Genesis of shale

geological formations and hydrocarbon extraction:

impact on environment and human health

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Vilnius | 2014

UDK 553.5(474.5)
Ge226

ANNOTATION

The Lithuanian Academy of Sciences falls into a number of national scientific institutions that have already completed their reviews on the shale gas and hydraulic fracturing, as it is noted by the EASAC expert review group. The document presented here contains a shortened version of comprehensive baseline study on unconventional gas resources performed up to the end of 2013 by competent authors (in Lithuanian)[1]. The Baltic Silurian Shale Basin is an area prospective for unconventional gas survey stretching through the North-Eastern Poland to Kaliningrad District and Western Lithuania. The paper presents data about genesis of shale geological formations, potential of the unconventional gas resources, presumable extraction and its possible impact on environment and human health. Preliminary estimated prognostic geological sources of generated hydrocarbons (oil and gas) in Western Lithuania (area of ca. 5700 km^2) show its rather high values; however, if technically recoverable reserves make one percent, the volumes would be 37 million m^3 of oil and 14 billion m^3 of gas.

The problems highlighted for Lithuania are:

- ✓ low information from exploratory drilling;
- ✓ high population density and lack of given area of land;
- ✓ low reclamation rate and sensitive public opinion;
- ✓ short state regulation on environmental, safety and health issues.

Reference: Genesis of shale geological formations and hydrocarbon extraction: impact on environment and human health / compiled by Algimantas Grigelis. Lithuanian Academy of Sciences, Vilnius, 2014, 60 pp. [Translated by Aloyzas Pranas Knabikas].

Layout design Miglė Datkūnaitė

Printed by *Utenos Indra* Ltd
Maironio g. 12, LT-28143 Utena
www.utenosindra.lt

ISBN 978-9955-9371-7-3

[1] Basys, V., Būda, V., Grigelis, A., Juodkazis, V., Lapinskas, P., Laškovas, J., Malinauskas, A., Motuzas, A. J., Vaitkus, J. V., Valiulis, A. V., Vilemas, J., Zdanavičiūtė, O. 2013. Skalūninių geologinių formacijų genezė ir angliavandenilių gavyba: poveikis aplinkai bei žmonių sveikatai / sudarytojas Algimantas Grigelis, mokslinis redaktorius Juozas Vidmantis Vaitkus. – Valstybinis mokslinių tyrimų institutas Gamtos tyrimų centras, Vilnius, 2013 m. birželio 25 d. 105 p., lent., iliustr.

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Introduction[1]

The minerals occurring in the underground make a base of mineral raw materials for industry and energy generation for any world country. Over the last decade, with prices of oil and especially natural gas increasing, new alternative sources of energy are widely searched for around the world, including unconventional gases such as gas hydrates and gases in clay shale and coal seams. These are hydrocarbons dispersed in a wide zones of deposits and extracted by unconventional techniques, thus they are called unconventional hydrocarbons.

In Lithuania, the issues of prospecting for unconventional hydrocarbons became relevant during several last years, after the attention was paid to their occurrence in the underground. The extraction of unconventional hydrocarbons can cover wide areas, thus raising concerns for local population and controversial attitudes. Two main attitudes towards extraction of shale hydrocarbons are formed by general public: *"for"* and *"against"* development of such activity. The differences in opinions, often without full understanding of the core of the problem, raise the tension within the society and confrontation with the government institutions.

After the intention to start shale gas prospecting and extraction in Western Lithuania was announced[2], the Lithuanian Academy of Sciences commission, basing on the Underground Law of the Republic of Lithuania (Žin., 2001, Nr. 35-1164) **[1]**, legal regulations on hydrocarbon resources prospecting, exploration and extraction in the Republic of Lithuania, as well as those on the underground supervision **[2]**, had reviewed the following documents: a report presented in 2011 on the Strategic Environmental Assessment (SEA) of the use of hydrocarbon resources in the Šilutė–Tauragė area **[3]**, the investigation done in 2011 by the European Parliament **[4]**, the report by EC Directorate-General for the Environment (DG Environment) in 2012 about the potential health and environmental risks of hydraulic fracturing applied for hydrocarbon production **[5]**, other documents of EC committees and reviews **[6, 7, 8]**, as well as data presented by EC invited experts, had reported its conclusions on March 18, 2013 with the following statements **[9]**:

1 Compiled by Algimantas Grigelis. Lithuanian Academy of Sciences, Vilnius, 2014, 108 pp.

2 A tender for hydrocarbon use (prospection, exploration and production) in the areas of Šilutė–Tauragė and Kudirkos–Kybartai had been announced on September 14, by the Geological Survey of Lithuania ant the Ministry of Environment. – The Official Journal of the European Union, 2012/C 278/02, LT, 14 September 2012.

- **shale gas exploration** is expedient as a single technique for investigation of its distribution and potential resources;
- **shale gas production**, when its exploration is finished, is possible, after a project on the gas use is presented and Strategic Environmental Assessment is done for a whole area and period of shale gas production;
- **exploration of shale gas resources and their production** from legal point of view is possible, after the laws and related legal acts on underground use and protection, environment and health protection, and local self-government activities are improved.

After reviewing the Commission conclusions, the Seimas (Lithuanian Parliament) committees on Environment Protection and Economics as well as the Energy Commission decided to prepare necessary amendments to the laws. A law on changes and additions in the articles of the Underground Law of the Republic of Lithuania had been passed in Seimas on May 30, 2013, signed by the President of Lithuania on June 14 and published in Valstybės Žinios (The State News) on June 18, 2013 [10]. The amendments passed require stricter environmental protection during the prospection, exploration and production of shale gas, as well as stricter conditions for storage of radioactive, toxic and hazardous wastes in the underground, moreover, they authorise two related terms:

- **unconventional hydrocarbons** – hydrocarbons occurring in low permeable primary sedimentary deposits without accumulation in conventional fields;
- **conventional hydrocarbons** – hydrocarbons accumulated in natural traps within porous, fissured rocks (traditional fields).

1. Geological setting

Oil rich deposits of the Lower Palaeozoic Cambrian, Ordovician and Silurian geological systems are distributed in entire western area of Lithuania. Traps of conventional hydrocarbons are known in the porous Cambrian sandstones of Deimena series, where liquid crude oil is extracted. The Ordovician deposits (40–250 m thick) best enriched with organic matter are black argillites (shales) of Upper Ordovician (their total thickness 3–4 m). The Silurian deposits (500–750 m thick) rich in organic matter mainly are dark grey and black Llandovery and Wenlock shales (clay shale) of Lower Silurian. Their occurrence depth ranges within 1750–2000 m (from land surface); total thickness of the effective beds is 30–80 m. During oil prospecting and exploration within the Silurian deposits in the Šilutė–Tauragė area, 2D seismic exploration profiles have been made (their total length is 1610 km) and 38 boreholes have been drilled. C_{org} amounts exceed 2 percent in the Upper Ordovician and Lower Silurian shales, while total organic carbon (TOC) ranges from 0.74 to 17.2 percent; its maturity R_o (according to vitrinite reflectance) is 0.8–1.5 percent. The organic matter present in the deposits can generate liquid and gas hydrocarbons with high efficiency of generation. The organic matter in the deposits is analysed only in small numbers of samples [12].

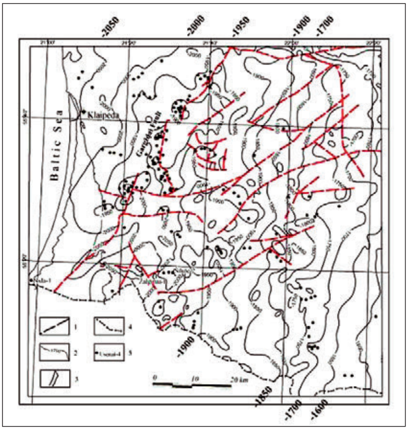

Fig. 1. The occurrence depth of Silurian deposits in Western Lithuania [11]

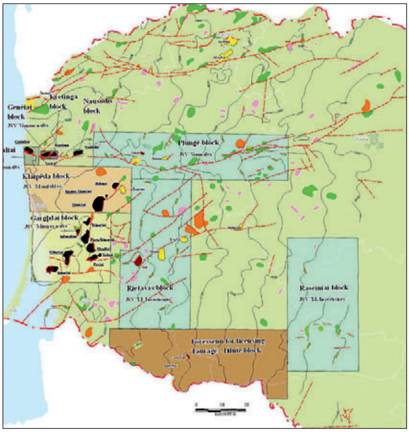

Fig. 2. Areas in Western Lithuania where permissions for the use of hydrocarbon resources are issued; the Šilutė–Tauragė area is marked in brown colour [9]

2. Technological solutions

Technologies for prospection, exploration (and production) of hydrocarbons are similar for both conventional and unconventional resources applied in other perspective areas in Western Lithuania [13]. These are analysis and assessment of information, seismic prospecting, drilling and extraction. Seismic prospecting is used to map surfaces of separate layers and to find structural or other possible traps of hydrocarbons. According to the purpose, drilling works are of prospection, exploration and production types. The prospecting hole is drilled to detect hydrocarbons in a certain site and perform all possible investigations in order to get data as much as possible about perspective beds and their features. Exploration wells are drilled to explore those beds where petroleum seepage had been detected, in order to determine conditions of useful mineral occurrence and production, effective production technologies and economic value. Production wells are drilled directly into the deposit that is already explored in detailed manner.

In the case of hydrocarbon searches in clay shale beds, horizontal drilling and hydraulic fracturing of shale should be performed in order to get an answer about the seeping of gases and/or fluids. Exploration and production wells can be drilled vertical, deviated or horizontal across a seam perspective for oil or gas. Technology used to prepare the site for prospection, exploration or production drilling, protection of environment and shallow, confined, fresh or mineral water, as well as the drilling method depends on local geological conditions and drilling goals [14].

Lithuania has experience in hydraulic fracturing to enhance oil seeping into a production well [14]. It is shown for the oil production well Pietų Šiūpariai-5 that hydraulic fracturing there required 234 m^3 of fresh water, 41 t of sand (proppant) and 1.267 m^3 of additives, i.e., 0.538 percent of total fluid volume. Chemicals such as hydrochloric acid, biocides (sodium hypochlorite, chlorine dioxide), friction reducers (polyacrylamide), gelling agents (Guar Gum, cellulose and its derivatives), and oxygen scavengers (ammonium bisulphite), as well as other chemicals were used. Analyses of groundwater samples performed after the hydraulic fracturing showed no impact of these chemicals on quality of water taken from above-lying aquifers [15].

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Peculiarities in origin of shale geological formations

1. Ordovician

The Ordovician (488–443.7 Ma B.P.) marine sedimentary basin had existed on the south-western margin of the East European Platform (Fig. 3). In Lithuania, the Ordovician section consists of terrigenous-carbonate formation that corresponds to the marine transgression inundation stage in the Caledonian tectonic sedimentary cycle [1]. During the Ordovician, the Baltica continent in southern hemisphere drifted towards the equator from 60^{o}–40^{o} and reached the 30^{o}–20^{o} subtropical climate belt [2, 3]. Major part of calcareous deposits formed in the sedimentary basin due to remains of benthic, phyto- and bio-planktonic organisms [4]. According to the bottom depths, formation of morphotectonic structures and distribution of sediments, the East Baltic, West Baltic and Skåne basin subformation regions are singled out [5]. The East Baltic subformation region lies at the marginal part of the basin and coincides with the Central Lithuanian–Brest Depression [4, 6], grey terrigenous-calcareous facies prevail, and sediment thickness reaches 194 metres. The West Baltic subformation region occupies the central part of the basin and coincides with the Jelgava depression and Lower Nemunas Uplift [7]; various-coloured (grey, red and black) calcareous-terrigenous facies prevail and sediment thickness ranges from 40–50 m to 250 m. The Skåne Basin subformation region lies in the basin's deepest part and coincides with the Notanga depression [8], grey calcareous-terrigenous (clay) facies prevail, and sediment thickness reaches 120 m.

In the West Baltic subformation region, the black shale rich in organic matter is observed in the Oandu and Vormsi stages of the Ordovician (Figs. 3, 4). The Oandu Stage [9] of Plungė (Mossen) Formation consists of black shale, while Žarėnai Formation contains grey marl with microcrystalline lime interlayers. Black shale is laid in laminas (from less than 1 mm to 1–3 mm) composed of clay minerals (hydromica, kaolinite, chlorite) and organic matter spread in the lamina. This causes laminated structure of the deposit, and with depths changing shaly character – due to increased pressure. Amount of organic matter in shale, limestone and marl deposits reaches, respectively, 14.9,0.11 and 0.21 percent [10]. Thickness of Plungė Formation black shale in Jelgava Depression is 3.5–4.5 m, while it does not exceed 1.5–2 m on the south-western slope of the Lower Nemunas Uplift. Black shale of Vormsi Stage (Fjäcka Formation) is similar in composition and structure; organic matter does

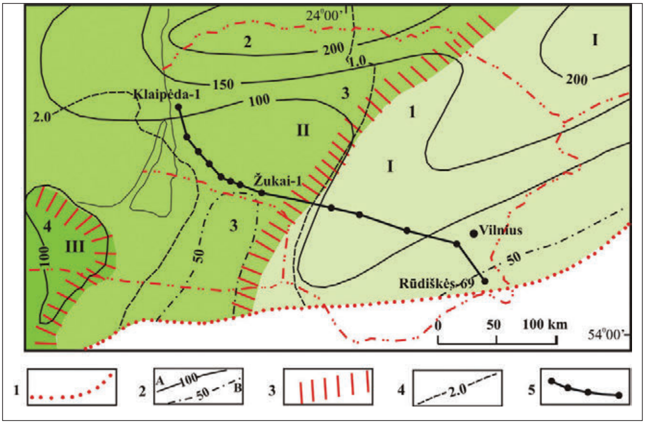

Fig. 3. Division of the Ordovician basin at the south-western margin of the East European Platform into subformation and morphotectonic regions. 1 – boundary of recent distribution of the Ordovician deposits; 2 – deposit thickness isolines (m), real (A) and restored (B); 3 – boundaries of subformation regions; 4 – Ordovician roof isohypses (km); 5 – stratigraphic section line (see Fig. 2). Subformation regions: I – East Baltic; II – West Baltic; III – Skåne. **Morphotectonic structures:** 1 – Central Lithuanian–Brest Depression; 2 – Jelgava Depression; 3 – Notanga Depression; 4 – Lower Nemunas uplift

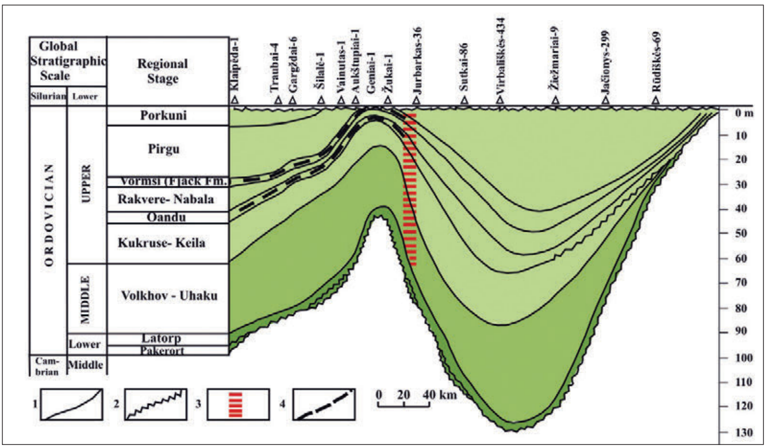

Fig. 4. Ordovician stratigraphic section across the subformation regions and morphotectonic structures of the sedimentary basin (see Fig. 1). 1 – boundaries of stratigraphic subdivisions; 2 – stratigraphic breaks; 3 – the boundary separating East Baltic and West Baltic subformation regions; 4 – black shale rich in organic matter

not exceed 7.9 percent; these beds in the south-eastern part of the Lower Nemunas uplift had suffered denudation due to the shallowing of the basin.

Oandu deposits under the conditions of marine transgression covered the eastern slope of the Central Lithuanian Depression, where littoral clastic facies were depositing. In the frontal part of the depression, the calcareous facies of shallow shelf wave and storm zone with rich benthic fauna prevailed. The axial part of the depression is notable for accumulation of post storm and storm clay rich facies. The deepest part of the basin saw quiet hydrodynamic conditions with clay rich in organic matter (phyto- and bio-plankton remains) accumulating. This is a facies of deep shelf stagnation zone. At the end of Oandu Stage (Žarėnai time), the basin became shallower. Due to basin further shallowing during the Rakvere-Nabala Stage, calcareous, terrigenous-calcareous facies of wave and storm zone were accumulating with the thickness of the deposits reaching 20 m.

The palaeogeographic-facies conditions in the basin during the Vormsi Stage were similar. After the Rakvere-Nabala basin prospering, a new marine transgression covered land most widely in the east (Fig. 4). The Central Lithuanian Depression saw formation of terrigenous-calcareous and calcareous facies of shallow shelf post-storm, storm and wave zones with deposits thickness reaching 20 m. Abundant settling of plankton in the Lower Nemunas Uplift and Jelgava Depression areas caused formation of stagnation facies.

1.1. Geological assessment

Total thickness of the organics-rich black shale of Oandu and Vormsi stages in the Lower Nemunas and Jelgava Depression area makes, respectively, 3–4 and 8–9 m. The shale beds are separated by limestone and marl deposits of Rakvere–Nabala stages with their thickness increasing northwards from 1–2 m in the western part of the Lower Nemunas to 8–10 m in the Jelgava Depression and combined with the Žarėnai Formation deposits making 14 m. Absolute altitude of the roof of the Vormsi black shale rich in organics ranges from -1100 m in the eastern part of their occurrence to -2000 m in the western part. Extraction of gas and liquid hydrocarbons from Oandu and Vormsi black shale deposits needs detailed investigation. Due to pressure caused by hydraulic fracturing of deposits, the permeability of shale seam increases, but, at the same time, the tectonic fractures can be damaged. In this case, the hydrocarbon gases and liquid oil can appear in the beds occurring above. Moreover, the clastic limestones of the Upper Ordovician Porkuni Stage (Saldus Formation) are found to contain oil signs. Local structures are linked to the tectonic faults in the basement rock and sedimentary cover [11, 12].

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2. Silurian

The Silurian (443.7–416 Ma B.P.) marine sedimentary basin lay at the south-western margin of the East European platform. Thickness of the Silurian in the Lithuanian Depression reached 144–828 m on land and up to 1120 m in the marine area; while its base depths range from 234 to 2044 m (Fig. 5).

For the first time the Silurian deposits had been drilled trough in 1949 as the Vilnius well. A great variety of Silurian formations (especially in latitudinal directions) had been found by later researches in West and East Lithuania (Fig. 6). The researches on stratigraphy and correlation of formations in the western and eastern parts of the Silurian basin [1, 2, 3] enabled to get a reliable reconstruction of palaeogeography and regularities in rock formation and distribution of the Silurian and its separate stages.

During the Silurian, the Baltic marine sedimentary basin lay in the southern hemisphere within the arid climate zone [4] surrounded by land from three sides. The area of the basin was changing due to alternations of transgressions and regressions [2]. In

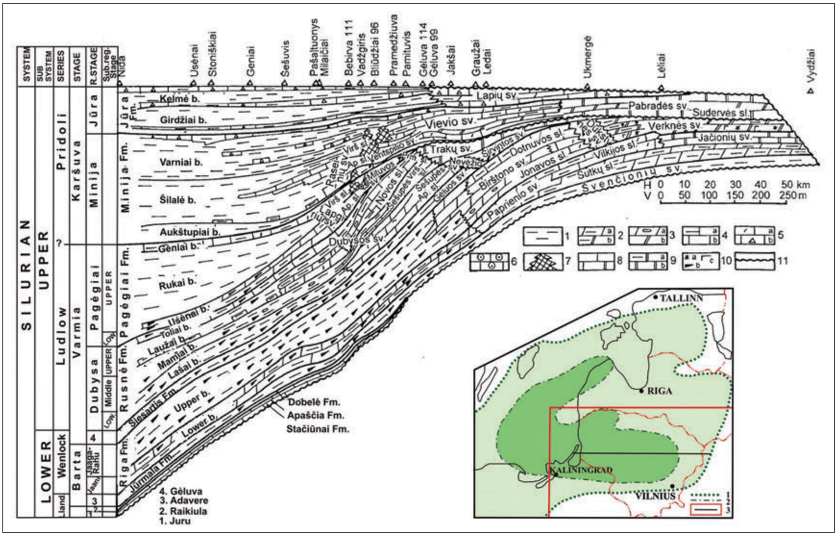

Fig. 5. The South Baltic Silurian geological-stratigraphic section: 1 – shale; 2a – clayey marl; 2b – clayey dolomitic marl; 3a – marl with limestone nodules; 3b – dolomitic marl; 4a – micro-grained clayey limestone; 4b – micro-grained limestone; 5a – organogenic detritic limestone; 5 b – clastic limestone; 6 – oolitic and oncolitic limestone; 7 – reef limestone; 8 – dolomitic limestone and calcareous dolomite; 9a – clayey dolomite; 9b – dolomite; 10a – red colour detections; 10b – organic admixture; 10c – gypsum lenses; 11 – surfaces of stratigraphic breaks. **Abbreviations**: Fm. (sv.) – formation; b. – beds; pl. – member; Prm. sl. – Pramedžiuva beds. **The Insert** shows a scheme of distribution of the Baltic Silurian formations: 1 – recent boundary of Silurian formations; 2 – recent boundary of the Silurian formations unaffected by post-Silurian erosion; 3 – distribution region of the Silurian formations discussed in the present paper and the line of its lithologic-stratigraphic section

southwest, it had connection with the ocean that lay at the margin of a tectonic plate. The eastern margin of the basin experienced accumulation of calcareous sediments, sometimes with the beds of red gypsum formations; thick terrigenous-clayey beds were formed in its larger central and south-western parts from intensive flow of mountain erosion material carried from southwest [5].

The Silurian palaeogeography shows a mixed view of geological environments and sediments settled. Their greatest variety is related to the Wenlock-Ludlow [2,3]. At the land and sea boundary there was a belt of sea-flooded plains (sebhs) and salt-rich lakes. Sediments settled here turned into greenish grey thin-laminated dolomite and variegated clayey dolomitic marl. For several time lengths, lagoons lay at the

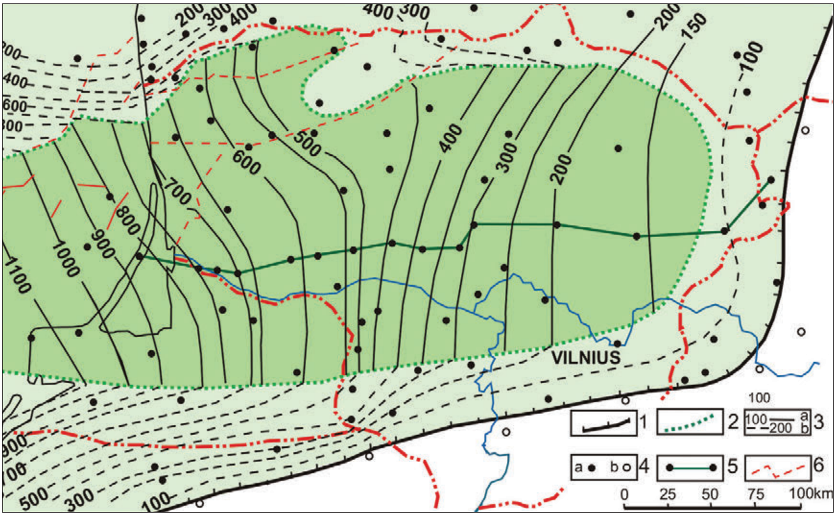

Fig. 6. Distribution of South Baltic Silurian formations. 1 – recent boundary of the Silurian formations; 2 – distribution boundary of Silurian formations unaffected by post-Silurian erosion; 3a – isopachs (thickness contour lines) of post-Silurian formations unaffected by post-Silurian erosion, m; 3b – isopachs of formations affected by post-Silurian erosion, m; 4a – boreholes with Silurian formations detected; 4b – boreholes without Silurian formations detected; 5 – the line of geologic-stratigraphic section (see Fig. 1); 6 – tectonic faults

margins of the basin, where calcareous deposits settled turned into dark dolomite with remains of benthic fauna. These lagoons were separated from the open sea by intensive wave-breaking zones; and calcareous sand bars or reefs at times were formed there. Westwards, a shallow open marine shelf with intense sedimentation of calcareous and clayey silt lay. Water turbulence saturated the bottom zone with oxygen creating conditions favourable for benthic fauna. Rich faunal remains are detected in marl and limestone formed of these shelf sediments.

The largest central part of the Baltic Silurian basin is occupied by areas of stagnational near-bottom water. Here, under deep shelf and low turbulence of water conditions, clayey sometimes calcareous silt rich in organics and planktonic faunal remains had been accumulating. Water pollution with hydrogen sulphide, due to decomposing organic remains, was high in the Middle Llandovery, when the content of organic matter in rather thin silt deposits (over 9 m) reached 19.2 percent [6]. During the Wenlock-Ludlow time, when total thickness of deposits increased to 320 m, the content of organic matter decreased to 1–2 percent [7], but the bottom water regime remained stagnational-anaerobic, unfavourable for benthic fauna that scarcely inhabited only the eastern zones of the basin margins (Photo 1).

During the Silurian, two bed systems had been formed in the central part of the sedimentary basin; they comprise Silurian dark coloured terrigenous complex (STTK) that is a major source for generation of hydrocarbons [8]. The first bed system is presented by the middle part of the Llandovery rocks: thin-laminated black shale rich (up to 19.2 percent) in organics and remains of planktonic fauna, especially graptolites, rare limestone concretions and interlayers; thickness does not exceed 9 m (Photo 2). The second bed system presented by the lower part of the Wenlock-Ludlow is composed of grey or black, massive or thinly laminated shale and clayey marl (Photo 3), rare limestone concretions (Photo 4); some sections contain micro-grained clayey limestone beds to 16 m thick. Sometimes small volcanic ash (metabentonite) layers, to several centimetres thick, are observed (Photo 5). Remains of planktonic fauna are abundant (Photo 6). Content of dispersed organic carbon reaches in average 1.24 percent in the lower part (Wenlock) and decreases to 0.76 percent in upper part (Ludlow) [7]. The rock structure details can be seen in the images of thin petrographic sections (Photos 7, 8 and 9). Thickness of this bed system reaches 320 m, and that of total is 360 m.

The coeval sequences of sedimentary environs and sediments at the beginning and end Llandovery, end Ludlow and Přidoli have their own specificities. The sedimentary sequences of the Přidoli beginning in Central Lithuania are notable for widely spread environment of anaerobic shelf with sedimentation of calcareous silt. There were abundant separate reefs, with oil fields detected, and their barrier belts were forming [2]. Beyond them, lagoons lay, where dark calcareous silt rich in abundant benthic fauna remains were settling. The calcareous sand and reef zones of wave surf environs from the beginning of the Wenlock to the end of the Ludlow were migrating from the eastern part of the basin in latitudinal direction westwards. At the end of the last regression of the Přidoli cycle, the land lifted up and the marine basins ceased to exist.

2.1. Assessment of the Silurian reef oil and shale gas

In 1964, a presumption had been made that during the Silurian, conditions favourable for reef formation and hydrocarbon accumulation there could be in Central Lithuania. In 1975–1992 70 structural profile boreholes had been drilled in Central Lithuania. In 1983, the first Silurian oil field had been detected in a large Kudirka Reef (height 88 m, area ~25 km^2). The geological oil resources in it were assessed to be about 1.5 million tons [2]. Later a smaller oil field had been found in a smaller reef Šiaurės (North) Bliūdžiai. A new Silurian oil-rich region is distinguished in Central Lithuania where the geological prognostic oil resources can reach 102 million

Photo 1. Dark grey shale with a crinoid stem; Lower Silurian, Rīga Formation, Pajavonys-13 borehole, depth 1137.3 m

Photo 2. Lamination of greenish grey and black shale; Lower Silurian, Jūrmala Formation, Kybartai-23 borehole, depth 1175.0–1175.3 m

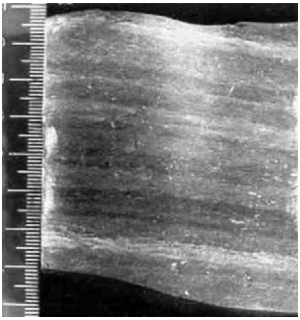

Photo 3. Dark grey thin horizontally laminated shale; Lower Silurian, Rīga Formation, Stačiūnai borehole, depth 1236.2 m

Photo 4. Limestone concretion in dark grey shale; Lower Silurian, Rīga Formation. Stačiūnai borehole, depth 1198.7 m

tons [2]. These investigations lasted by 1992 and were renewed in 2013, when the *TanOil* company began drilling of an exploration well in Jurbarkas District.

In 2009, it had been announced about a possibility to find shale oil in the Lower Silurian beds in Lithuania [6]. In 2011, US Energy Information Administration (EIA) published its assessment about shale gas resources in the Lower Silurian of south-west Lithuania [9]. The same year, it was assumed that the whole western area of Silurian hydrocarbon generation could be perspective for searches of shale gas [10]. In 2013, the Commission of the Lithuanian Academy of Sciences made calculations of 2.5 billion cubic metres (bcm) liquid and about 800 bcm of gas hydrocarbon

Photo 5. Greenish grey shale with a metabentonite interlayer; Lower Silurian, Jūrmala Formation, Kybartai-23 borehole, depth 1182 m

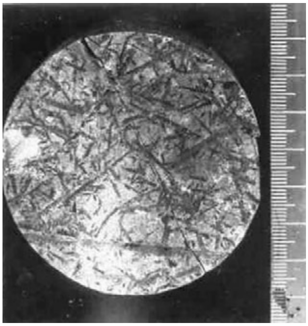

Photo 6. Black shale with abundant chaotic oriented graptolites; Lower Silurian, Jūrmala Formation, Stačiūnai borehole, depth 1243.2 m

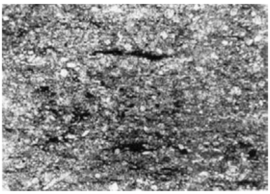

Photo 7. Dark grey shale rich in organics; thin section x 10; Lower Silurian, Rīga Formation, Stačiūnai borehole, depth 1108.8 m

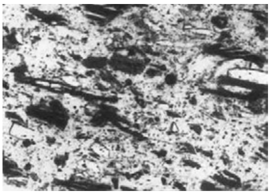

Photo 8. Light brownish metabentonite clay with abundant chips of biotite, quartz and feldspar, thin section x 60; Lower Silurian, Jūrmala Formation, Kunkojai borehole, depth 1372.2 m

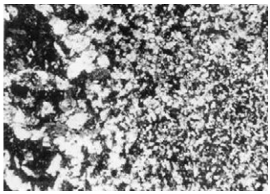

Photo 9. Dark grey crystalline limestone concretion, thin section x 5; Lower Silurian, Rīga Formation, Stačiūnai borehole, depth 1154.4 m

geological resources in the Lower Silurian in the licensed Šilutė–Tauragė area (1800 km^2) [11]. In the case of potential 10 percent recovery factor, the production resources would make 80 bcm of shale gas.

In 2013, the newest geological and geochemical information about STTK had been studied and compared to that for similar US and Canada basins, where shale gas production is proceeding [8]. On this basis, potential shale gas reserves associated to oil had been calculated for a western part of hydrocarbon generation in the Silurian of Lithuania (~10 000 km^2; Fig. 7). Maximum geological reserves can reach 5.1

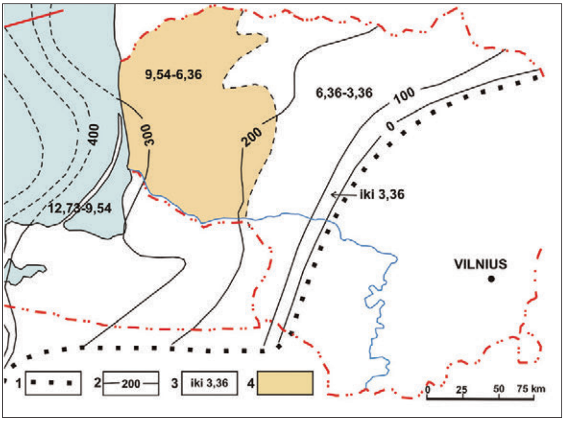

Fig. 7. Distribution of the Silurian dark coloured terrigenous complex (STTK) in Lithuania. 1 – STTK occurrence boundary; 2 – STTK isopachs; 3 – organic carbon (Corg) amounts in million tons per km^2 [7]; 4 – area where prognostic shale gas reserves are calculated for STTK

trillion cubic meters (tcm), while those productional (applying 25 percent recovery factor [9]) range from 380 (30 percent success in case of risk) to 1280 billion m^3 (bcm). Occurrence of other hydrocarbons (gas condensate and oil) is presumptive and their production probable in the western part of the STTK area.

According to the latest US EIA data, the production coefficient/recovery factor/ for oil associated shale gas in Lithuania is taken to be 10 percent [12]. Applying this value, the lowest volume of the recovered shale gas (in case of 30 percent success factor) could reach about 150 billion cubic metres (bcm) and the largest one reaching 510 bcm. The EIA presented shale oil and associated shale gas resources (geological 113.3 bcm, and recoverable 11.3 bcm) as well as shale oil risked resources (geological 954 bcm, recoverable 47.7 bcm) [12] seem to be applicable for a small area of Silurian oil generation zone in Lithuania and only for its STTK Lower Silurian complex.

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3. Origin of shale hydrocarbons and their resources

Assessing the perspectives in prospecting unconventional hydrocarbons (shale gas and shale oil) in Western Lithuania, it is most important to determine the content of organic matter in the rocks, its maturity and distribution as well as to assess the amounts of generated hydrocarbons. Shale oil and gas, as is known, can be generated in the rocks with organic carbon content higher than 1–2 percent and maturity according to the vitrinite reflectance R_o reaching 0.9–1.0 percent [1]. According to the research data, the beds generating liquid and gas hydrocarbons can be the Ordovician Oandu (Mossen Formation) and Vormsi (Fjäcka Formation) as well as Lower Silurian Llandovery and maybe Wenlock shales [2, 3] (Fig. 8).

The organic matter in a rock is defined by the amount of total organic carbon (TOC) that is determined by standard *Rock-Eval* pyrolysis method [4]. The basic quantities measured by *Rock-Eval* are: S_1 – content of free hydrocarbons present in a sample and released during pyrolysis at 300°C. S_1 is expressed in mg of hydrocarbons per gram of rock; S_2 – amount of hydrocarbons produced during primary kerogen cracking at 300–650°C. S_2 is called the residual hydrocarbon potential and expressed in mg of hydrocarbons per gram of rock; S_3 – amount of CO_2 derived from organic matter; T_{max} – temperature determined at the S_2 peak maximum, i.e. from the maximum of hydrocarbon generation. All these parameters are the basis for calculation of differ-

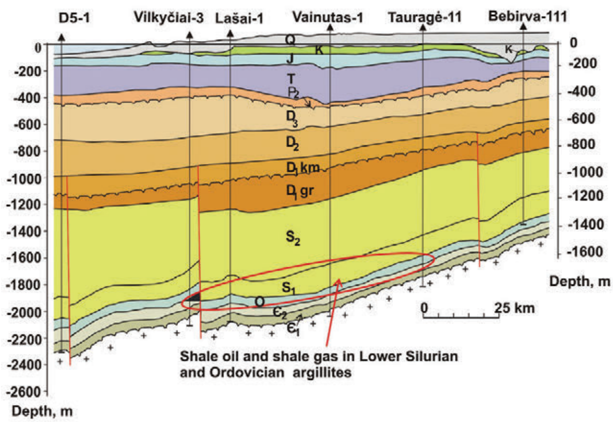

Fig. 8. Geological profile of sedimentary beds in Southwest Lithuania

ent indices used for evaluation of the organic matter present in the sample: TOC – total organic carbon; HI – hydrogen index; OI – oxygen index; PI – production index.

The organic matter amounts in **the Ordovician** section depend on geochemical facies and lithology. The organic contents regularly increase in the following sequence of rocks: limestone–dolomite–marl–shale. Black shale contains organics at amounts 15 times higher than the greenish grey shale and marl, while the latter contain it nearly twice more than the light grey limestone and dolomite. Contents of organic matter in red rocks are very low [2, 3]. The organic-rich rock intervals in Oandu ir Vormsi stages are composed of dark grey and black shale reaching 5–10 m in thickness [5]. TOC ranges within 0.9–10 percent, but sometime reaches 15 percent; hydrocarbon generation potential is averagely 22 kg HC/t rock, but sometimes can reach 55–70 kg HC/t rock; hydrogen index (HI) ranges within 187–511 limits.

Formation of hydrocarbons in the sedimentary basin depends on content of organic matter, its type and maturity. According to the Tissot classification, the kerogen types I, II and III are distinguished [6]. The Type II kerogen generates more liquid hydrocarbons, Type III is notable for gaseous, and mixed type for both liquid and gas hydrocarbons. Organic matter in the Ordovician shale can be attributed to the Type II (marine version), and only its small part (where TOC is lower) belongs to the mixed Type II/III.

The organic matter in **the Silurian section** of Western Lithuania was accumulating and remained in the deeper shelf zone during the early time of the Silurian. The intervals of dark grey and black marl and shale are most rich in organic matter [2, 3, 7]. The *Rock-Eval* pyrolysis analysis showed TOC in the Lower Silurian rocks ranging from 0.01 to 19.2 percent. The top HI value (540) of non-mature organic matter is detected in the Baubliai-1 well, and majority of organic rich samples (TOC >1.0 percent) have low HI values, i.e., about 300–400. The potential of oil and gas generation in the Lower Silurian beds range from 1.82 to 113.82 kg HC/t rock. This indicates very good conditions in these rocks to generate hydrocarbons [8]. Majority of samples studied are attributed to the Type II and mixed type kerogen. Genesis of such a type of organic matter is related to the remains of phyto- and zoo-plankton and bacteria in the sediments of marine origin [1].

3.1. The maturity of organic matter

The maturity of organic matter depends on intensity and duration of temperature and pressure effect. To determine this, various indicators are used: data of investigations of micro-particles similar to vitrinite, variations in colour of spores, pollen and conodonts in the rocks, as well as data of biomarker analyses. Thermal maturity of organic matter in the present work has been determined by measuring light reflectance index (R_o) in vitrinite resembling particles, as well as based on the data of *Rock-Eval* pyrolysis maximum temperature (T_{max}) and production index. The T_{max} values have also been recalculated into the values of vitrinite reflectance index (R_o).

Rock-Eval T_{max} values in the Ordovician section range from 412 (Pajūris-1 borehole, depth 1870.2 m) to 455°C (Ramučiai-3 borehole, depth 2047.7 m). The production index varies in a similar manner, its increases with the increasing depth of rock occurrence from 0.09 in Vilkaviškis-131 borehole (depth 1252 m) to 0.5 in Malūkai-1 borehole (depth 2042 m). T_{max} values in the Silurian rocks in Western Lithuania increase within the range of 425–448°C with rock occurrence depths increasing. PI values within a limit of 0.04–0.39, but majority samples showed PI values below 0.1. So organic matter in the Lithuanian Silurian shale has reached a stage of 'oil window' or 'oil peak'.

The *Rock-Eval* pyrolysis method is found to be less accurate for investigations of rocks both of high and low maturity [6]. This is confirmed by the data obtained in Western Lithuania: R_o calculated from *Rock-Eval* T_{max} is lower than that measured directly in 'vitrinite' particles. Especially large difference is observed in the area of Ramučiai as well as in the boreholes Pajūris-1, Nida-1 and Rūkai-2, where irregularly low maturity of organic matter is obtained for T_{max} data.

R_o values range from 0.48–0.61 percent in the north-western part of Lithuania to 1.04 percent in the south-western part of Lithuania. A slight increase of R_o is observed in the boreholes Laužai-1, Šatrija-1 and Šiupyliai-67, where its values slightly exceed 0.7 percent. The lowest R_o determined in the borehole Malūkai-1 in North Lithuania is 0.48 percent (recalculated from T_{max}).

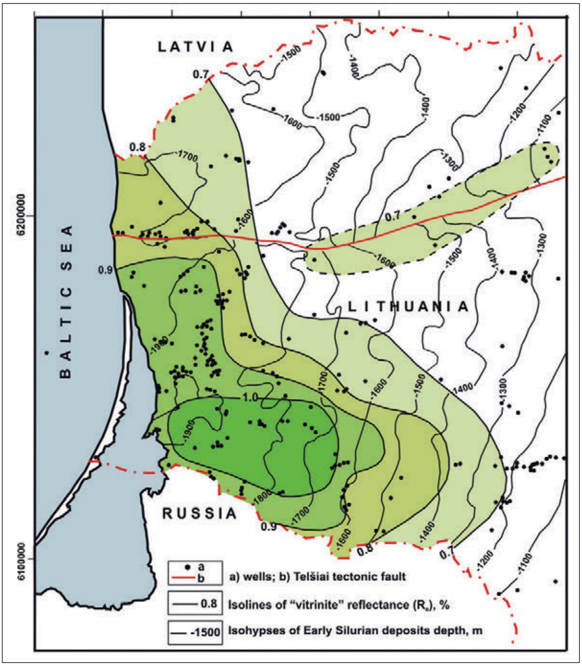

Fig. 9. A map of organic matter maturity (to the vitrinite reflectance based) of Lower Palaeozoic

3.2. Generated hydrocarbon quantity

A preliminary calculation of shale hydrocarbon (oil and gas) prognostic resources has been carried out in the present work, where the Claypool G. E. equations [1] have been used (Table 1).

Table 1. The calculated data of generated hydrocarbon quantities [9, 10]

Formation age and thickness, m	HI_p*mgHC/ gTOC	HI_o*mgHC/ gTOC	PI_p*	PI_o*	TOC_p* %	TOC_p* %	f*	$SI_{expelled}$* mgHC/g rock	ExEf* %
O+S_1 ln; 30 m	276	571	0.2	0.04	3.5	4.86	0.658	17.04	87.5
S_1 w; 80 m	250	562	0.2	0.07	1.8	2.94	0.731	13.98	91.7

Abbreviations: HI_p & HI_o – the present day (measured) and the original hydrogen index; PI_p & PI_o – the present day and the original production index; TOC_p & TOC_o – the present day and the original total organic carbon quantity in the organic matter; f – organic matter fractional conversion to petroleum; $SI_{expelled}$ – amount of petroleum expelled from the source rock; ExEf – expulsion efficiency.

Prognostic gas and oil resources are calculated for the areas limited by different 'vitrinite' isolines (Table 2). Minimum value of resources is calculated for the area of 1143 km^2 limited by a 'vitrinite' contour line R_o = 1 percent; medium value of resources is calculated for the area of 2912 km^2 limited by 'vitrnite' isoline of R_o = 0.9 percent; and maximum value of resources is calculated for the area of 5691 km^2 limited by 'vitrinite' contour line R_o = 0.8 percent.

Volumetric-genetic method applied to calculated prognostic resources of generated hydrocarbons in Western Lithuania shows high value, but technically recoverable reserves make only 1–10 percent of it. For the recovery factor equal to 1 percent, the volumes would be 37×10^6 m^3 of oil and 14×10^9 m^3 of gas. Due to small available data, the calculations of the resources are preliminary.

Table 2. Volumes of generated hydrocarbons (oil and gas) in separate beds and areas of Western Lithuania

Formation	Volumes of generated hydrocarbons (m^3)			Technical recoverable, recovery factor 1–10 % (m^3)		
	Min S=1143 km^2	Median S=2912 km^2	Max S=5691 km^2	Min	Median	Max
Ordovician and Lower Silurian: oil (m^3)	3680 x 10^6	9376 x 10^6	18324 x 10^6	37 ÷ 368 x 10^6	94 ÷ 937 x 10^6	183 ÷ 1832 x 10^6
Ordovician and Lower Silurian: gas (m^3)	1489 x 10^9	3794 x 10^9	7415 x 10^9	14 ÷ 148 x 10^9	37 ÷ 379 x 10^9	74 ÷ 741 x 10^9

In 2011 the US Energy Information Administration (EIA) assessed the potential of unconventional gas as 4 trillion cubic feet, that corresponds to approx. 107 billion cubic metres (bcm) of gas [11], the prognostic geological resources presented in 2013 made up 113.3 bcm of gas and 954 bcm of oil; wile the technically recoverable resources were 11.3 bcm of gas and 47.7 bcm of oil [12]. Earlier the prognostic generated hydrocarbon resources had been assessed for Western Lithuania [2, 13].

For comparison it can be mentioned, that according to the US data [14], in Poland, only in the Baltic Sea basin, there are 3.66 trillion m^3 (tcm) of shale gas, and for total Poland area EIA indicates 5.3 tcm of shale gas [15]. In Lithuania, because the prospecting of shale gas did not start, it is unknown how much gas can be detected in the Silurian shale, what are their features and in what area the drilling is to be performed. It is obvious, that prospecting trials should be attempted at least in two drilling sites. Having more information about clay shale features and drilling conditions, as well as recoverable gas volumes, the decisions can be made on further exploration and possible production actions.

Assessing the perspective of **shale has prospecting and exploration** it should be noted that the organic matter occurring in Western Lithuania in the Llandovery and Wenlock rocks is not studied enough, although this part of the section can be most promising for the prospecting of shale hydrocarbons. The maturity of organic matter reaches the stage of 'oil window' and only in the south-western part of Lithuania the 'wet gas' stage, i.e., the organic matter present in the Ordovician and Silurian rocks could produce more liquid and gas hydrocarbons.

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A review of shale hydrocarbon production and environment

The interests of natural gas production monopolists, advocates of renewable energy and environmentalists are crossing in production of shale gas. As is reported [1], Lithuanian underground contains about 4 trillion cubic feet (tcf) of gas. According to *Bloomberg* agency, *Chevron* company planned to invest at least 31 million US dollars into Western Lithuania for prospecting of shale gas. After the retreat of *Chevron*, we know today only published speculations about potential shale gas resources but not real data based scientifically and practically.

Nature [2] has presented information that hydraulic fracturing is safe method and there are only two documented cases confirming pollution of groundwater. Scientists are more concerned about gas escapes reaching 4–9 percent, i.e., considerably more than the 2.3 percent level recommended in the environment protection documents. According to the environmentalists, such production of gas can be allowed in strictly regulated areas and keeping to strict technological and environmental requirements; others, however, believe that development of shale gas production causes risk to air and water and can impede transition to renewable energy (sun, wind and bio-fuel).

The debates at the European Parliament voiced that refusal of production of this energy source would be a great loss [3]: thousands of work places would not be created, energy security would decline, and import of energy resources would increase. UK member of the European Parliament Roger Helmer thinks that all forms of energy resources production have safety problems. In his opinion, hydraulic 'fracking' technology raises no more risk than coal production or hydropower. Other sources [4] write about a very low risk of water pollution. In the USA, 9 of 10 oil and gas on-land wells use the technology of hydraulic fracturing (Fig. 10). Improperly sealed wells can cause such threats because chemicals and gas can reach above-lying aquifers and environment above the land surface.

The environment minister of Quebec province (Canada) had re-tabled a bill to authorise a moratorium on gas production in the Lowlands of the St. Lawrence River for further five years. This act would ban hydraulic fracturing, drilling and research [5]. UK energy minister stressed the high potential of shale gas and its importance for ensuring energy safety of the state, creating new workplaces and attracting investments. On the other hand, development of this business should be co-ordinated with local communities [6].

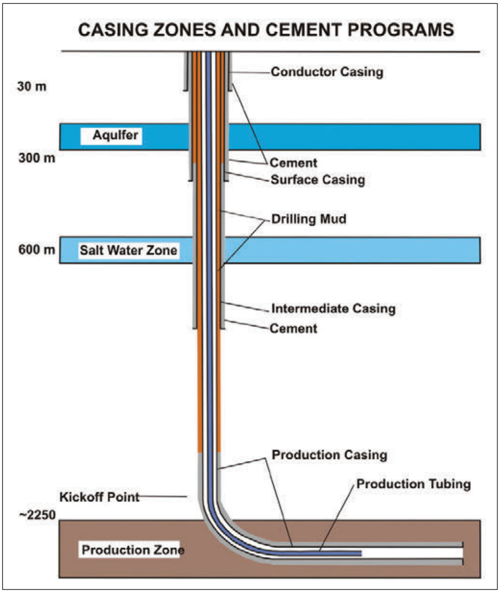

Fig. 10. A scheme of typical shale gas well where hydraulic fracturing is used for gas production. A horizontal part of the well is in the shale seam

One Canadian and Chinese company plans to drill two shale gas wells in the area between Manchester and Liverpool (UK), however, it would not use hydraulic fracturing yet. This method is planned but it would be applied only after permission is obtained from local communities [7]. Replying to the criticism of society on shale gas production and relying on importance of this energy source, UK government proposed to establish an *Office for Unconventional Gas* that would deal with creation of legal basis for production using hydraulic fracturing [8].

On February 28, 2013 the *United Kingdom Onshore Operators Group (UKOOG)* announced for the first time the guidelines on shale gas well operation. It contains rules and requirements coordinated with the Department for Energy and Climate Change, Health and Safety Executive, Environment Agency and Scottish Environment Protection Agency. The guidelines include hydraulic fracturing processes and set out that operators must publically disclose all chemical additives of hydraulic fracturing fluids (including their safe quantities) for each well. These requirements meet or exceed all known standards in the shale gas industry [9].

Greenpeace says [10] that there are no confirmed data about gas escapes from underground hydro-fracturing sites. In their opinion, the input of methane gases into atmosphere can be a considerably higher contribution into hothouse effect than the carbon dioxide formed by burning gas.

A study performed by EC Directorate-General for the Environment (DG Environment) and published on May 28, 2012 [11] envisages quite a few potential threats of shale gas production by means of hydraulic fracturing technology:

- If compared to conventional gas production, higher volumes of water should be used, moreover, with chemical additives;
- Lower yield of a well if compared to conventional gas wells, i.e., the impacts on environment can be greater per unit of gas extracted;
- Higher challenges of ensuring the integrity of wells to avoid the risk of contamination throughout the development, operational and post-abandonment lifetime of the plant;
- Higher challenges of ensuring a correct selection of geological sites for drilling, because of the risk of the long-term presence of hydraulic fracturing fluid in the underground;
- Potential toxicity of chemical additives;
- Unavoidable requirement for transportation of equipment, materials and wastes to and from the sites;
- Wider area of technogenic impact created, if compared to conventional gas fields;
- Requirement to establish a certain plant that is to produce various types of pollution (air, noise, dust) on the site.

Chemical substances are known to enter underground at a different scale: drilling, cementing drilled wells, exploding during hydraulic fracturing, and part of them remains there. In Lithuanian area, there are many wells of different depth, but their hazardous impact on water or environment had not been detected or at least not registered. UAB *Minijos nafta* is said to have performed over 20 hydraulic fracturing cases, but their monitoring had not revealed any hazardous impact [12]. Wells drilled to find sites suitable for gas storage also would require underground exploding or other underground impacts. In this case, the society demands absolutely no discussions on methane gas release into the atmosphere or deep contamination.

Lately, scientific investigations on shale production are widely developed, and the data obtained rapidly change, therefore for our small nation it is important not be involved into small problems; on the contrary, we should watch the tendencies and development trends in global shale production and use the experience accumulated by others. Is it expedient to start shale gas production in Lithuania, it is not clear. So, in Poland, taking into account its geological conditions, larger population density than in the USA (123 and 30.4 people per km^2 in Poland and USA, correspondingly) and all costs of the drilling, shale gas production would not be viable economically [13]. By the way, population density in Southwestern Lithuanian Šilutė–Tauragė area resembles that in the USA: 41 people per km^2 in Tauragė municipality, 29 people per km^2 in Šilutė municipality and 22 people per km^2 in Jurbarkas municipality. The formula of profit split in case of shale gas is not clear, because one can lose both his property and incomes. The shale gas will be purchased at a market price, and nobody knows how high it will be after 5 or 10 years, because volumes of gas recovered in Lithuania will have no significant influence on market price.

Technological means available used for shale gas prospecting, production and monitoring are technically safe, if the safety requirements are met. If the requirements are not observed, any production technology stage contains more or less risk: carless utilisation of fluids returning to the surface, low quality cementing of well wall, migration of methane gas from underground to the surface or its escape to the atmosphere from leaky pipes, storages, quality of drilling equipment etc. Concerns would be raised not by the exploration of the shale gas itself, since number of such wells is low, but by a larger scale production causing more problems:

- Gathering of gas from wellheads in a field. It is unclear, whether these should be gathering pipelines (underground or surface), or the gas should be pressed and liquefied. Pipelines would raise problems for farmers.
- Road network and related land size would depend on density of drilling sites. Small country roads are not designed for heavy load, therefore their quality would deteriorate rapidly. Gas production companies should invest into the improvement of roadways.
- Larger basins for return water should be monitored constantly due to potential leaks to environment (leaky pipes, container cracks etc.). Type of storage of liquids should be chosen depending on the scale of works (long-term or short-term production).

Drilling sites should be chosen at a certain distance from living buildings and water fields (open or groundwater intakes). The plot prepared for drilling can affect the ecosystems and wildlife habitat. Drilling equipment, pumps, noise caused by transport, constant traffic (24/7) problems an be solved by different means:

- erecting barrier fences (panels);
- diverting direct light sources from the settlements;
- choosing minimum traffic routes;

Table 3. Environmental risk factors in shale gas production

Technological actions	Environmental impact	Impact targets
Preparation of site and infrastructure	Area division by roads and/or pipelines	Area in general
	Formation of rainwater streams	Land surface water
Methane gas venting during a drilling	Air pollution with methane gas	Air quality
Hydraulic fracturing of shale seam	Fresh water consumption	Surface and underground (shallow) water
	Fracturing fluids	Surface water
	Methane gas	Air quality
Storage of fracturing fluids and water returned to the surface from a well and its utilisation:	Suspension returned	Surface and underground (shallow) water
	Fracturing fluids	Surface water
• processing in municipal wastewater treatment plants	Suspension returned and water cleaned	Surface water
• processing in industrial wastewater treatment plants	Suspension returned and water cleaned	Surface water

- working during the daylight period (might be difficulties in drilling a well);
- choosing work sites farther away from urban zones.

About 12–20 million litres of water are used per well. The fracturing fluid pumped into the shale reservoir is made up of 80.25 percent of fresh water, 14 percent of recycled water, and 5 percent of sand, as well as about 0.75 percent of other additives. The latter consists of about 0.07 percent of friction reducer, 0.03 percent of antibacterial agent, 0.02 percent of scale inhibitor, 0.0006 percent of corrosion inhibitor and etc. About 10–50 percent of the injected hydraulic fluids are returned to the surface. It is called a flowback. Proper management of these fluids are necessary [14–17]. Chemical settling, evaporation, electro-coagulation and filtration are used as flowback treatment technologies.

The growing shale gas production industry can raise a tension for local resources, self-government, living zones, roads, environment and emergency services. After the works are completed, it is very important to perform environmental reclamation of the site. According to the data published in the USA, if all field costs make 100 percent, the drill site preparation costs make about 6.75 percent, drilling – 32.5 percent, pipelines – 8.25 percent, equipment 6.25 percent, maintenance operation expenditures make 46.25 percent.

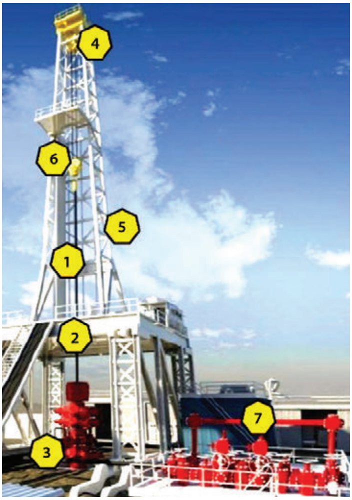

Fig. 11. Conventional drilling rig: 1 – well drill pipe, 2 – rotary table (turntable), 3 – blowout preventer and well hole, 4 – crown block, 5 – derick, 6 – travelling block with a hook, 7 – gate or hatch

Fig. 12. Drilling of wells from one site (Colorado, USA). The arrows show wells drill in a single pad by the same drill rig

The drilling equipment is big in size (Fig. 11), therefore to transport them good roads, bridges etc. are necessary. The best way to move the drill rig is not to bring it from far away but to drill several wells from a single pad (Fig. 12).

In the region neighbouring to Lithuania, a valuable experience obtained by Polish state-owned company in Wejherowo area close to Gdansk can be noted. Apparent and real threats for the environment are well seen in the drilling site for shale gas (Fig. 13). The geologically based selection of drilling site is agreed with the local community and all participants of the process. The planned depth of the well is 3280 m. The drilling pad is arranged in the state forest and covers the area of hectare (100 x 100 m), but when the hydraulic fracturing began the area will increase to two hectares.

To protect shallow and deep aquifers, a three-stage protection is cemented in the drill hole (Fig. 14). The outer protective casing, 47.3 cm in diameter, is cemented as deep as 30 m. Intermediate cement casing reaches 300 m depth and its diameter is 34 cm. Inner blocking casing reaches 1370 m and its diameter is 24.4 cm. The main drilling pipe is 17.8 cm in diameter. This complex protection ensures reliable

Fig. 13. The access road and drilling rig; photo by A. Valiulis (May 28, 2013)

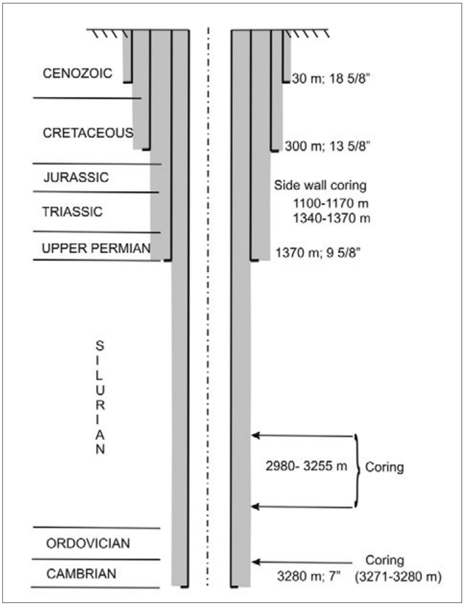

Fig. 14. A scheme of vertical exploration well in Wejherowo for deep shale gas

isolation of shallow groundwater from technological fluids circulating in the main drilling pipe.

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Environmental impact of shale hydrocarbon production

1. Possible impact on biota

Any economic human activities always has impact on biota: areas suitable for flora and fauna decrease, their fragmentation increase, disturbances in normal reproduction appear, survival and population density decrease, and at extreme conditions the populations and species decline, hence, the biodiversity decreases and stability of ecosystems is violated.

The impact on biota is related to the scale and intensity of human activities, therefore the impacts from shale gas prospecting and production on biota are assumed to be greatly differing. It should be noted that the impact depends also on the area where the works are planned to be done and on nature values defined in the EU directives and laws of the Republic of Lithuania.

The Šilutė–Tauragė licensed area has one nature reservation, two regional parks, 5 bird protection sites and 16 territories important for biodiversity. According to the Law on Protected Areas, new drilling sites for oil and gas exploration and production in the state parks and reserves are banned. Any works to change the environment, including land, drilling and preparation activities should be performed only taking into account the laws regulating the above mentioned nature units.

The impact on biota during the shale gas prospecting can be considerably lower, when wells are drilled in small numbers and compulsory Environmental Impact Assessment documentation is prepared properly according to the laws and ensuring the implementation of the measures planned there. The impact of shale gas production on biota should be envisaged to be significantly higher due to booming technogenic loads on the environment. In this case, the assessment of impact of a whole production field on the environment is mandatory. Also it is important that all production stages – from exploration and production to abandonment (buildings, site abandonment and soil reclamation) – were covered by the assessment. The nature recovery means also should be foreseen in the cases when the unfavourable impact is not avoidable. The following potential threats for the biota are assessed as follows: those related to possible air contamination are minimal, those related to water contamination are moderate in the case of an accident; those related to changes in soil mechanical properties and contamination are moderate; and those related to noise pollution are locally moderate.

2. Potential impact on soil, land use and landscape

The soil is a fertile multicomponent layer at the surface of weathering crust; it is formed due to interactions of local climate, plants and animals, soil-forming rocks, relief and region's age. The major property of the soil is its fertility we understand as a capability to provide plants with food elements and moisture and their root system with sufficient heat and air in the whole depth of their spreading. In the modern approach to soil-formation, the fertility should satisfy two more requirements for plants to grow: an extent needed and clean environment.

Potential special capabilities of soil as a system neutralising various human impact loads are not inexhaustible. A time comes inevitably, when the soil is not capable to resist increased physical, chemical and biological loads and becomes damaged in one or another way or degraded. Then contamination of soil takes place, i.e., accumulation of hazardous substances in the soil, threatening plants and biota. When the level of soil contamination exceeds Maximum Permissible Concentrations (MPCs), the soil is referred to as contaminated. Therefore, soil observance is necessary as a basic part in the biosphere monitoring.

The projects of shale gas exploration and production should foresee soil fertility restoration or its damaged cover reclamation during all stages of these works. According to the report published in 2001 on Lithuanian soil [1], major part of the Šilutė–Tauragė shale gas prospecting area is within the south-western margin of the Western Lithuanian soil zone. Choosing the sites for shale gas exploration or production, it is necessary to take into account the soil cover and protect it. Soil formation is affected here by the Baltic Sea, abundant rainfall, longer rainy autumn, milder winter, cooler spring and summer. Such climatic conditions induce soil erosion and podzolisation processes. The prevailing soil forming deposits are less calcareous sandy or moderate loams, but there are also glacio-fluvial and alluvial sands. Content of humus in the soils is 0.5–1.0 percent higher than in the Baltic Upland, but they contain also more organic remains which are not decomposed. Therefore, this higher content of humus has no significant influence on soil fertility. In the Šilutė–Tauragė shale gas prospecting area, the prevalence of glossisols and podzols is observed with signs of sogginess due to shallow occurrence of unconfined aquifer (about 2 m); they are very sensitive to any chemical pollution at the land surface.

Land use data in the administrative districts of Tauragė, Šilutė and Jurbarkas, where the Šilutė–Tauragė shale gas prospecting area lies, are given in Table 4. The main part in these districts is occupied by agricultural lands (50.2–54.7 percent), while

Table 4. Landed property percentages in Šilutė–Tauragė shale gas prospecting area [2, 3]

District	Area, km^2	Land use				
		farming land	forests	waters	urban areas and road	other lands
Tauragė	1179	50.2	38.3	2.0	4.2	5.3
Šilutė	1706	54.7	18.8	16.4	4.0	6.1
Jurbarkas	1507	53.9	35.1	3.0	4.4	3.6

forests in Jurbarkas and Tauragė districts cover 35.1–38.3 percent of the territory, and in Šilutė district forest area makes 18.8 percent of the land. All three districts have about 3.6–6.1 percent of land of other purposes, or undefined purposes.

Two landed property types prevail in the area of the Šilutė–Tauragė shale gas prospecting. **Firstly**, slightly wet and podzolised heavy lands with light and moderate heaviness loam typical of slightly wavy or more wavy plains occupy the undulating till plains. Quality of these lands is moderate or good, the landed property is valued at 40–45 points, majority of soggy lands are drained. **Secondly**, slightly wet sand lands of low and moderate wavy plains are covered by a thin layer of glacio-fluvial deposits. Quality of these lands is low; they are valued at 15–20 points, if dried – at 30–35 points. In the future, these lands in agriculture hardly will be more intensively and widely used. Choosing the sites for drilling, the shale gas prospectors should keep in mind these lands.

The landscape is defined as a territorial combination of natural (land surface rocks and relief, ground-level air, surface water, unconfined groundwater, soil and biota) and/or human-affected (archaeological remains, buildings, engineering, land use and information field) components related by material, energy and information links. Thus, the landscape is a most general concept. It consists of specific territorial units, which consist of areas with different material base, and smaller units of local level. According to a classical physical geographic division proposed by A. Basalykas [4], the Šilutė–Tauragė shale gas prospecting area covers a part of West Žemaičiai plain, West Žemaičiai plateau and Lower Nemunas plain.

According to the data published by J. Milius in 2001, environmentally, the quantitative result is controversial due to interaction of natural and anthropogenic factors and variations in main landscape components (land use and forest plots): the farming land areas decreased, forest areas increased, while the landscape became bare and its environmental stability damaged. Therefore, several nature protected territories are established in the area of Šilutė–Tauragė shale gas prospecting area: Viešvilė Nature Reservation, Panemunė Regional Park and 9 state reserves in Jurbarkas District; Kaskalnis Geomorphologic Reserve, a part of Viešvilė State Natural

Reservation and Jūra Ichthyologic Reserve in Tauragė District; Veiviržas Landscape Reserve, Vainutas Forest Biosphere Polygon, Svencelė Technological Reserve and other protected areas in Šilutė District. Due to shale gas prospecting in Šilutė–Tauragė area the anthropogenic impact on landscape is to increase.

In shale gas protection area, it is necessary to apply constant monitoring of landscape structure changes, use lands of 'other or undefined purposes' (covering 15 percent of the licensed area) for drilling wells, carry on constant monitoring of soil properties and environmental state, soil fertility regeneration and land ground reclamation.

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3. Potential impact on surface water

According to a document of the European Parliament Directorate General of Internal Policies 'Impacts of shale gas and shale oil extraction on the environment and on human health' (2011) [1] and specialised website supported by the US *Ground Water Protection Council and US Interstate Oil and Gas Compact Commission* [2], basic sources of potential pollution are:

- chemicals in fluids used for hydraulic fracturing;
- hazardous substances in flow-back fluids.

Surface water can be polluted from the following contamination sources:

- due to blowouts or fluid spills from waste storages or tanks, due to inadequate cementing of wells, when the environment is contaminated in spite of rather strict control;
- leaks through geological structures due to natural or artificial cracks.

To prepare a fluid for hydraulic fracturing in shale gas production, about 13,000–45,000 m^3 of water is consumed per well. Moreover, during the period when the well is used, sometimes additional fracturing is performed; this demands still more water. Even up to 10 additional fracturing cycles can be performed in a well. The data available show that 20–50 percent of hydraulic fracturing fluid (other data

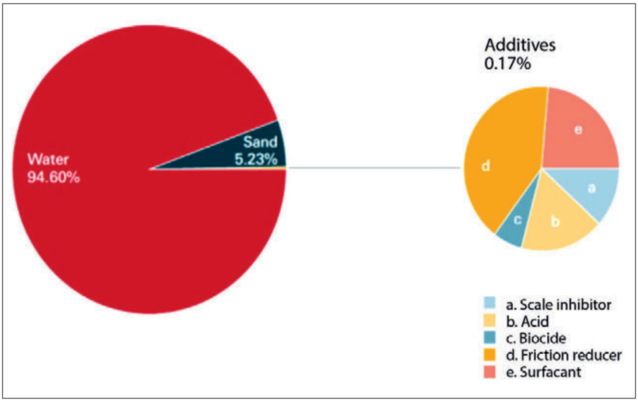

Fig. 15. Composition of fracturing fluid; to make a hydraulic fracture, a mixture of water and sand (98–99.9 percent) with chemical additives (0.1–2 percents) is injected into a well

show 9–35 percent) flows back to the surface. The flowback fluid is stored in open ponds. Part of this fluid is recycled and used in other wells.

A real composition of the fluid is chosen or adjusted taking into account concrete local conditions. More detailed information, as is said, is not published due to commercial reasons. However, the fluid composition and its threats can be assessed considering general available data. Main part of the fracturing fluid (98 percent) consists of water and sand, while the rest 2 percent embrace chemicals, which might possess toxic, allergic, mutagenic or carcinogenic properties. An approximate list of chemicals known as used in the fracturing and their properties is given below. For each particular case, a blend can be formed consisting of different combinations and quantities (proportions) of these substances.

Chemical and toxic properties of these substances are given in the websites of US EPA [3] and US Department of Labour [4].

Except the above-mentioned chemicals, the flowback fluid can have other toxic substances brought in from deep beds, including toxic metal ions – mercury, lead and arsenic. Other toxic substances can be formed due to complicated biogeochemical reactions with the chemicals in the fracturing fluid. Furthermore, radioactive elements, such as uranium, can be in the fluid flowed back from deep beds. Radioactive radon is especially often observed; its decay products are also radioactive and can settle with other substances as a film on the inner walls of pipes, pumps and other equipment, as well as reach unconfined groundwater. One more aspect of water pollution is salting of ground in the nearby environment. Its intensity depends on production scale and environment conditions in the district, e. g., rainfall etc.

Methane gas dissolved in the fluid also can be hazardous. It is reliably proved that the production areas contain rather high contents of dissolved methane, which is

Table 5. Chemicals contained in hydraulic fracturing fluids

Goal	Chemical	Function
Friction reduction	Polyacrylamid	Lessens friction of fracturing fluid (makes it more slippery)
	Oil distillate (hydrocarbon mixtures)	Keeps polyacrylamid in solution
	Methanol	Makes product stable and enhances freeze resistance
	Ethylenglycol	
Thickening	Guar gum	Makes solution thicker and supports sand suspension
	Polysaccharide blend	
	Oil distillate (hydrocarbon mixture)	Keeps guar gum in solution
	Methanol	Makes product stable and enhances freeze resistance
	Ethylene glycol	
Crosslinking (viscosity regulation)	Triethanol amine zirconate	Maintains fluid viscosity as temperature increases
	Zirconium complex	
	Potassium metaborate	
	Sodium tetraborate (borax)	
	Boric acid salts	
	Boric acid	
	Oil distillate (hydrocarbon mixture)	A solvent for borate or zirconate crosslinking agent
	Methanol	Makes product stable and enhances frost resistance
	Ethylene glycol	
Regulation of surface tension	Lauryl sulphate	Used to regulate fluid viscosity
	Methanol	Makes product stable and enhances freeze resistance
	Ethanol	
	Isopropanol	
	2-Butoxyethanol	
	Naphtalene	A solvent for surfactants
Prevention of emulsion formation	Lauryl sulphate	Reduces formation of emulsion in fracturing fluid
	Isopropanol	Makes product stable and enhances freeze resistance
	Ethylene glycol	
pH adjusting	Sodium hydroxide	Adjusts acidity of a fluid and controls effectiveness of other additives
	Potassium hydroxide	
	Sodium carbonate	
	Potassium carbonate	
	Acetic acid	
	Hydrochloric acid	
Precipitation prevention	Acrylamide and sodium acrylate copolymer	Reduces precipitation in pipes
	Sodium polycarboxylate	
	Phosphonic acid salts	

Table 5. Chemicals contained in hydraulic fracturing fluids

Goal	Chemical	Function
Prevention of precipitation of metal oxides	Acetic acid	Reduces formation of metal oxides and their precipitation
	Citric acid	
	Thioglycollic acid	
Reduction of pipe corrosion	Formic acid	Reduces corrosion of pipes
	Acetaldehyde	
	Methanol	Makes product stable and enhances freeze resistance
	Isopropanol	
Clay stabilisation	Choline chloride	Reduces swelling and migration of clay minerals
	Tetramethyl ammonium chloride	
	Sodium chloride	
Initialisation of acid fracturing	Hydrochloric acid	Helps to break minerals and initiate cracks in the rocks
Biocidic action	Glutaraldehyde	Kills corrosion causing bacteria in water
	Quaternary ammonium salts	
	Phosphonic acid salts	
Breaking viscous fluid	Ammonium persulphate	Allows a breakdown of viscous fluid after fracturing
	Magnesium oxide	
	Magnesium peroxide	
	Sodium chloride	Makes product stable
	Sodium chloride	

found by isotope method to be of thermogenic origin. Numerous investigations have shown that unconfined water is contaminated most often due to accidents, violations of work technologies, old worn equipment and similar reasons. Therefore the role of strong and constant control is often stressed during the gas production. On the other hand, fluid leakages via tectonic cracks cause great danger, especially because of unpredicted character of this phenomenon. Therefore, for instance the UK environmental agency recommends refusing from using hydraulic fracturing technology in the sites near the operated or potential groundwater intakes.

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4. Potential impact of activities on groundwater

Shale oil and gas are extracted from mother rocks by horizontal wells, which can reach several kilometres in length; and even more horizontal well branches can be drilled from one vertical well. Main factors and aftermaths able to cause negative impact on fresh groundwater quality state during prospecting and potential production of unconventional hydrocarbons might be as follows:

- contamination of shallow (unconfined) aquifers with water used for splitting shale seams by hydraulic fracturing. In this case, the drilling fluid flown back to land surface should not be allowed to cross boundaries of the drill pad;

  contamination of confined (artesian) groundwater might take place in two cases: (1) by seepage of water from the contaminated shallow aquifer into the fresh water zone, and (2) as potentially contaminated shale fracturing backflow rises from deeper beds via tectonic fractures of the rocks;

- a risk of eruption of hydraulic fracturing fluid from the cracked bed into the fresh water aquifer through a potentially permeable space between the pipe wall and the rock.

Total thickness of the Silurian in the Western Lithuanian area (Šilutė–Tauragė shale prospecting site) is about 700 m; geologically it consists of impermeable rocks (regional aquitard). Shale gas **production** would cause a risk for groundwater, because the gas extraction technology is related to hydraulic fracturing of the bed. For this purpose a mixture of sand and chemicals is used. However, in case of **geological exploration**, the volumes of water, sand and chemicals will be significantly smaller than during the production, therefore the environmental risks would be also lower [1, 2]. After the hydraulic fracturing of shale bed, a certain portion of fluids remain in the rock cracks formed, but the rest flows up to the surface and is directed to special ponds or tanks. If such water gets into the environment, it can contaminate soil, surface water and unconfined aquifer. The flowback water with additives must be processed in soil and/or wastewater treatment plants. The recycled water is recommended to be used in the next hydraulic fracturing cycle [2].

While extracting shale gas, shallow aquifer water can be contaminated, this is the first aquifer from land surface to accept rainwater filtered through a soil and accumulating above an aquitard. Hydrochemical analyses of water taken from dug wells show that this aquifer is contaminated in many wells [3], because it is not protected from pollutants, or wells were dug in a wrong place or without meeting sanitary requirements. Shallow water quality in the Šilutė–Tauragė area is satisfactory or bad. This is a tendency of general pollution of water. Therefore, selecting the sites for shale gas exploration wells, one should search for areas, where till clay loam lies at the land surface.

Confined (artesian) groundwater is used for public supply of drinking water. The fresh confined water occurring in the artesian basins is accumulating in multi-layered geodynamical system separated from the below-lying aquifers by absolutely impermeable aquifuge, i.e. water content (discharge Q) is zero (Fig. 16). Having in mind that before the hydraulic fracturing the impermeable bed becomes permeable, and multiple fracturing cycles favours formation of big volumes of water, it is important that this water could not seep from the deep beds upwards, i.e. from a zone of slow exchange to that of fresh water.

In the southwestern part of Lithuania, vertical upward seepage of deep water takes place, as the piezometric level rising above the land surface shows during the hydraulic trial of wells. Deep groundwater in the Šilutė–Tauragė area is to seep from the shale bed upwards through 1.7–1.8 km thick rocks, where there are different aquitards: permeable, low permeable (aquiclude) or absolutely impermeable (aquifuge). Water seeping upwards should penetrate through absolutely impermeable 50-m thick Permian anhydrite seam and overlying it 150-m thick Triassic clay [5]. Therefore the fresh groundwater zone occurring above 1100 m depth level is re-

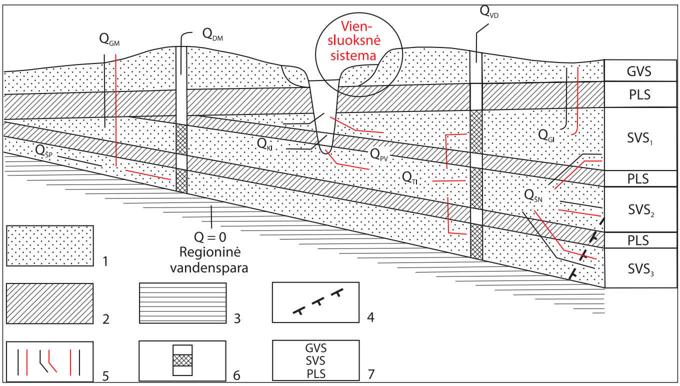

Fig. 16. Water seepage directions in multi-layered hydrogeodynamical system, under natural conditions and those disturbed by operation: 1 – water-bearing rocks, 2 – semi-permeable rocks, 3 – impermeable rocks; 4 – mineral water contour – a factor of possible worsening of fresh groundwater quality; 5 – drinking groundwater flow directions under natural (black arrows) and disturbed by operation (red arrows) conditions; 6 – well filtering part of a water intake (Q_{VD}) and artificial recharge plant (Q_{DM}); 7 – names of aquifers and semi-permeable beds: GVS – shallow unconfined aquifer, SVS – confined aquifer; PLS– semi-permeable beds; Q = 0 – regional aquifuge, absolutely impermeable [4]

liably protected from vertical seepage of water migrating from below. This area, however, has tectonic cracks at the depths from 2.2 to 1.1 kilometres. Drilling sites chosen for shale gas exploration should not be in the zones of potential tectonic faults [1, 2, 6]. If such faults exist, the safety of fresh groundwater would be doubtful. Therefore, during the geological prospecting of the whole area of Šilutės–Tauragė, it is necessary to perform investigations of helium content in groundwater; they would allow to decide, whether the deep water can penetrate to the zone of active exchange (aeration zone).

However, there are direct hydrogeological marks that some of these faults can be permeable for water (Fig. 17). This is indicated by hydrogeochemical anomalies forming mineral sources in the Lithuanian zone of fresh water. South-western Lithuania also might have such anomalous sites as the similarly formed hydrogeochemical anomalies long-time known on the left bank of the Nemunas River in Kaliningrad Region. Therefore, performing helium content investigations, chemical water composition should be determined, and new hydrogeochemical map compiled, because activities of tectonic faults are seen from water chemistry data. During the shale gas exploration the monitoring of methane content should be performed. Experience of the countries shows

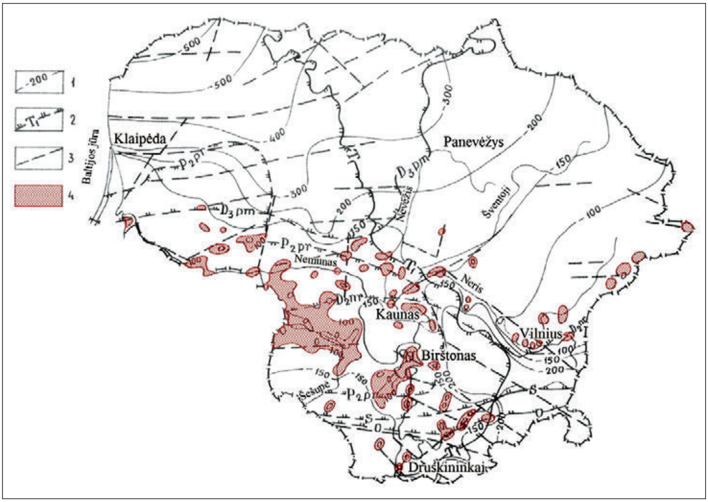

Fig. 17. A scheme of hydrochemical anomalies of groundwater in the area of Lithuania: 1 – water table depth isoline (absolute altitude) for groundwater containing chlorides above 350 mg/l (total dissolved solids 1 g/l); 2 – regional aquitard index and distribution boundary; 3 – regional tectonic fault line; 4 – sites of hydrogeochemical anomalies [7]

that, during shale gas production, methane contents can reach dangerous level of 60–65 mg/l or even higher.

One important function of a borehole casing is to separate its inner part from a rock, therefore the **room outside of a casing** is cemented, and the cement must air-tightly cohere with the casing wall and the rock. During the operation of a well, its state is regularly checked, and when cementing defects are detected, these places are cemented additionally. The environmental monitoring of oil production sites in Western Lithuania is being performed from 2001 [8], the environmental requirements are strictly observed; there are no cases of pollution of living areas [9]. The same approach should be used in shale gas prospecting and exploration developments.

Preparing a document of the environmental impact assessment in case of shale gas exploration, a monitoring of groundwater dynamics and hydrogeochemistry should be envisaged; it should cover three exchange (active, slower and slow) zones and all chemical and isotope ingredients as well as physical parameters.

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Impact of shale hydrocarbon production on human health

The impact of shale gas production on human health related to mechanical actions (drilling, transportation) is **noise**, **vibration** and **air pollution**. Another hazardous factor is **environmental pollution** related to substances extracted from underground during the gas production (the gas itself (methane, first of all), core content, deep groundwater), and to chemicals use on shale gas production. Direct impact of these factors can be determined by observing health of people living and working in that environment. Secondly, distant impact of chemicals and other substances is likely; its assessment needs long-term observation system (e.g., 5–10 years each).

Potential sources of noise and vibration are:

- noise produced by drilling equipment, ground and metal friction, as well as auxiliary mechanisms;
- noise generated by electric motors, reducers, pumps and gas flaring;
- traffic noise;
- ground vibration on land surface during a drilling activities;
- noise and vibration caused by hydraulic fracturing.

Drilling works in one pad last up to 6 months. At the beginning of this activity, it is necessary to determine the background level of noise in the site. During drilling process, noise monitoring must be carried on in the drilling pads at living houses during the day, evening and night, as well as to define sanitary protection zones.

Potential air pollution sources are:

- emissions (particulates) from trucks and drilling equipment: sulphur dioxide (SO_2), nitrogen oxide (NO_x), non-methane volatile organic compounds (NMVOC) and carbon monoxides (CO);
- emissions from natural gas processing and transportation (particulates, SO_2, NO_x, NMVOC and CO);
- evaporative emissions of chemicals from drilling well waste water ponds;

- emissions due to spills and well blow outs (spread drilling or fracturing fluids combined with particulates from the deposit);
- methane gas leakage in the production site, ozone.

Table 6. Typical specific emissions of air pollutants from stationary diesel engines used for drilling [1]

Pollutants	Emissions per engine mechanical output (g/kWh$_{MECH}$)	Emissions per engine fuel input (g/kWh$_{diesel}$)	Emissions per natural gas throughput of well (g/kWh$_{GD}$)
Sulphur dioxide	0.767	0.253	0.004
Nitrogen oxide	10.568	3.487	0.059
Particulates	0.881	0.291	0.005
Carbon monoxide	2.290	0.756	0.013
NMVOC	0.033	0.011	0.0

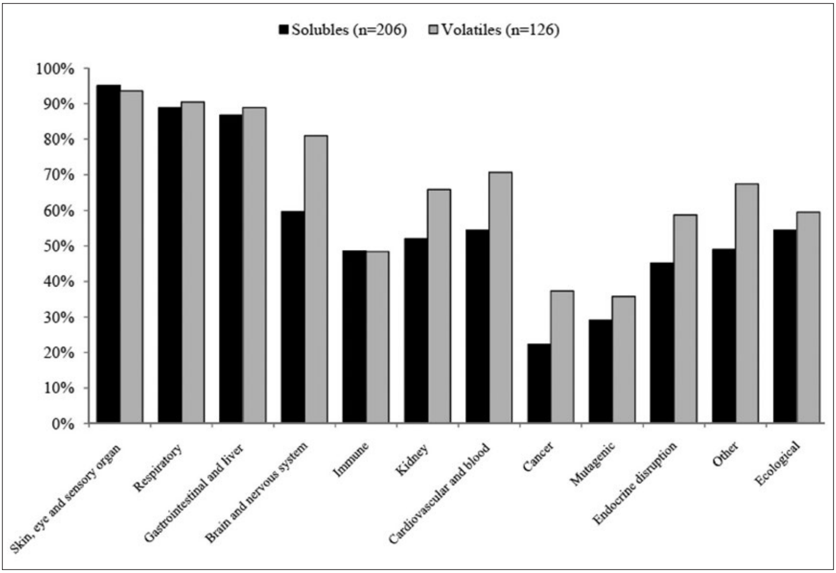

Fig. 18. Frequency of health impact of chemicals marked by CAS identification numbers and used in natural gas production [2]. [Orig.: Profile of possible health effects of soluble and volatile chemicals with CAS numbers used in natural gas operations]

Environment air pollutants, risk of their emissions and quantities should be assessed for each drilling pad during hydrocarbon production and pad operation. As of May, 2010 TEDX identified about 950 products used in the USA in gas production, including 353 chemicals marked by so-called CAS (*Chemical Abstract Service*) numbers. About 37 percent of them are volatile substances, which can spread in the atmospheric air. More than 89 percent of the chemicals could affect the eyes, skin, sensory organs, respiratory and gastrointestinal systems, 70 percent could affect cardiovascular system and blood formation, 81 percent – brain and nervous system, and 66 percent – kidney (Fig. 18). Part of them can enter a body by swallowing and through skin.

Conclusions of an investigation done in 2009 also 'confirmed the presence in high concentrations of carcinogenic and neurotoxin compounds in ambient air near and/or on residential properties'. The emissions of aromatic compounds, such as benzene and xylene, determined in Texas most often take place from pressing and processing natural gas, where heavier components are released into the ambient air. Emissions of these compounds in the European Union are limited by legal acts [1]. Highly reactive ozone molecules can penetrate into deeper tissues of lung alveoli and cause premature aging of the lungs. Its persistent impact can stimulate asthma and formation of chronic obstructive pulmonary disease. Ozone linked with smaller than 2.5-micron solid particles can form certain smog that damages respiratory organs [3]. Such smog can spread to a distance even of 200 miles from the pollution site [4].

The US organisation TEDX (*The Endocrine Disruption Exchange, Inc.*) investigates small amounts of chemicals, called endocrine disruptors, present in human environment and causing developmental and functional disorders. It states that endocrine disruptors affect directly endocrine glands, the hormones released by them and hormone receptors, as well as transfer of humoral signals, and, thus, they can affect adversely various reproductive functions, foetal development, nerve system, immune system, metabolism, bone, as well as other organs and tissues [3]. The latest data confirm that endocrine disruptors can affect gene-controlled signals determining every aspect of embryonic and foetal development. Disorders that have increased in prevalence in recent years such as abnormal male gonadal development, infertility, ADHD, autism, diabetes, thyroid disorders, and childhood and adult cancers are now being linked to foetal exposure.

Thus, it should not be denied the potential of impact of chemicals used in production on human health, especially at a long-term exposure. The products, which can harm health of people, should be banned in the shale gas production. Therefore, all the trade names of products used in gas production and their chemical composition must be publicly announced. Every operation performed during the drilling and production must be registered, as well as the amounts and concentrations of all fluids used should be known. Monitoring of chemical pollutants and ozone in the ambient air should be a standard procedure in any part of the shale gas production with their background concentrations in the region determined beforehand. The water condition and epidemiological monitoring programs validated by legal health and hygiene acts should be strictly observed; they should contain a system of regular monitoring of air and water and health surveillance of population and employees.

Theoretically, human health can be harmed also by **Naturally Occurring Radioactive Materials** (NORM), i.e., uranium, thorium and radium. They are detectable in any geological formation, but their amounts are low: for instance, uranium in the shale is assessed to be at 0.0003–0.0004 percent, equivalent to its content in granite [1]. During the hydraulic fracturing, together with fluids these materials can reach land surface and form a waste enriched with vanadium, uranium, thorium, radon of natural gas and radon with its decay elements of lead, bismuth and polonium. They can precipitate as a film on inner walls of pipes, processing blocks, pumps and valves, mainly related to propylene, ethane and propane processing flows and surfaces, as well as in the products of technical fluid treatment.

The threats caused by radioactive and other hazardous materials extracted from shale beds can be determined only by analyses of the core lifted and liquid extracted as well as gas emitted. The experience gained in oil production show that these emitted substances are not hazardous, although not all analyses (composition of gases emitted) are carried on. The NORM substances during the shale gas exploration and production are concentrated as they flow with flowback through pipes, storages and filters. This can influence environment pollution and irradiation of people (personnel or local population) when dealing with wastes. Radiation risk is possible also during technical incidents or accidents. In Lithuania, the assessment of radiation safety in the oil production and gas transportation and storage enterprises showed that concentration of NORM substances is very low; they are not detected in the pipes, flowback filters and storage environment.

With the start of shale gas exploration (and production), it is necessary to determine contents of natural radioactive materials in the rocks lifted during the drilling, in order to prevent environment pollution and irradiation of the personnel and the local population; to assess conditions of storage of flowback in open reservoirs due to potential concentration of NORM in the environment of these reservoirs and emission of radon into the ambient air; to envisage measures for would-be radiation safety and radiological monitoring.

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Economic assessment of shale hydrocarbon resources

Conventional gas resources in the world are very large, and their proved geological reserves would satisfy the demand for at least 100 years under a present level of consumption. The share of natural gas in the world primary energy balance grew from 17 percent in 1970 to 25 percent in 2013 m. [1] (Fig. 19), and total consumption grew from 644 billion m^3 (644×10^9) 1965 m. to 3190 billion m^3 2010 m. [1, 2].

The role of natural gas in world energy is growing because of the fact that burning natural gas produces half as much carbon dioxide if compared to the burning coal that is an important source of electric energy. This is one of the cheapest ways to reduce carbon dioxide emissions. In Lithuania, natural gas in primary energy structure made 33.5 percent in 2011, when 3.4 billion m^3 of natural gas had been consumed [3].

Production of unconventional (shale) gas technologically is significantly more complicated and more expensive. Main factor that forced US power companies to invest into its production technologies was the growth of gas market price in the world up to 2010, as gas consumption in the USA was also rapidly growing (Fig. 20). Having in mind that over 70 percent of proved natural gas reserves are concentrated in Russia, Iran and Persian Gulf regions, while the US geopolitical situation was becoming rather dangerous. Therefore, oil and gas production and technology development companies in the USA had to take their interest into national geological reserves and invest into long-time known unconventional sources. Their efforts were successful and the results exceeded all expectations. Gas production from unconventional geological structures (shale) was rapidly growing, and at the same time gas prices in the market rapidly falling. In several years, the natural gas price in the US wholesale (Henry Hub) market dropped more than three times [4] (Fig. 20) and, contrary to forecasts remains stable low ~$2.5–3 per MBtu[1], i.e., $95–115 per thousand m^3. Such low price in the USA motivates countries in other regions to search for ways how to start using their own shale gas reserves.

Thus, the circumstances in the USA caused rapid and economically viable production of shale gas. In other countries, due to weakly developed infrastructures, production costs would be considerably higher. With market prices growing or remaining stable high, the production from conventional deposits is to be developed, because

1 1 thousand$m^3 \cong 37.9$ MBtu; 1 MBtu $\cong 2.638 \times 10^{-2}$ thousand m^3.

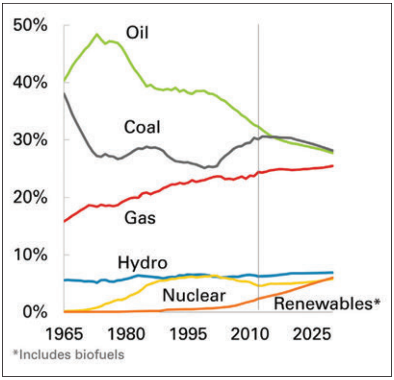

Fig. 19. World primary energy, percentages

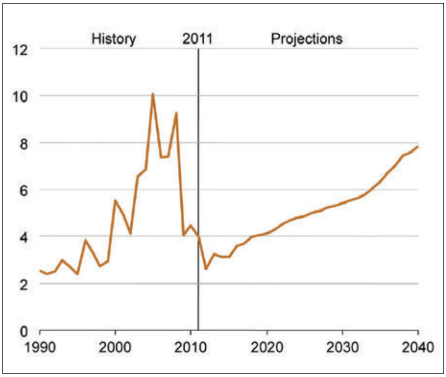

Fig. 20. Average annual Henry Hub natural gas price, US dollars per million Btu

lower production costs would remain there for a long time. Economic factors seem to hinder shale gas production beyond the USA. In Europe, this process is being blocked by different attitude to the environment protection. However, factors of political and energetic security will open the way for more intensive processes in EU space as well.

In Lithuania, natural gas consumption is expected to decrease in the future, if its use for power generation will not grow, or if its price will not fall significantly in the regional market. It is believed that, for many years, natural gas consumption in Lithuania would not exceed 3 billion m^3/year. The information given in the present study about potential technically recoverable resources of shale gas embrace maximum, moderate and minimum assessments (within a range of 14×10^9–741×10^9 m^3; Table 7). A very approximate evaluation of economic potential of shale gas in Lithuania, the following presumptions are made:

- gas production cost price is to be close to \$300 per thousand m^3 (\$8 per Btu); this corresponds to evaluations given in literature [5–8] ;
- natural gas price in EU general gas market after 2020 is to be close to \$500 per thousand m^3 (\$13.2 per MBtu);
- gas producing company is to pay royalty into Lithuanian budget as 25 percent from sold gas value.

Table 7. Shale gas market value in Lithuania and expected budget incomes from royalties on natural resources in US dollars

	Gas volume produce		
	Low 14×10^9 m³	Medium 350×10^9 m³	High 740×10^9 m³
Value of all gas volume at market price of $500 per thousand m³	7.0×10^9	175×10^9	370×10^9
Production price $300 per thousand m³	4.2×10^9	105×10^9	185×10^9
Budget incomes 25 percent from sold gas value	1.75×10^9	43.7×10^9	92.5×10^9

Taking into account the above-mentioned presumptions that the 3.0×10^9 m³ annual demand of Lithuania will be satisfied by local shale gas, and that gas production company is to pay Lithuania 25 percent royalty from the gas sold, the state treasury would get annually:

$3.0 \times 10^9 \text{ m}^3 \times \$500/\text{thousand m}^3 \times 0.25 = \$0.375 \times 10^9$.

The profit of the gas production company is obtained by subtraction of production costs and royalty for resources from the incomes:

$3.0 \times 10^9 \text{ m}^3 \times (\$500–\$300)/\text{thousand m}^3 – \$0.375 \times 10^9 = \$0.225 \times 10^9$.

Thus, the profit of the company is obtained nearly 1.7 times lower than the royalties into the state treasury. Therefore, nobody should expect that large international companies would like to extract gas in Lithuania, if the royalty for resources is more than 25 percent. In case of 40 percent the annual royalties would make:

$3.0 \times 10^9 \text{ m}^3 \times \$500/\text{thousand m}^3 \times 0.4 = \$0.60 \times 10^9$,

and the profit of the gas producing company would be:

$3.0 \times 10^9 \text{ m}^3 \times (\$500–\$300)/\text{thousand m}^3 – \$0.60 \times 10^9 = 0$.

The situation could change, if the market price grows and production costs decrease. Generally, it could be said that the royalty of 40 percent as proposed by the Seimas (Lithuanian parliament) would block not only shale gas production in Lithuania, but also even its exploration.

The present chapter presents analysis based on prognostic (imprecise) preliminary about volumes of shale gas reserves, production costs and future price of gas in the European market. The results presented can be applied only to approximate assessments of what could be expected from shale gas production in Lithuania.

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Problems and solutions: Lithuanian case

The relations of business dealing with shale hydrocarbon prospecting and production to general public are insufficiently developed. This branch of industry in Lithuania is at the very start of its development, and the information reaching the public is very different and often contradictory. Currently, both in Lithuania and all European Union, many misleading statements are circulating about production of natural gas, especially in relation to hydraulic fracturing of rocks and use of water with other chemicals in it. These false opinions can be denied by educating people on all actual subjects. The representatives of shale hydrocarbon business, governmental institutions (Ministry of Environment, Ministry of Energy, Ministry of Education and Science and their subordinate organisations) as well as science community should actively participate in this educational work.

Activities of representatives of shale hydrocarbon production business must be transparent; they must present information available to the public about the course of works. The companies on their websites must announce not only works done and water, air and soil monitoring data, but also the benefit obtained from shale hydrocarbon extraction, i.e., financial deductions into state budget, social insurance fund SODRA, support funds etc. Representatives of businesses for public relations must provide explanations to the people about the benefits of natural gas production and potential environmental problems.

Lithuanian Government and Parliament Seimas should improve legal acts, including those regulating financial deductions into the state and municipal budgets from the use of natural resources. The government should establish institutions for control and supervision of hydrocarbon production works with authorisation to interrupt these works, if necessary. Ministry o Education and Science should add chapters on useful minerals in Lithuania and their production methods into the geography manuals for secondary schools.

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