**2)** Algae early mature
**Ro – 0,61%**

**3)** Algae immature
**Ro – 0,73%**

**4)** Algae early mature
**Ro – 0,83%**

## Shales with zooclasts (graptolite fragments)




**5)** Gas window

**6)** Overmature

**7)** Gas window

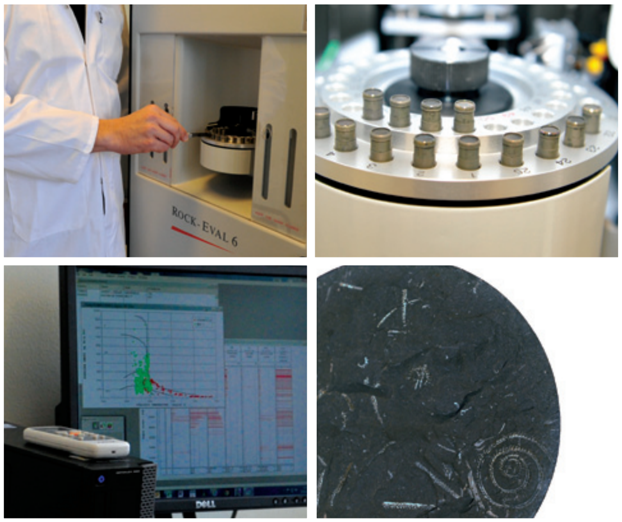
**8)** Overmature

# 07 GEOCHEMICAL LAB

## ROCK-EVAL 6 ANALYSER

**The Rock-Eval 6 instrument is a source rock analyzer dedicated to determining parameters which might describe specific geochemical properties reflecting the hydrocarbon potential of the source rocks.**

Available in the Polish Geological Institute – NRI, the Rock--Eval instrument is sixth generation machine which allows us to obtain a wide range of results. The instrument is a new type of fully automated pyrolyzer, used to analyze rock samples. It has been designed to increase the domain of application of the Rock-Eval method, in the field of source rock characterization (better kerogen type and kinetic parameters determination), and in reservoir studies (tarmat location).




Rock-Eval 6 apparatus with computer

**The instrument delivers the usual standard 'Rock-Eval' parameters:**

Gas and free oil content: **S1**

Petroleum Potential, or hydrocarbons cracked during pyrolysis: **S2**

**In addition, the Rock-Eval 6 also delivers new parameters, such as:**

- Total quantity of organic carbon measured during the pyrolysis step: PC (Pyrolysable Carbon).
- Temperature measured at the apex of the new S4 peaks; these values can be used to characterize the maturity of coal samples.
- Temperature measured at the apex of S2 peak (maturity parameter): Tmax.
- Total quantity of residual organic carbon measured during the oxidation step: RC.
- Total quantity of mineral carbon: MinC.
- Total quantity of organic carbon contained in the sample: TOC (PC + RC).

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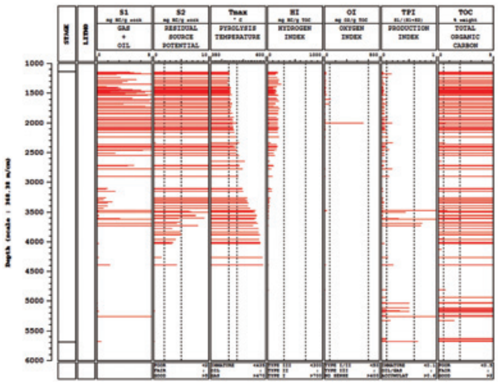
1

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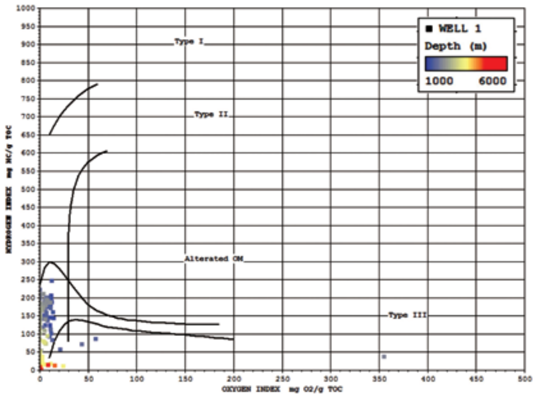
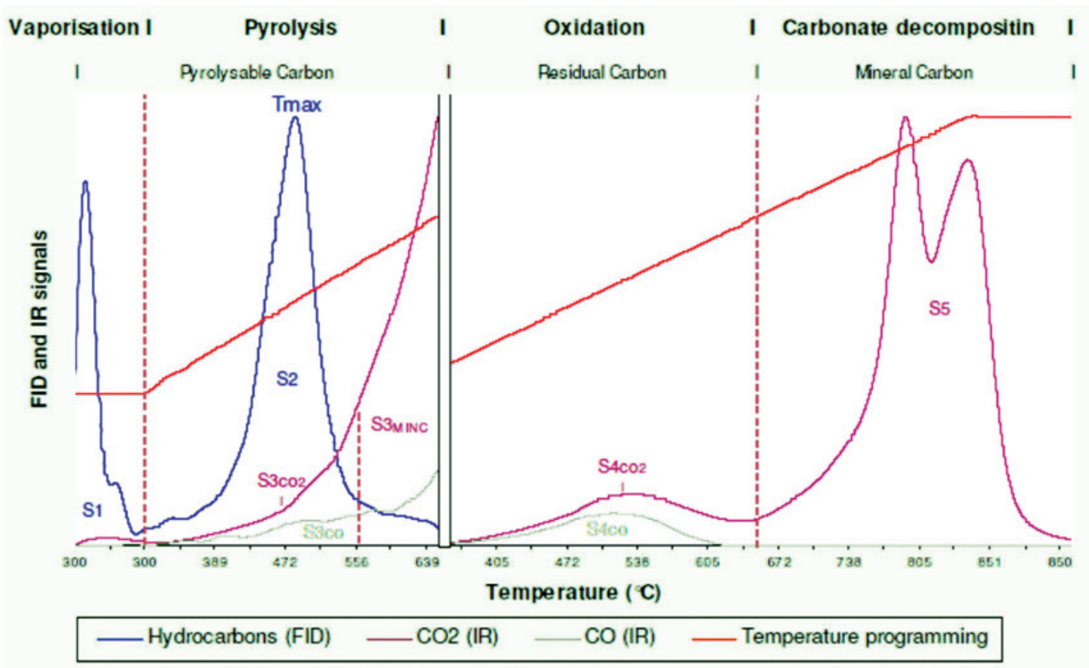



**1)** Presentation of plotting geochemical logs from selected pyrolysis

**2)** Presentation of plotting geochemical parameters from selected pyrolysis






Presentation of the complete Rock-Eval 6 analysis of a source rock sample (type II) containing carbonates – dolomite

# 08 CHEMICAL LAB

## ANALYTICAL SERVICES, RESEARCH & STUDIES

**Our Lab provides analytical services on properties of water, wastewaters, environmental, geological and plant samples, quantification and qualification of minerals, identification of various petroleum products, studies on mineral and fuel composition and others.**

The Central Chemical Laboratory established in the Polish Geological Institute – NRI has been accredited according to ISO 17025 since 2000. It provides analytical services in the determination of the physical and chemical properties of water, wastewaters, environmental, geological and plant samples.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Nr AB 283
Potwierdza się, że: / This is to confirm that:
PAŃSTWOWY INSTYTUT GEOLOGICZNY
PAŃSTWOWY INSTYTUT BADAWCZY
CENTRALNE LABORATORIUM CHEMICZNE
ul. Rakowiecka 4, 00-975 Warszawa
spełnia wymagania normy PN-EN ISO/IEC 17025:2005
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Warszawa, dnia 26 stycznia 2011 roku


contact:

**Przemysław DRZEWICZ, Ph.D.**
przemyslaw.drzewicz@pgi.gov.pl
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**The following analytical equipment is available in the Laboratory:**

- Inductively coupled plasma mass spectrometer (determination of Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Li, Mn, Mo, Ni, Pb,Sb, Se, Sn, Sr, Tl, U, V, Zn in water according to accredited laboratory analytical method PB-37).
- Inductively coupled plasma optical emission spectrometer (determination of Al, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb,Si, Sr, Ti, V, Zn in water and Ca, Fe, Mg, Mn, $P_T$, $S_T$, As, Ba, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sn, Zn, Sr, V in solid samples according to accredited laboratory analytical methods PB-28 and PB-40, respectively ).
- X-ray fluorescence spectrometer (determination of $SiO_2$, $Na_2O$, $K_2O$, MgO, CaO, $(Fe_2O_3)_T$, $Al_2O_3$, $TiO_2$, $P_2O_5$, $SO_3$, Cl, F and determination of As, Ba, Co, Cr, Cu, Mo, Ni, Pb, Zn, Sr, V, Bi, Ga, Hf, Nb, Rb, Th, U, Zr, Ce, La, Y, Br, Cd, Sn in solid samples according to accredited laboratory analytical methods PB-33 and PB-29, respectively).
- Total mercury analyzer (determination of total mercury in water and solid samples according to accredited laboratory analytical method PB-06).
- Gas chromatograph-mass spectrometer (determination of polycyclic aromatic hydrocarbons according to accredited laboratory analytical methods PB-15 and PB-16, respectively).
- Ion chromatograph (determination of $Br^-$, $Cl^-$, $F^-$, $NO_2^-$, $NO_3^-$, $SO_4^{2-}$, $HPO_4^{2-}$, $I^-$ in water samples according to accredited laboratory analytical methods PB-04 and PB-14).
- Fourier Transform Infra-Red Spectrometer (determination of Total Petroleum Hydrocarbons in water and solid samples according to accredited laboratory analytical method PB-38 and PB-39, respectively).

**Additionally, the Laboratory offers quantification and qualification of clay and other minerals by the X-ray powder diffraction method, and identification of various petroleum products by gas chromatography-mass spectrometry. The laboratory is also equipped with a Fourier Transform Infra-Red Spectrometer with Photoacoustic and Attenuated Total Reflectance accessories that enable studies of mineral and fuel composition in the range 27000 to 300 $cm^{-1}$.**

A photoacoustic accessory may be used for in-depth analysis of the materials (e.g. petroleum fluid inclusion analysis). There is also equipment for elemental analysis of C, H, N, S, O and Cl in solid and liquid samples (non-aqueous). The elemental analyzer may be used in assessments of the origin and maturity of kerogen and petroleum, based on the Van Krevelen diagram (a plot of the atomic hydrogen-carbon ratio versus the atomic oxygen-carbon ratio).

**Together, the equipment available in the Central Chemical Laboratory may be applied in broad chemical, geological and environmental investigations on unconventional shale gas and oil, tight gas and coal bed methane.**



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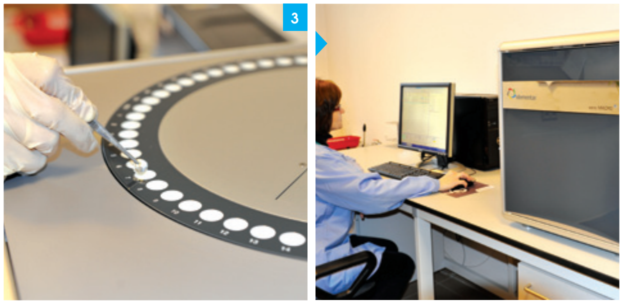

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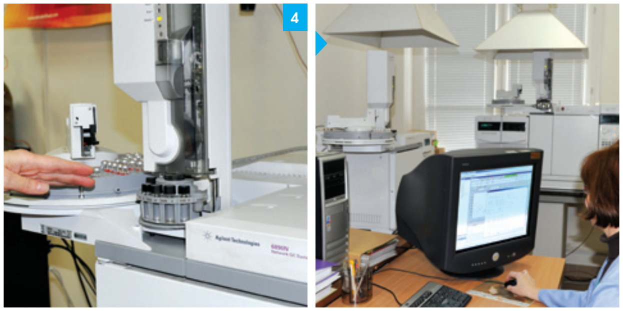

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**1)** GC-MS/MS: gas chromatograph with triple quad mass spectrometer detector (7890A-7000, Agilent Technologies)

**2)** HS-GC-MS: gas chromatograph with mass spectrometer detector and headspace analyser (6890N-5973/7694E, Agilent Technologies)

**3)** Elemental analyser (Vario Macro Cube CHNS/Cl/O, Elementar)

**4)** GC-ECD: gas chromatograph with electron capture detector (6890N, Agilent Technologies)

# 09 HYDRO-GEOCHEMICAL LAB

## STABLE ISOTOPES



**The newly opened Hydrogeochemical Laboratory of the Polish Geological Institute – NRI measures the isotopic composition of oxygen and hydrogen in water molecules by Off-Axis Integrated Cavity Output Spectroscopy (off axis ICOS). The water isotopic composition expressed as $\delta^{18}O$ and $\delta D$ (in permil) enables one to determine the origin of waters, mixing processes and provides a direct link to the water cycle.**

A further development plan of the Hydrogeochemical Laboratory is to measure carbon isotope ratios by CRDS (Cavity Ring Down Spectroscopy) instrument in dissolved carbonates, organic carbon and methane. Such studies will supply information on ecosystem – groundwater interactions and differentiate between thermogenic, biogenic and fermentation methanes in shale gas prospecting and exploitation.

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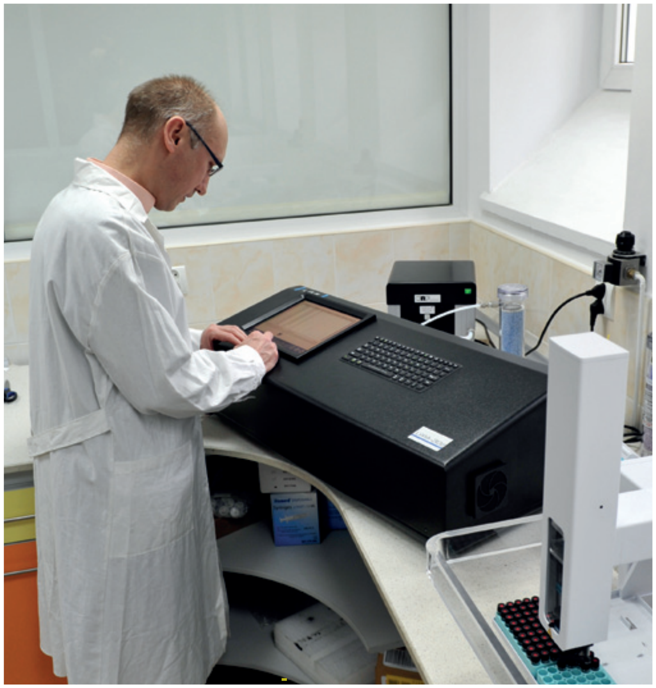

LGR DT-100 Liquid Water Stable Isotope Analyzer developed by Los Gatos Research Inc. to measure ratios of oxygen and hydrogen isotopes in liquid water

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# GEOLOGICAL MODELING & VISUALIZATION LAB

## MODELING & VISUALIZATION OF GEOLOGICAL STRUCTURES, UPDATES & NEW MODELS

All the data acquired during the exploration, development and production phase should be integrated and visualized as 3D geological models. For this purpose, the Polish Geological Institute – NRI use Petrel (Schlumberger) and SKUA-GOCAD software, which enables us to integrate geological, geophysical, cartographic and other data in coherent 3D models.

Digital models are built of a network of small three-dimensional cells. Each of them contains information on specific rock properties, such as rock type, porosity, permeability, gas content, fracturability, etc. Moreover, structural data such as faults and joints are presented in a digital three-dimensional space.

**Geological modeling and 3D visualization help in tackling the most complex geological and modeling challenges. Representation of geological structure in the form of geological models is helpful in choosing economically prospective drilling locations, assessment of resources or production planning, etc. As new information is available (from new wells or seismic tests) digital geological models are updated and strengthened so as to enable a more efficient exploration for hydrocarbon accumulations.**

**We provide 3D geological models ready for dynamic petroleum systems simulation.**

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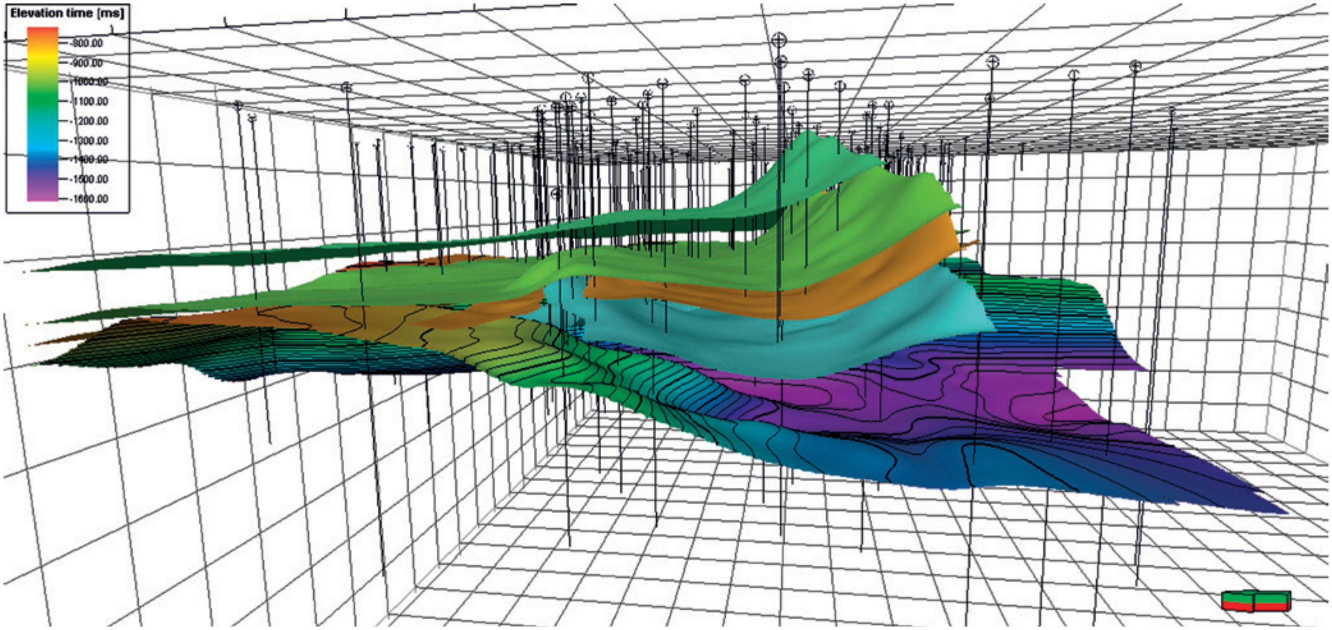
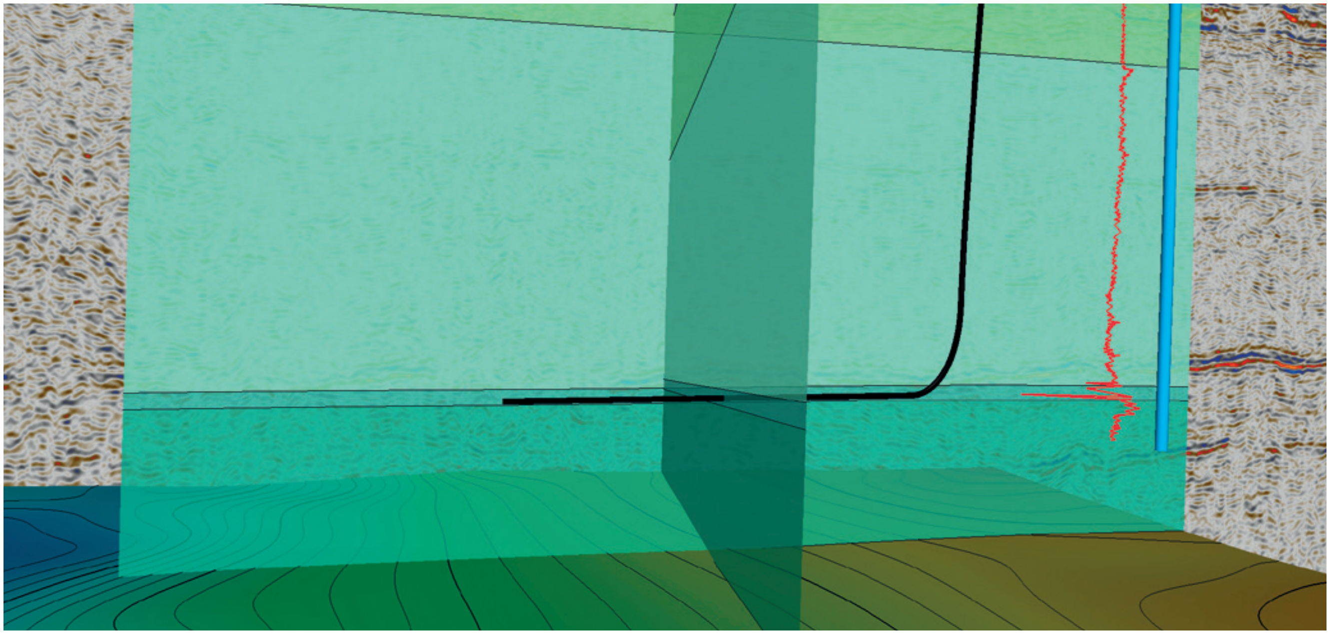



Perspective view on 3D structural model





Geological model-derived cross-section made for the purposes of horizontal well trajectory planning

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# TECTONIC & STRUCTURAL ANALYSIS LAB

## STRUCTURAL & GEOMECHANICAL STUDIES OF SHALES

**We have expertise in structural studies of core rock samples and surface outcrops.** The best analogue of the Lower Paleozoic shale gas prospect present in the Holy Cross Mountains gives us the opportunity to study detailed fracture networks in large volumes of shale rock. We perform detailed analyses of natural fault and fracture pattern geometry, supplemented by diagenetic and vein mineralization studies, which results in a knowledge of the evolution of tectonic deformation and the origin of geomechanical differentiation links with facies distribution.

**We have the capability to analyze the recent stress field and geodynamics cascade across multiple scales** from (1) intragranular stress propagation, through (2) stress disturbance in the vicinity of a borehole wall, (3) stress variations between sedimentary basin complexes to (4) lithospheric plate stress propagation (Jarosiński, 2009) using analytical and numerical methods.

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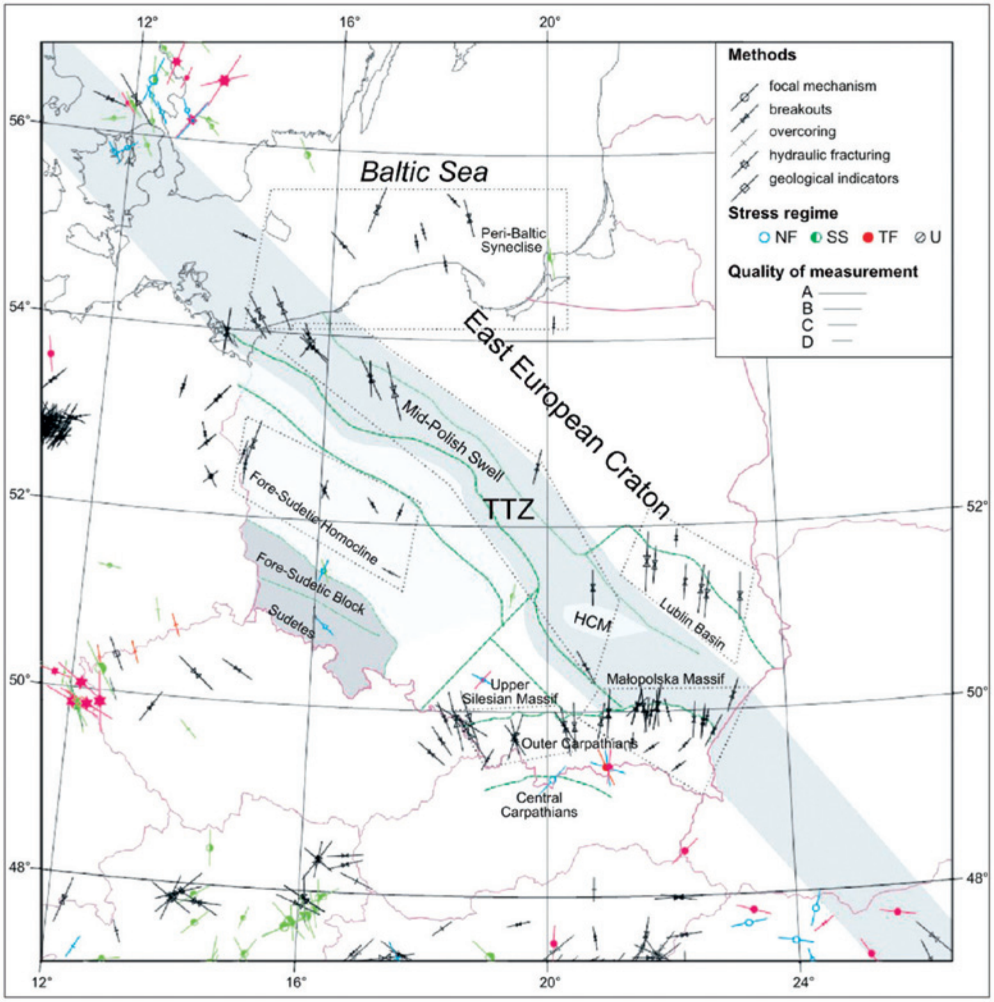
Tectonic fractures accompanying normal faulting (borehole core) and regular joint system in Silurian shales (outcrop in the Holy Cross Mts)

**In the PGI-NRI we have started the numerical modeling of stress field heterogeneity in shale complexes.** Our stochastic structural and parametric 3D FEM models take into account viscous relaxation and plastic yielding mechanics, and discontinuity effect on stress heterogeneity and address the mechanical barriers for induced fracture propagation across shale complexes.

Modeling is performed using: (1) the original FEM code MILAMIN (Dąbrowski et al., 2008); (2) a simplified set of key parameters such as noise level and spectrum, characteristic length scales and spatial correlations, (3) synthetic models of shear and bulk moduli fields. The spatial model can be augmented by the addition of fracture networks.






Recent maximum horizontal stress directions, most of them determined by mean of borehole breakout analysis (according to Jarosiński, 2006; off-Poland data are taken from the World Stress Map Database Heidbach et al., 2008).

Different symbols stand for methods of stress direction determination, their colors represent stress regimes: NF – normal fault, SS – strike-slip, TF – thrust fault. Symbol length stands for quality according to WSMDB

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# GEOPHYSICAL LAB

## SEISMIC METHODS IN SHALE GAS PROSPECTING

**Seismic reflection is one of the basic methods used in hydrocarbon prospecting.**

**During seismic interpretation the following analyses are done:**

- **Structural interpretation**

Structural analysis allows a description of the configuration of a structural layer. It is important in shale gas prospecting that a well and its vertical and horizontal parts are well located and in consequence are protected from interception of fracturing energy by faults. A structural analysis of distinctive reflection pattern (seismic signature) also enables the location of conventional hydrocarbon structural traps .

- **Stratigraphic interpretation**

Seismic stratigraphy allows the determination of the architecture of the depositional sequences of a petroleum system and surrounding rocks. It provides a basis for sedimentary basin analysis and a description of basin subsidence speed and thermal history analysis. Seismic facies identification is performed through correlation of seismic data, well logs and well core. Seismic facies analysis together with reservoir interpretation allows the identification of perspective facies for hydrocarbon accumulations and saturated zones.

- **Reservoir interpretation / source rock analysis**

Reservoir interpretation allows the localization of hydrocarbon saturated zones (sweet spots) on the basis of Direct Hydrocarbon Indicators – DHI analysis (i.a. bright spot, P and S waves anomalies) and seismic attributes (i.a. reflection strength, instantaneous phase). As a consequence of the reservoir rocks being saturated in hydrocarbons and the influence on wave velocity, propagation and attenuation anomalies in seismic images are observed.

Seismic inversion is the next stage of seismic research. It uses seismic data, well logs and geological data. It allows for the creation of acoustic pseudoimpedance curves or pseudovelocity. The calculated acoustic impedance change is associated with changes in lithology, porosity and gas saturation, so the results of this simulation enable perspective zones to be located.



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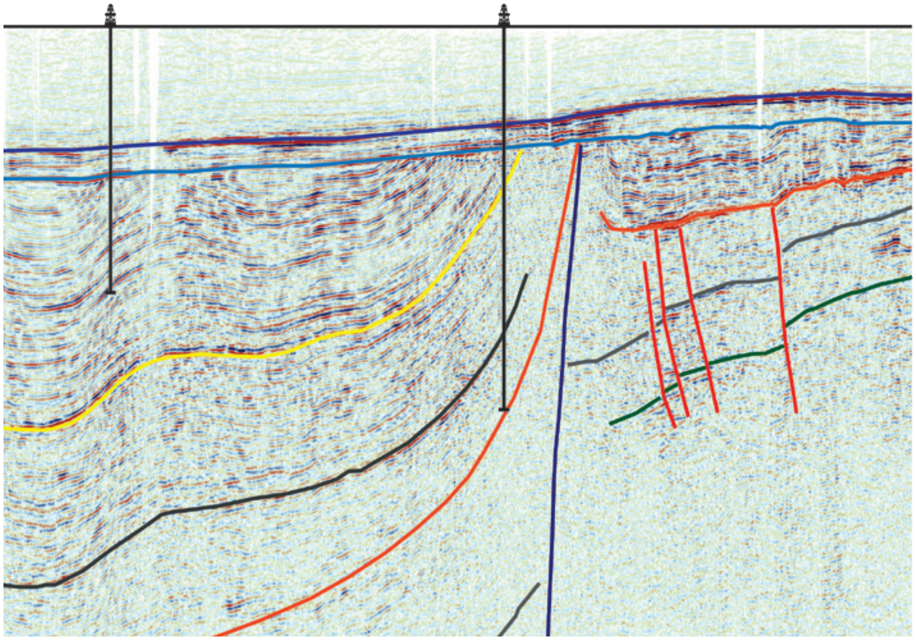
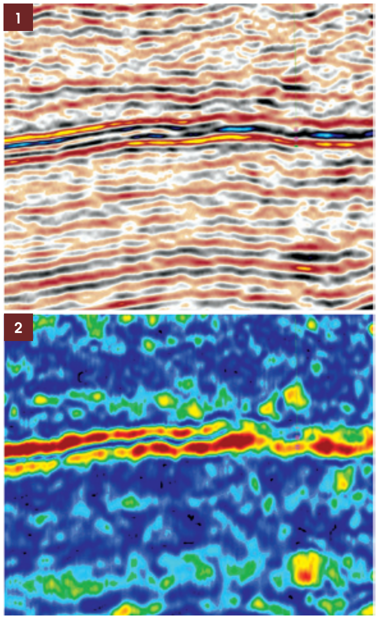
An additional possibility of credibility assessment of interpreted seismic measurements is carried out by the seismic modeling by taking into account the reservoir and seismic parameters and structural model.

The compatibility of a real seismic section with the adopted synthetic section allows one to confirm the interpretation of the analyzed shale complex. Complex seismic interpretation, calculated seismic attributes and seismic inversion with measured TOC values and gamma and resistivity curves allows us to analyse the relationships among the parameters, an assessment of shale heterogeneity and an initial prediction of sweet spots.





Structural interpretation of seismic section




**1)** Part of seismic section after migration

**2)** Part of seismic section in reflection version

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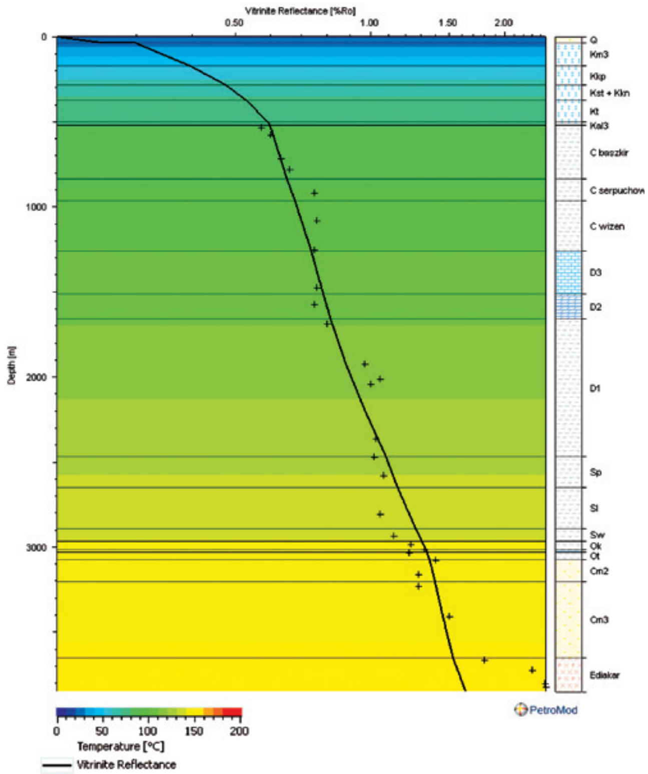
# PETROLEUM GEOLOGY LAB

## BASIN ANALYSIS & PETROLEUM SYSTEMS MODELING

**Petroleum system modeling combines seismic, well, and geological information to model the evolution of a sedimentary basin. The 1D, 2D, 3D models provide a complete record of the evolution of a petroleum system, including its pressure and temperature history.**

### Analyses of petroleum systems modeling include:

- Construction of subsurface cross-section models based on interpretation of geological surface maps, seismic cross-sections and litostratigraphic profiles from wells.
- Reconstruction of lithofacies subsidence and deposition rate of an analyzed petroleum system.
- Paleo-thermal modeling of organic matter transformation parameters, which include the determination of the paleo-thermal conductivity coefficient of shale rocks and paleo-heat flow calibrated by temperature measurements of $T_{max}$ (Rock-Eval analysis) and vitrinite reflectance Ro, determined from samples collected from drilling cores.
- Spatiotemporal modeling and numerical simulations of the generation and expulsion processes of various hydrocarbon phases and hydrocarbon migration – oil and gas-prone shales tests.




Calibration of analyzed model with measurements of thermal maturity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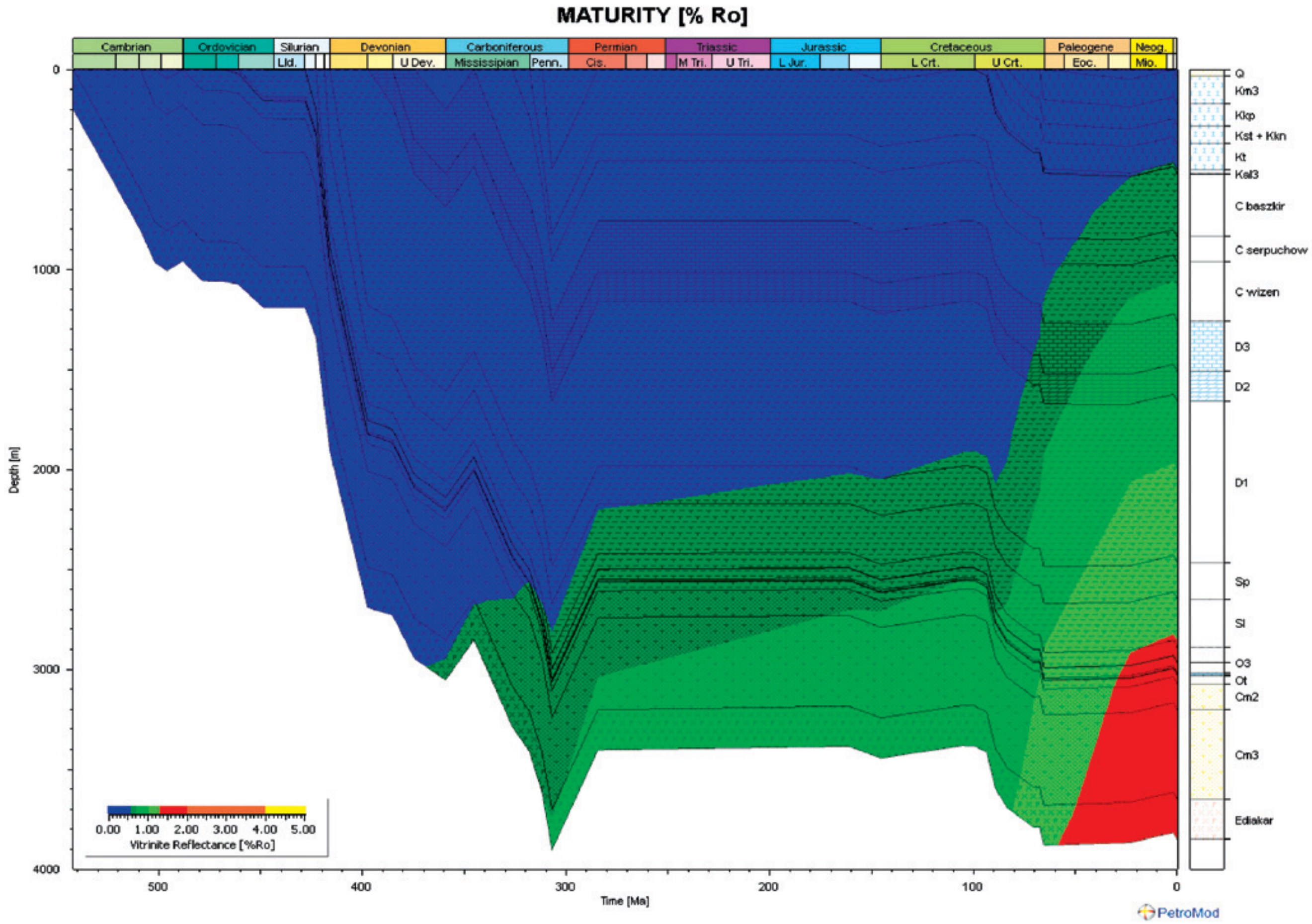
Modeling using lithology and stratigraphic data, petrographic, petrophysical, geochemical, geophysical and geomechanical data.

**Completed modeling 1D, 2D and 3D allows us to locate sweet-spots by visualization of gas and oil saturated zones and hydrocarbon migration paths from source rocks in geological time.**




Example of PetroMod 1D burial history and maturity modeling

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# GEOPHYSICAL LAB

## WELL DATA & CORE ANALYSIS

The well logging delivers numerous parameters which are the continuous source of information on the presence and estimated size of the source rocks and their petrophysical, geomechanical and geochemical parameters.

**A comprehensive analysis of the interesting stratigraphic horizons in the boreholes allows us to separate particular complexes, construct a lithological section and evaluate horizons that potentially can be shale gas reservoirs. To perform such an analysis a set of calibrated well logs and core analysis is used.**

Estimates of TOC (Total Organic Carbon) content can be performed using, for instance, the Passey method. This method use porosity logs (Sonic Log, Gamma-Gamma Density Log or Neutron-Neutron Log) and Electrical Resistivity Log to calculate the TOC. To obtain quantitative data, results should be correlated with core-derived LOM (Level of Organic Maturity) and TOC measurements. Another way to estimate the TOC is the Geochemical Log – this method can be quantitative even without usage of core measurements.

Estimations of *in situ* mechanical parameters can be performed if full-wave sonic logs are available.

Data from approximately 8000 archival, Polish boreholes deeper than 1000 m are stored in the Polish Geological Institute – NRI geological data base. Most of these wells were logged with uncalibrated tools (for example Gamma Ray was scaled in counts per minute instead of API). Therefore some attempts to recalibrate "Russian-style" logs are made. The data obtained might not be as informative as brand-new measurements, on the other hand, in some regionsit is the only way to assess the unconventional potential of deeply buried rocks.

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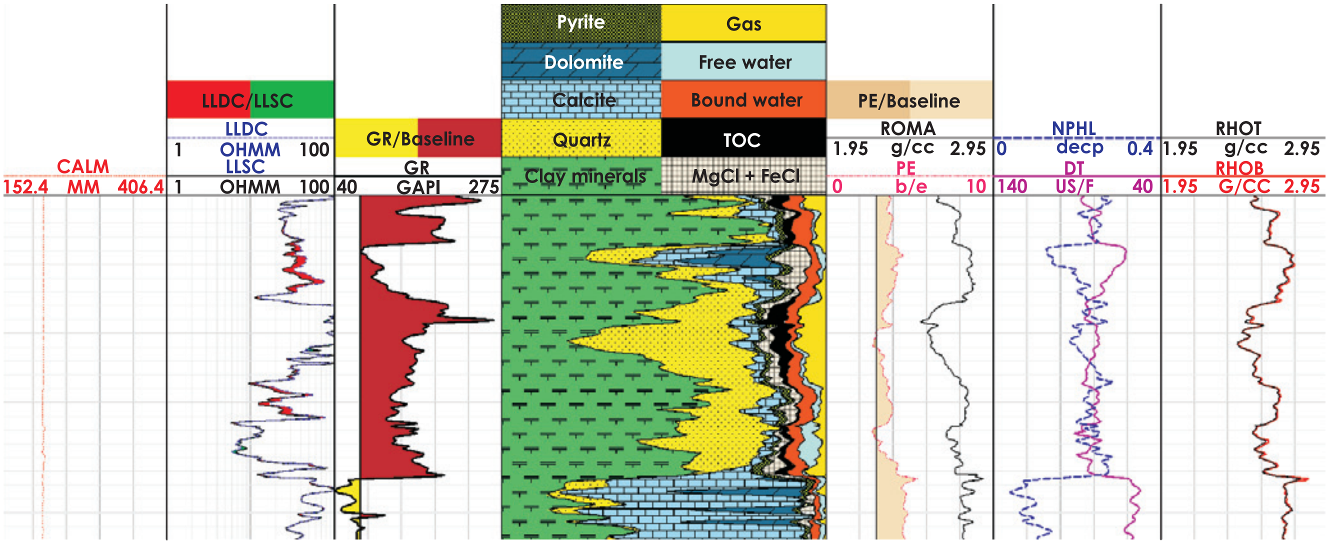


Simplified, exemplary layout of a perspective interval in a shale gas borehole in Poland. Note the good correlation between GR and TOC values – in organic rich intervals the GR reading is off the standard scale and comes up to 260 API. Most measurements were performed by Halliburton's GEM™ tool: CALM – caliper, LLDC/SC – laterolog deep/shallow, GR – gamma ray, ROMA – matrix density, PE – photoelectric absorption factor, NPHL – neutron porosity (L.P.U.), DT – compressional slowness, RHOT – theoretically derived bulk density, RHOB – measured bulk density. Layout has been visualized in Techlog©.

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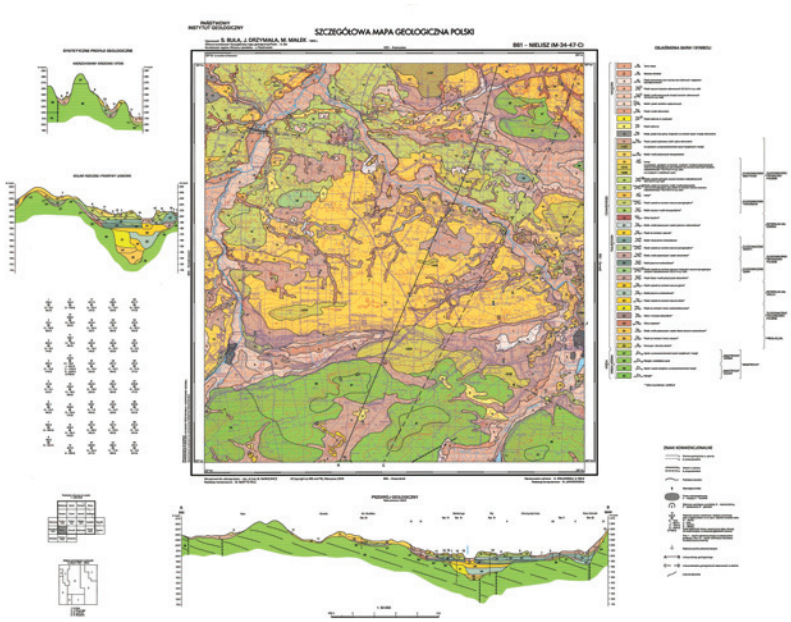
# GIS DATA & GEOLOGICAL MAPPING LAB

**We have several fields of interest being useful for unconventional hydrocarbon exploration:**

- Creation of geothematic maps, e.g. geological, geophysical, lithogenetic at any scale - from field work to GIS databases.
- Compilation of digital geological series maps for the whole of Poland (e.g. Detailed Geological Map of Poland in scale 1:50k, Geological Map of Poland in scale 1:200K).
- Geological and geomorphological surveying.
- Geological studies aimed at identifying sites for large-scale constructions, including nuclear power plants.
- Lithologic, petrographic and genetic studies of sediments.
- Interpretation of geophysical data (electrical resistivity, shallow seismics and semi-detailed gravimetric surveys) aimed at identification of the main subsurface structures (lithologic, morphologic, and tectonic) and selection of drilling sites.
- Drilling supervision and drill core logging.
- 3D modeling of geological structures facilitates and economizes planning in various geology-related disciplines, e.g. mineral resources exploitation and risk assessment in mining.



Detailed Geological Map of Poland – sheet Nielisz

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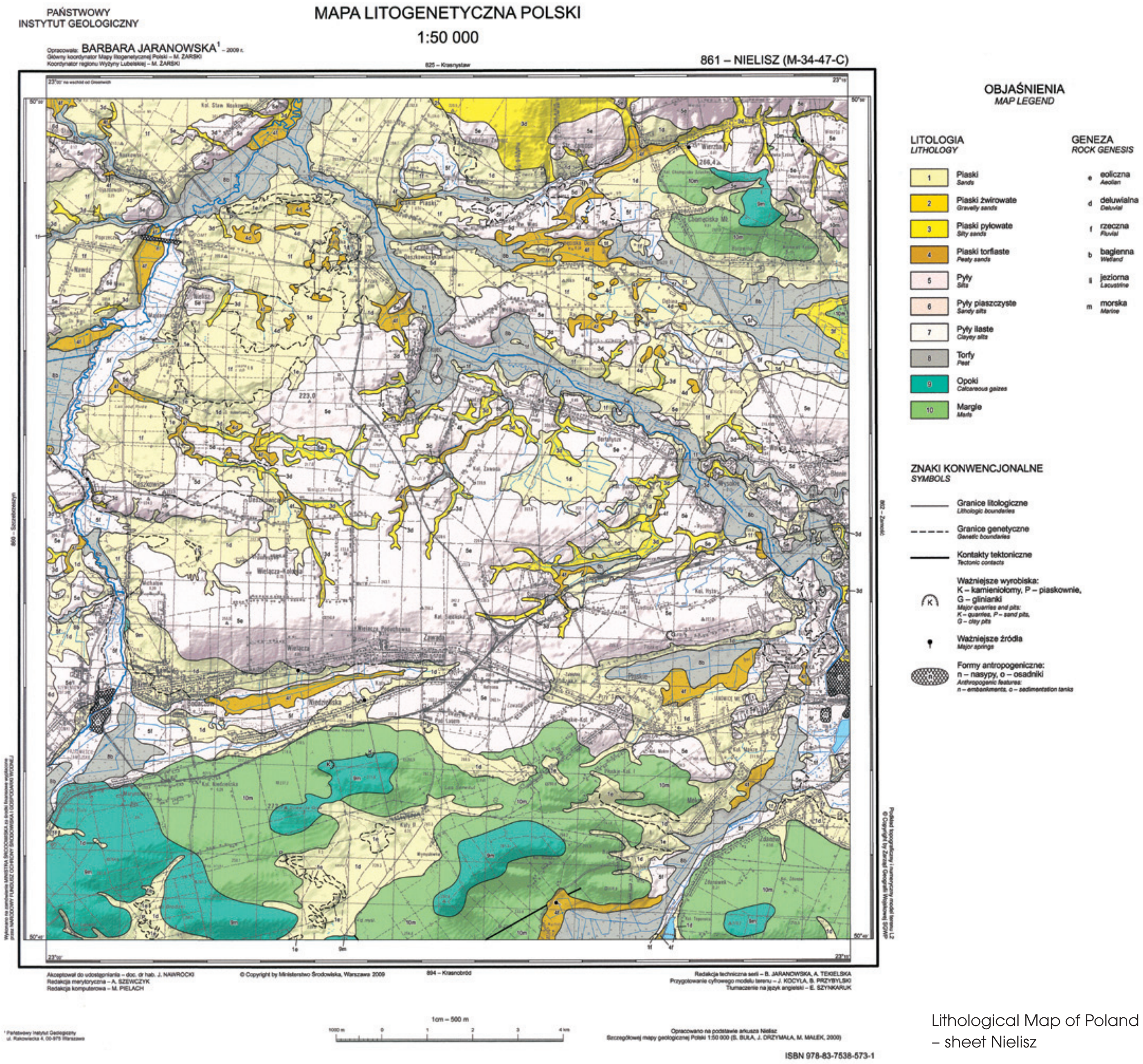


Lithological Map of Poland – sheet Nielisz

# 16 ENVIRONMENT PROTECTION LAB

## DRILLING & FRACKING JOBS AREA

**Continuous environmental impact monitoring of hydrocarbons resources exploration and hydrocarbon production:**

- Environmental state measurements before the start of any operation – as a benchmark.
- Observations and measurements during site preparation.
- Observations and measurements during borehole drilling.
- Observations and measurements during hydraulic fracturing process and gas tests.
- Environmental state measurements after well completion.
- Possible environmental damage evaluation and reclamation measures.
- Environmental monitoring planning and performance for production stage.

**Characteristics of the studied area**

- Geomorphology.
- Geological structure.
- Hydrogeological conditions including potable water reservoirs and hydrogeological modeling.
- Land use patterns and landscape values.
- Demography, employment structure.
- Buildings and technical infrastructure.
- Areas under legal protection.

(Based on serial mapping on big scales, national archive documentation and databases.)

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## Documentation and field data collection

- Inventory of hydrogeological objects within relevant radius from the well pad.
- Validation of water wells as representative of groundwater sampling sites.
- Groundwater level measurements and hydrogeological modeling.
- Contemporary methane sources inventory and characterization.
- Baseline soil, surface and groundwater measurements and analysis.
- Review of all administrative decisions on concession, drilling and fracking.

- Collection of data concerned with chemicals, proppant and drilling and fracking program.
- Waste sampling and waste management monitoring.
- Flowback sampling and analysis.
- Induced seismicity: measurement, coordination, and validation.
- Noise and air quality measurements: planning and co-ordination.
- Photographic documentation.

## Laboratory tests and analysis

**1)** Gas chromatograph AGILENT 7890B with FID detector for $C_1$-$C_4$ analysis in soil gas and water samples

**2)** CRDS (Cavity Ring Down Spectroscopy) gauge for methane and carbon dioxide concentration and $C^{12}/C^{13}$ ratio measurement


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Warsaw, 2014

# about us:

**The Polish Geological Institute is a research institute having the status of a National Research Institute.** It was established in May 1919 and is supervised by the Minister of the Environment. Under *the Act on Geological and Mining Law*, and *the Act on Water Law*, it performs the tasks of the **Polish Geological Survey** and the **Polish Hydrogeological Survey**.

The Polish Geological Institute – NRI performs its mission through intense activities in all fields of earth sciences all over Poland. It is the main depositary and a source of knowledge, information and geological, hydrogeological and geoenvironmental data in Poland.

The Association of the Geological Surveys of Europe, EuroGeoSurveys, will remain the basic platform of international cooperation for the Institute.

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