SEA BOTTOM (GEOPHYSICAL AND GEOTECHNICAL) SURVEYS IN THE LITHUANIAN MARINE AREA WHERE IT IS REASONABLE TO ORGANISE TENDERS FOR THE DEVELOPMENT AND EXPLOITATION OF THE WIND POWER PLANTS

Part I

GEOPHYSICAL DEEP SEISMIC SURVEY

2022-11-03

Funded by the European Union
NextGenerationEU

NEW GENERATION LITHUANIA

Client	Ministry of Energy of the Republic of Lithuania, Gedimino pr. 38, Vilnius, el. p. info@enmin.lt, tel. +37070664715
Supplier	Acting on behalf of joint venture agreement between: JSC „Garant Diving“ (Responsible partner) and JSC „Geobaltic“ (Partner)
Responsible executor	JSC „Geobaltic “, Miglos g. 5-13, Vilnius, el. p. info@geobaltic.lt, tel. +37069954953

Table of contents

I. Methods and equipment

I. 1. Survey task

According to the undersigned agreement (hereafter – Agreement) with Ministry of Energy of the Republic of Lithuania (No. 8-34; dated 2022-04-26), it is obliged to carry out the sea bottom (geophysical and geotechnical) surveys in the Lithuanian marine area where it is reasonable to organize tenders for the development and exploitation of the wind power plants (hereafter - WPP). This report presents Part I of the survey, which includes deep seismic surveys. The main research objectives are as follows:

- location of potentially active seismic zones (geologically young tectonic faults crossing the entire sedimentary cover) and, possibly, elimination from potential WPP installation (development) areas.
- identification of geological structures suitable for oil accumulation (potential oil structures) and clarify their spatial position/distribution in relation to the planned WPP location. During the research it is necessary to determine the exact position, area and volume of the potential structures, to assess whether the planned development of WPP does not overlap with prospects and, possibly, exploitation of oil resources in the Lithuanian marine areas.

I.2. Survey vessels

SITULA	
• Type: Vienkorpusinis • Registration (IMO) number: 9246188 • Flag: Panama • Built: 2001 • Length: 38,08 m. • Breadth: 9,5 m. • Draught: 3,43 m. • Gross tonnage: 466 tons • DGPS: RTK DGPS Spectra Geospatial SP90m	

I. 3. Survey method and equipment

Marine seismic multi-channel survey.

While sailing along predetermined profiles, a seismic source (array of 4 air guns) generates a seismic pulse that travels through the water and the deeper geological medium and is reflected from geological boundaries characterized by a high contrast in physical properties (density and seismic wave propagation speed) between of the rocks above and below. The reflected signal travels back and is recorded in seismic receivers (hydrophones) installed in the ship's towed seismic streamer

Equipment	**Parameters and characteristics**
Source –air guns array, Seamap Sleeve Gun (Seamap, USA)	Penetration: up to 2000 m into the ground. Source grouping: 4 air guns of 0.65 l (40 cu.in). Distance between shot points: 25 m
Data registration: multi-channel GeoEel (Geometrics, USA) seismic streamer	Number of active channels: 96. Distance between registration channels: 12.5 m. Data sampling interval: 0.25 ms. Number of hydrophones in 1 channel: 12. Active line length: 1200 m. Seismic record length: 2s. Data registration format: SEG-D
Positioning: Vessel positioning Septentrio RTK DGPS AsteRx-U MARINE Fg	The coordinates of the shots and registration points were assigned by knowing the exact coordinates of the GPS receiver on the ship and adding the known distance from the ship's GPS to the excitation electrodes and each receiver channel.

I. 4. Scope of the survey

According to the requirements of the technical specification, deep seismic surveys were performed in 23 parallel profiles (D01-D23) located at 1 km distance from each other and in 2 submeridian profiles (M02-M03). Additionally, the profile M01 was added to the data set, where testing was performed in order to select the most suitable research parameters. The position of the profiles is given in Fig. 1, and the coordinates of start and end of the seismic profiles as well as the length are given in Table 1.

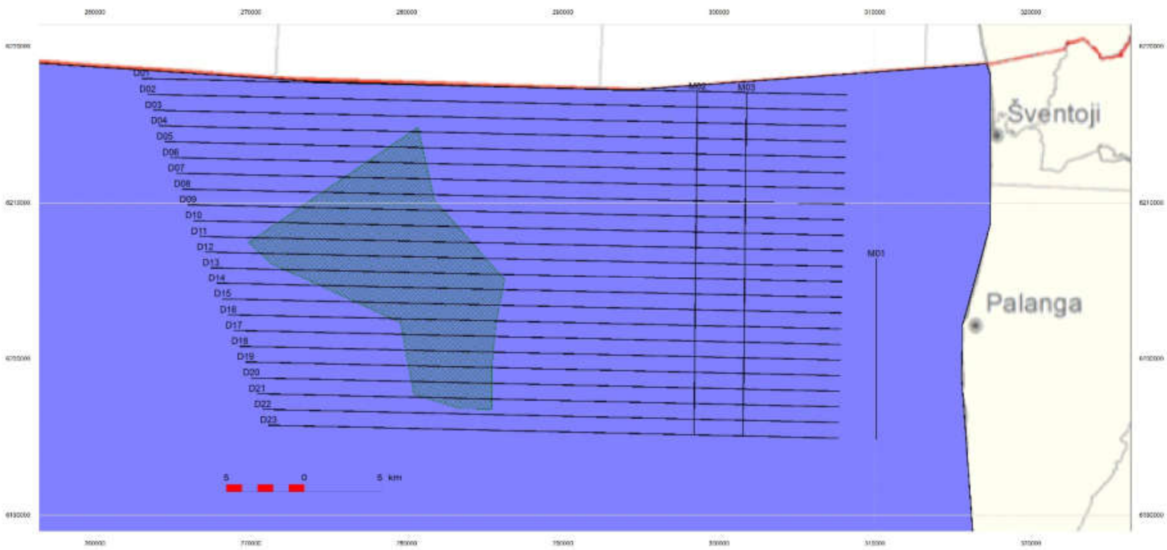


Figure 1 Position of deep seismic profiles

Table 1. Lengths of seismic profiles, start and end coordinates in LKS-94 projection

ID	Length, km	X1	Y1	X2	Y2
D01	45,213	262993.7	6217949.7	308194.8	6216914.8
D02	44,818	263363.4	6216940.5	308169.9	6215914.9
D03	44,424	263733.0	6215931.2	308144.9	6214915.0
D04	44,029	264102.6	6214922.0	308120.0	6213915.0
D05	43,634	264472.3	6213912.8	308095.0	6212915.1
D06	43,239	264841.9	6212903.6	308070.1	6211915.1
D07	42,845	265211.5	6211894.5	308045.1	6210915.2
D08	42,450	265581.1	6210885.3	308020.2	6209915.2
D09	42,055	265950.7	6209876.1	307995.2	6208915.3
D10	41,661	266320.4	6208866.9	307970.3	6207915.3
D11	41,266	266690.0	6207857.7	307945.3	6206915.4
D12	40,871	267059.6	6206848.6	307920.4	6205915.5
D13	40,477	267429.2	6205839.4	307895.4	6204915.5
D14	40,082	267798.8	6204830.2	307870.5	6203915.6
D15	39,687	268168.4	6203821.1	307845.5	6202915.6
D16	39,293	268538.0	6202811.9	307820.6	6201915.7
D17	38,898	268907.6	6201802.8	307795.6	6200915.7
D18	38,503	269277.2	6200793.6	307770.7	6199915.8
D19	38,109	269646.8	6199784.5	307745.7	6198915.8
D20	37,714	270016.4	6198775.3	307720.8	6197915.9
D21	37,319	270386.0	6197766.2	307695.8	6196915.9
D22	36,925	270755.6	6196757.1	307670.9	6195916.0
D23	36,521	271125.2	6195747.9	307646.0	6195916.0
M01	12,032	310060.1	6206427.2	310000.3	6194395.4
M02	22,006	298618.1	6217133.9	298405.5	6195129.4
M03	22,013	301760.8	6217061.0	301548.3	6195049.5
Total, km:	**996,085**				

II. Data processing

II.1. Dataset and key parameters

Acquired seismic data was processed in the JSC Geobaltic processing center. The total dataset for processing consisted of 26 seismic profiles with a total length of 996 km. Profiles D13 and D23 were registered in 2 attempts, so they consist of 2 segments: D13_1 and D13_2, and D23_1 and D23_2

The main seismic parameters of the processed profiles are as follows:

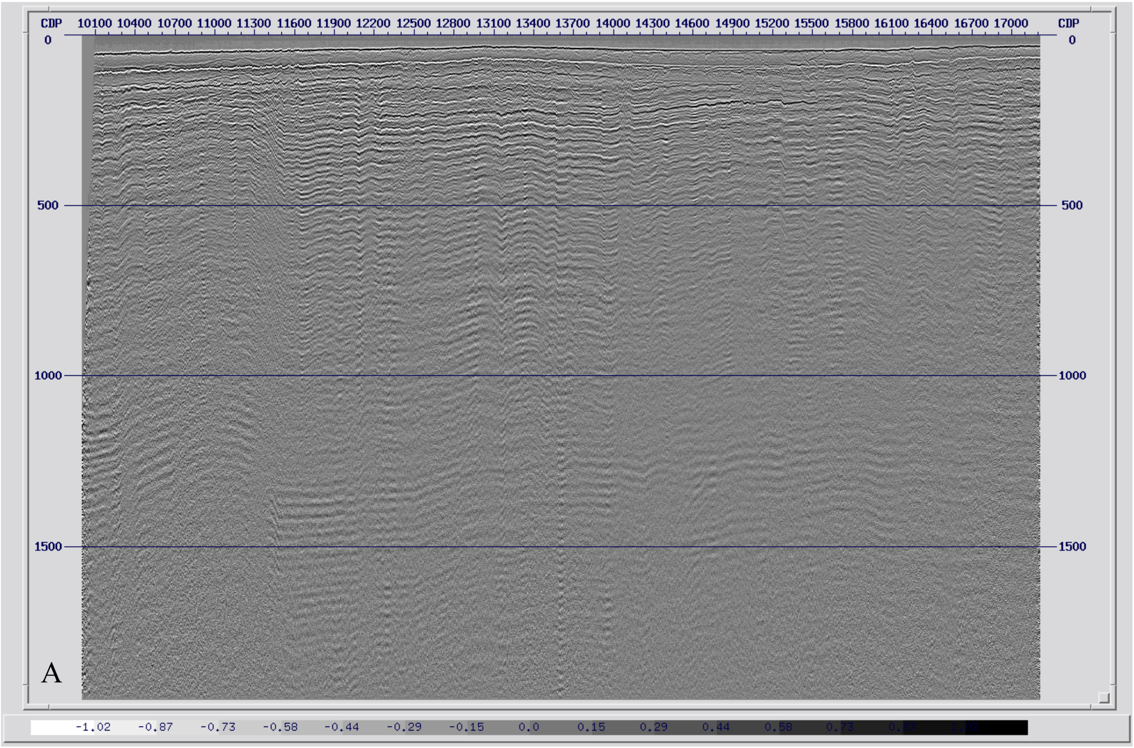
Record length	2 s,
Sampling interval	0.25 ms,
Survey geometry	Single ended spread
Distance between receivers	12.5 m,
Distance between shots	25 m,
Source	Array of 4 Air Guns
Number of active channels	96

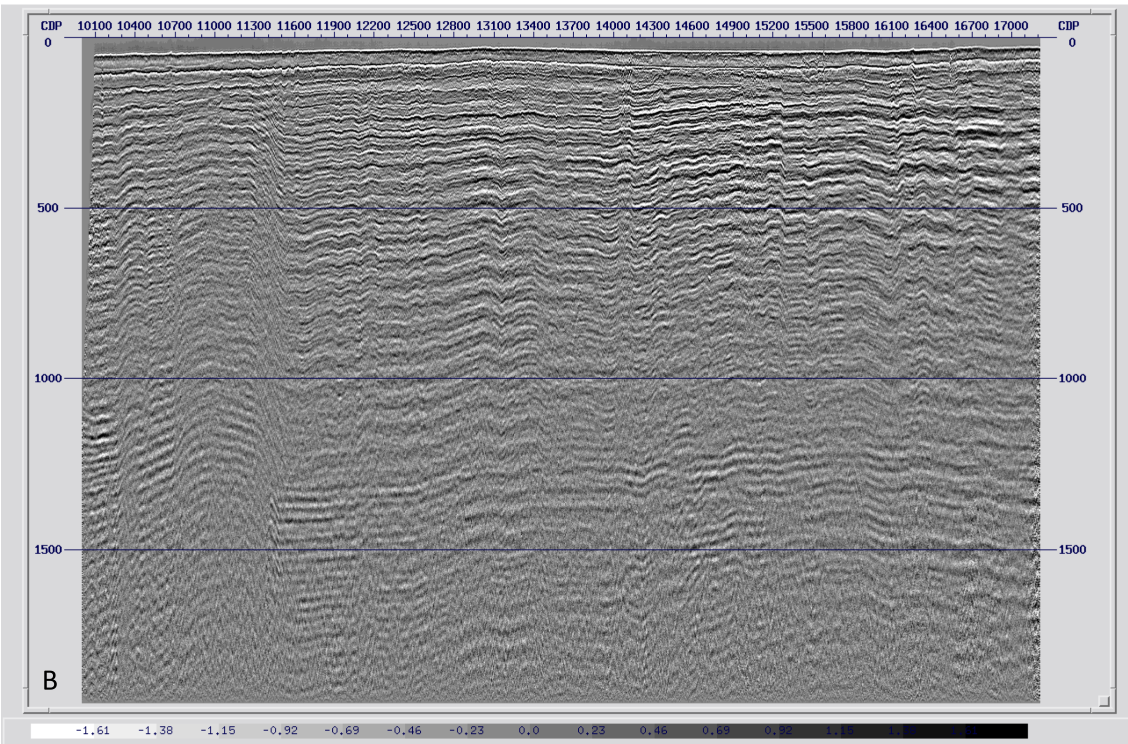
II.2. Data processing sequence

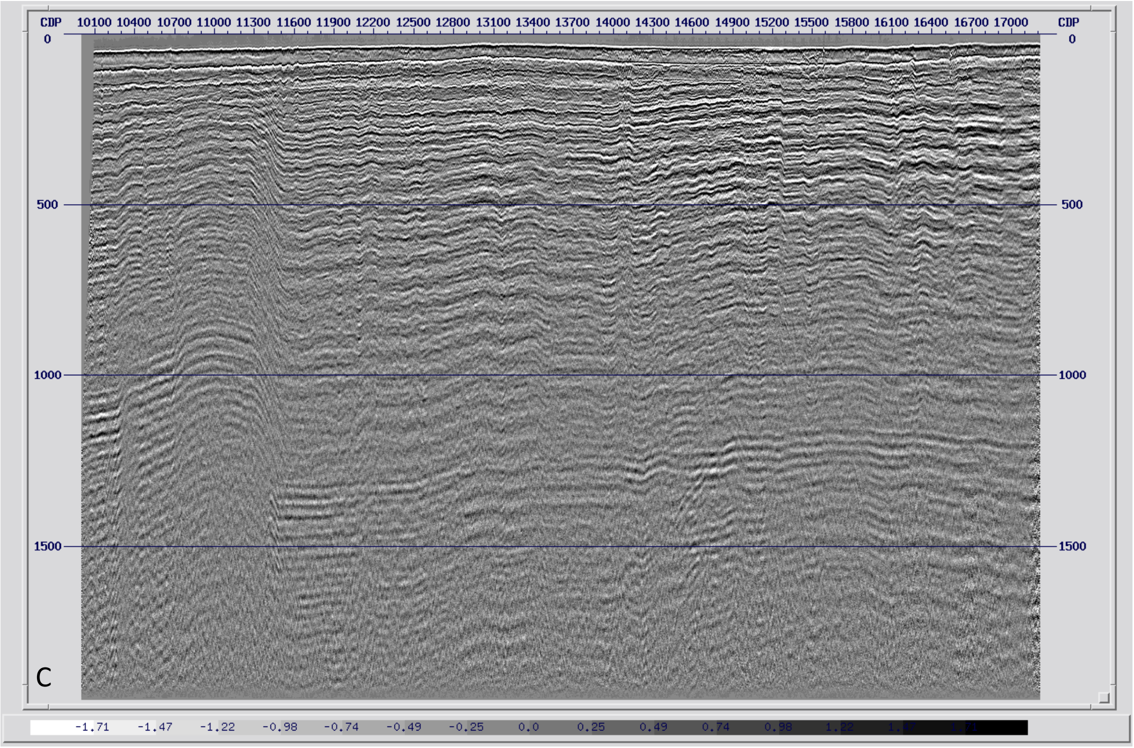
Data was processed using Globe Claritas software. After the test processing, the following sequence of processing algorithms was selected:

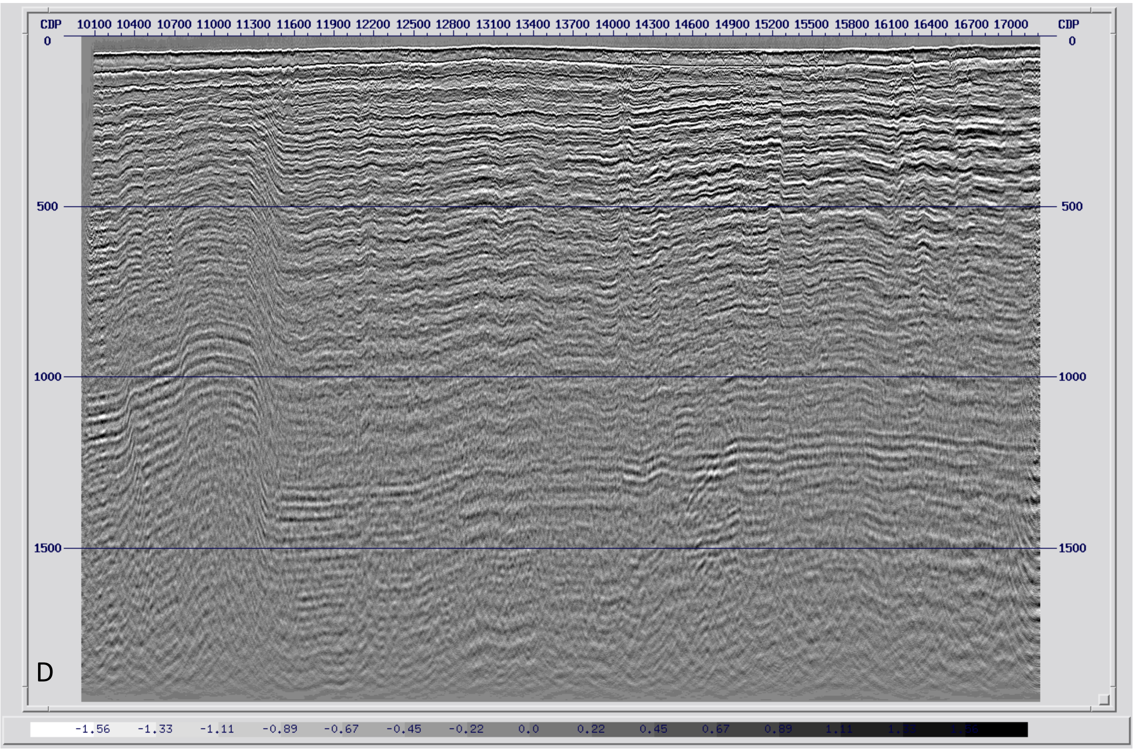
1. Reformatting SEG-D to internal format
2. Geometry assignment
3. Trace editing
4. Raw stack CDP (common depth point).
5. Amplitude corrections
6. Damping of surface waves
7. Suppression of linear coherent noises
8. Deconvolution and bandpass filter
9. Velocity analysis
10. Muting of far-offset channels
11. Stack of CDP after velocity analysis
12. Suppression of residual coherent and random noises
13. Final stack of CDP
14. Migration
15. Migrated stack of CDP
16. Post-processing: deconvolution, band-pass filter, suppression of random noises (FX decon)
17. Export to SEG-Y

The illustrations below show the progress of the data processing in different stages of processing sequence (Fig. 2).


CDP
10100 10400 10700 11000 11300 11600 11900 12200 12500 12800 13100 13400 13700 14000 14300 14600 14900 15200 15500 15800 16100 16400 16700 17000
0
500
1000
1500
A
-1.02 -0.87 -0.73 -0.58 -0.44 -0.29 -0.15 0.0 0.15 0.29 0.44 0.58


CDP
10100 10400 10700 11000 11300 11600 11900 12200 12500 12800 13100 13400 13700 14000 14300 14600 14900 15200 15500 15800 16100 16400 16700 17000
0
500
1000
1500
B
-1.61 -1.38 -1.15 -0.92 -0.69 -0.46 -0.23 0.0 0.23 0.46 0.69 0.92


CDP
10100 10400 10700 11000 11300 11600 11900 12200 12500 12800 13100 13400 13700 14000 14300 14600 14900 15200 15500 15800 16100 16400 16700 17000
0
500
1000
1500
C
-1.71 -1.47 -1.22 -0.98 -0.74 -0.49 -0.25 0.0 0.25 0.49 0.74 0.98


CDP
10100 10400 10700 11000 11300 11600 11900 12200 12500 12800 13100 13400 13700 14000 14300 14600 14900 15200 15500 15800 16100 16400 16700 17000
0
500
1000
1500
D
-1.56 -1.33 -1.11 -0.89 -0.67 -0.45 -0.22 0.0 0.22 0.45 0.67 0.89

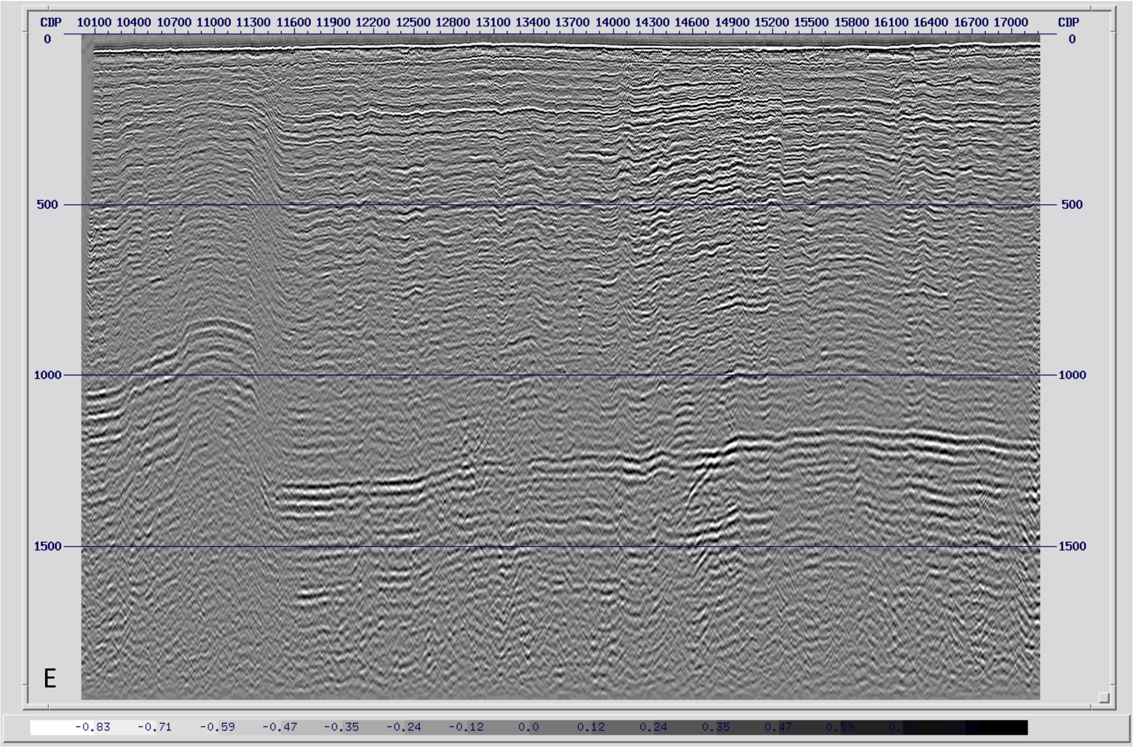


Figure 2 D03 stack at different processing stages: raw field data (A), after denoising and deconvolution (B), after velocity analysis (C), after migration (D), after post-processing (E)

II. 3. Presentation of processed digital data

Processed seismic sections are provided to the customer in digital form in SEG-Y (IBM Float 4 byte) format.

CDP trace information for data import in SEG-Y files is provided in the following bytes:

CDP no:	1 byte
X coordinate:	181 bytes
Y coordinate:	185 bytes

III. Data interpretation

III. 1. Seismic horizons identification and tracing

During data interpretation 3 seismic horizons were well observed in the seismic sections and were successfully interpreted in the entire dataset. Since no new deep well has been drilled in the research area, the Girkaliai-1 (GRK1) borehole located closest to the research area on land was used to identify the seismic horizons. Identification of seismic horizons was performed using time-depth relationship obtained from GRK1 vertical seismic profiling (VSP) survey data. Figure 3 shows projection of the GRK1 borehole on a nearest fragment of seismic section M01, where the picked seismic horizons are identified as follows:

P (yellow) – top Permian seismic horizon
D3 (purple) - top Devonian seismic horizon
O3 (green) – top Ordovician seismic horizon

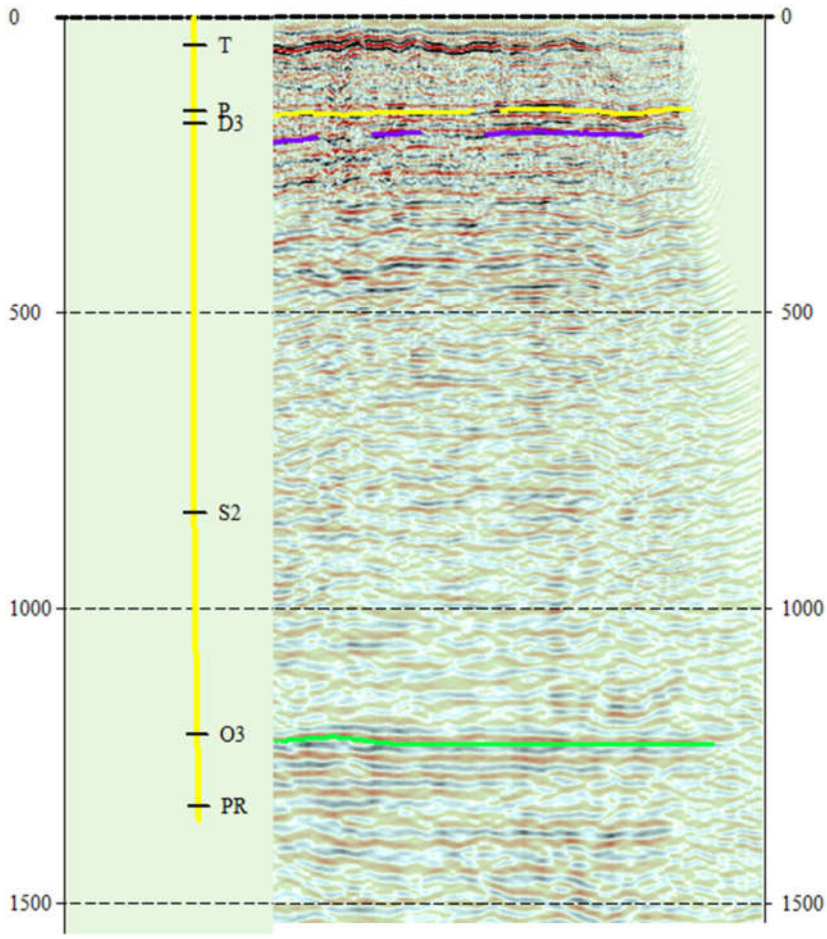


Figure 3 Projection of the Girkaliai-1 well (based on VSP data) on the fragment of seismic section M01 and identified seismic horizons (top Permian -yellow, top Devonian – purple, top Ordovician – green)

The interpretation of the mentioned seismic horizons in representative seismic profiles (D03, D11, D20 and M03) is presented in Fig. 4-7.

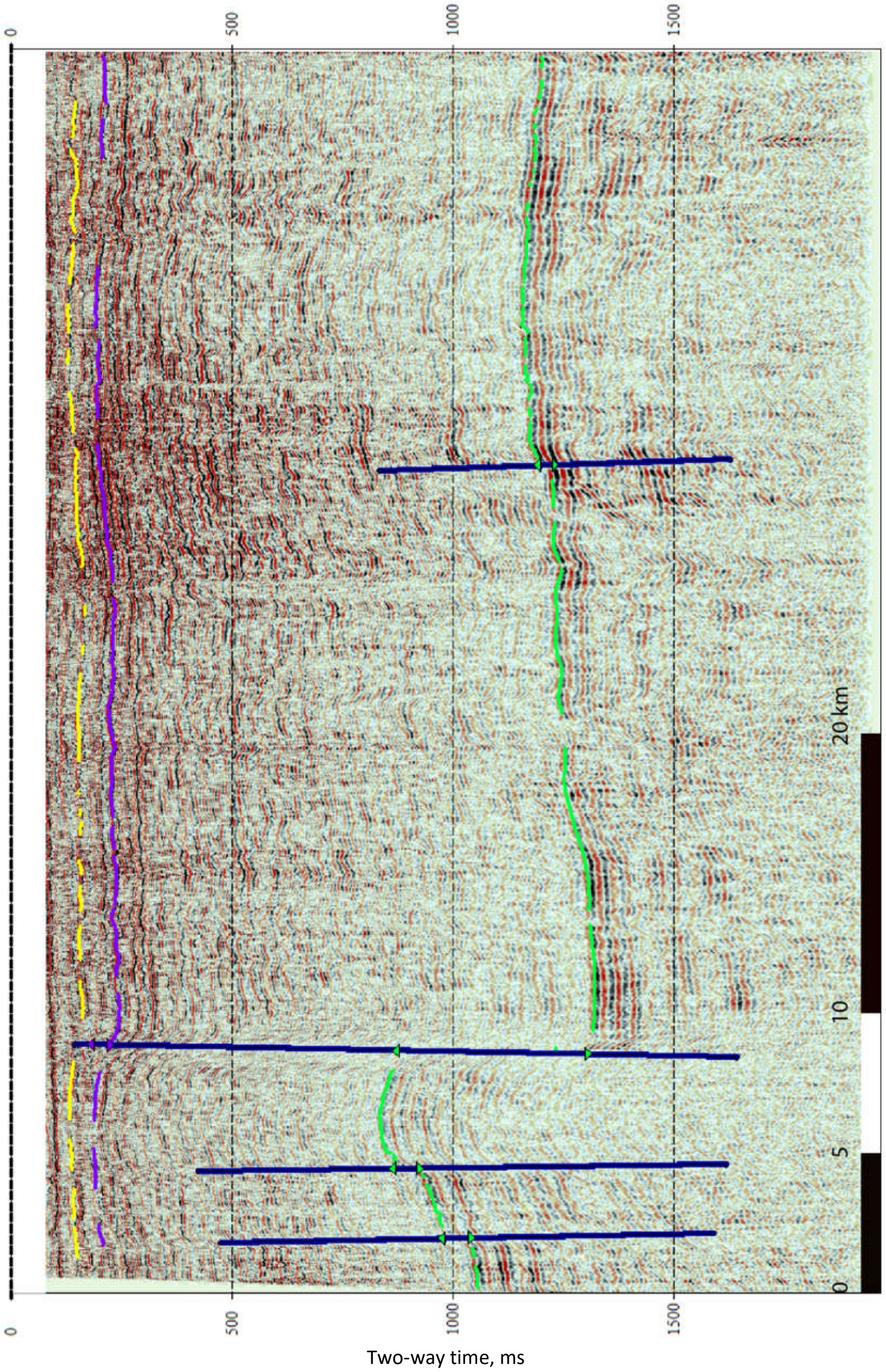


Figure 4 Interpretation of seismic section D03 (Permian ridge-yellow, Devonian – purple, Ordovician – green, tectonic faults – dark blue)

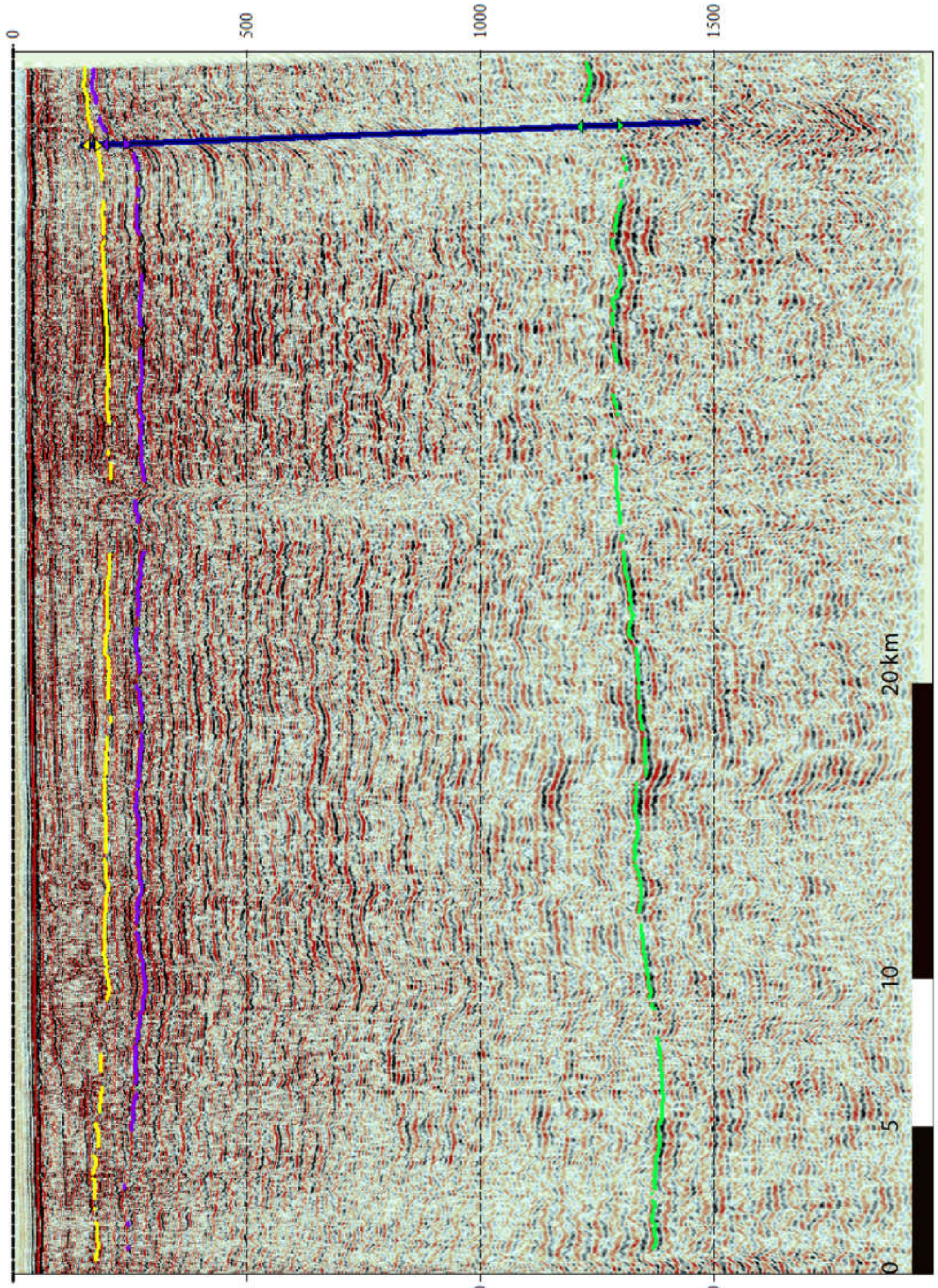


Figure 5 Interpretation of seismic section D11 (Permian ridge - yellow, Devonian - purple, Ordovician - green, tectonic faults - dark blue)

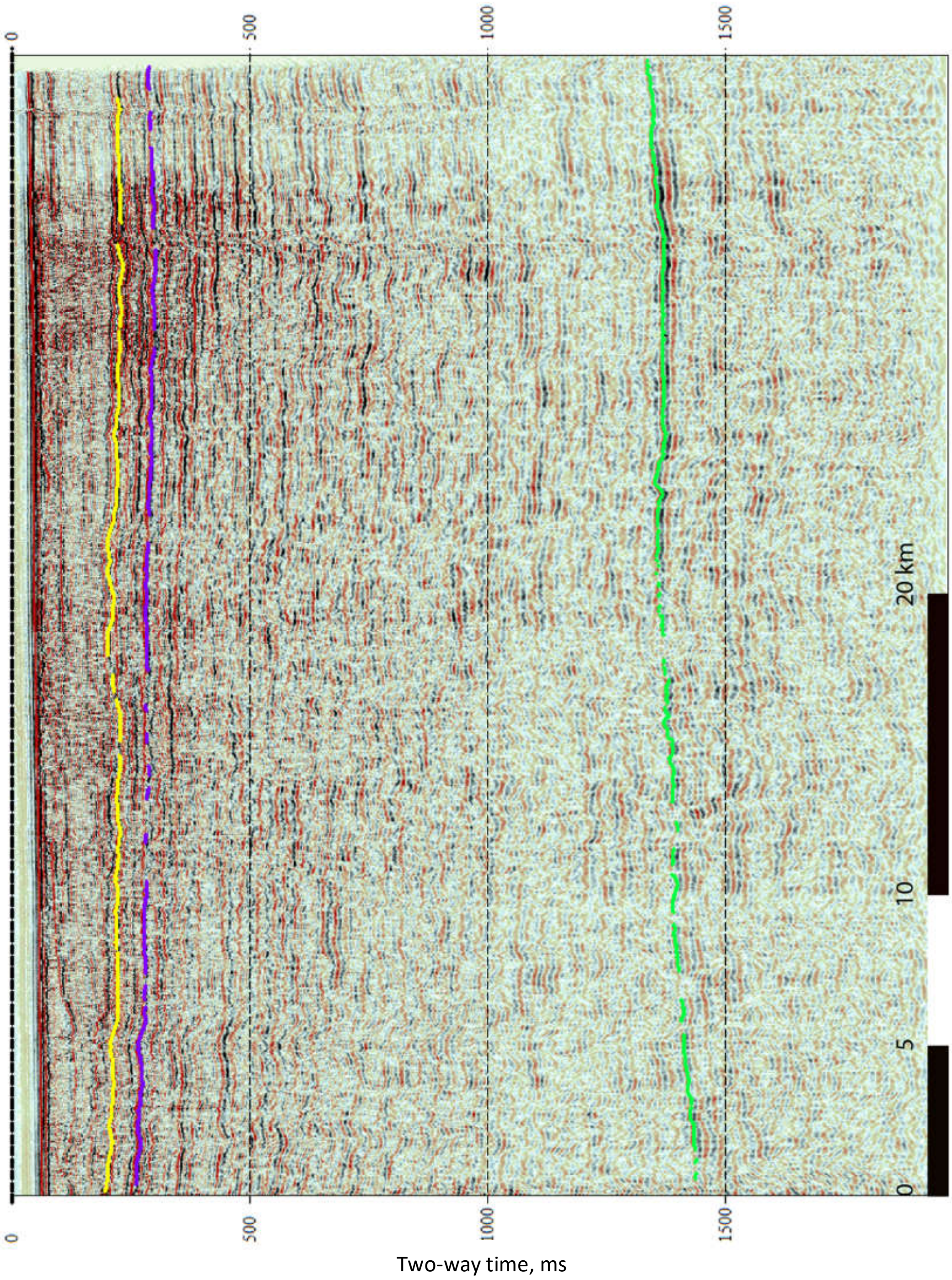


Figure 6 Interpretation of the D20 seismic section (Permian ridge-yellow, Devonian - purple, Ordovician - green, tectonic faults - dark blue)

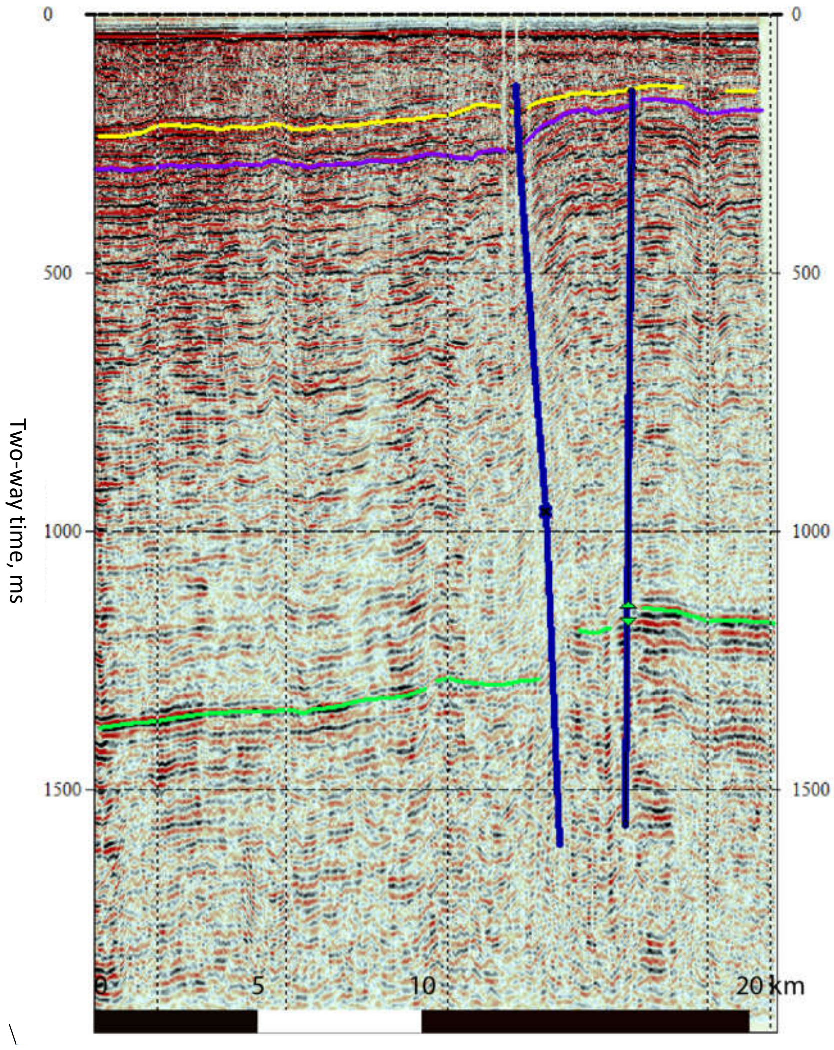


Figure 7 Interpretation of seismic section M03 (Permian ridge - yellow, Devonian - purple, Ordovician - green, tectonic faults - dark blue)

III. 2. Structural depth maps

Structural time maps were made for the seismic horizons P, D3 and O3. The average velocity method was used to convert maps to depth scale. Since there are no deep boreholes in the study area, the average seismic velocities of the closest to the study area borehole GRK1 were used: top Permian and Devonian depth maps were depth converted using 2000 m/s, Ordovician – applying 3000 m/s average velocities.

Permian, Devonian, and Ordovician structural depth maps were obtained by multiplying the seismic time maps by the corresponding mean velocity. The resulting structural depth maps are presented in Fig. 8-10. The reference for structural depth maps is subsea level (SS).

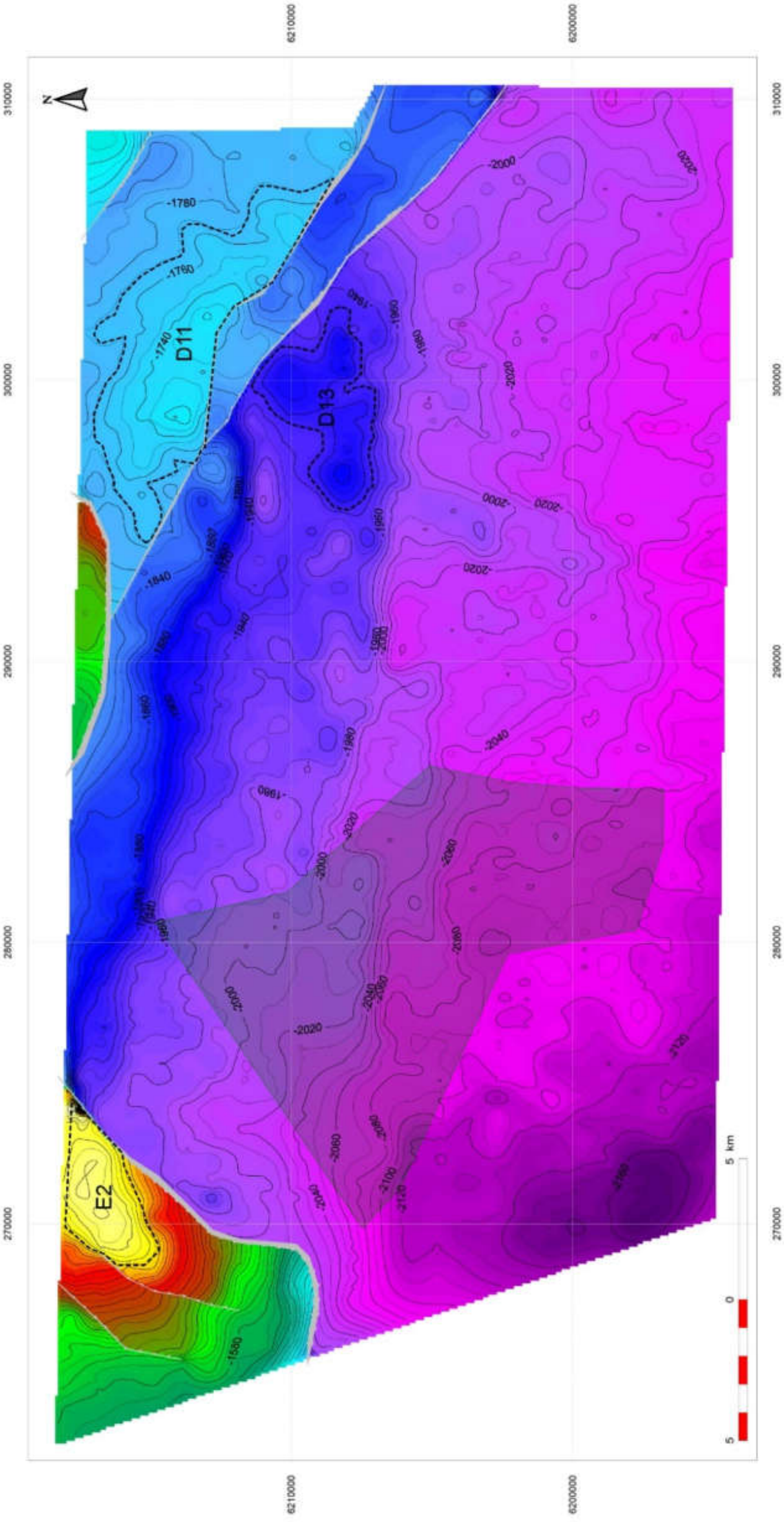


Figure 8. Top Ordovician structural depth map (tectonic faults - gray, closed geological structures - black dotted line, anticipated WPP area – hatched)

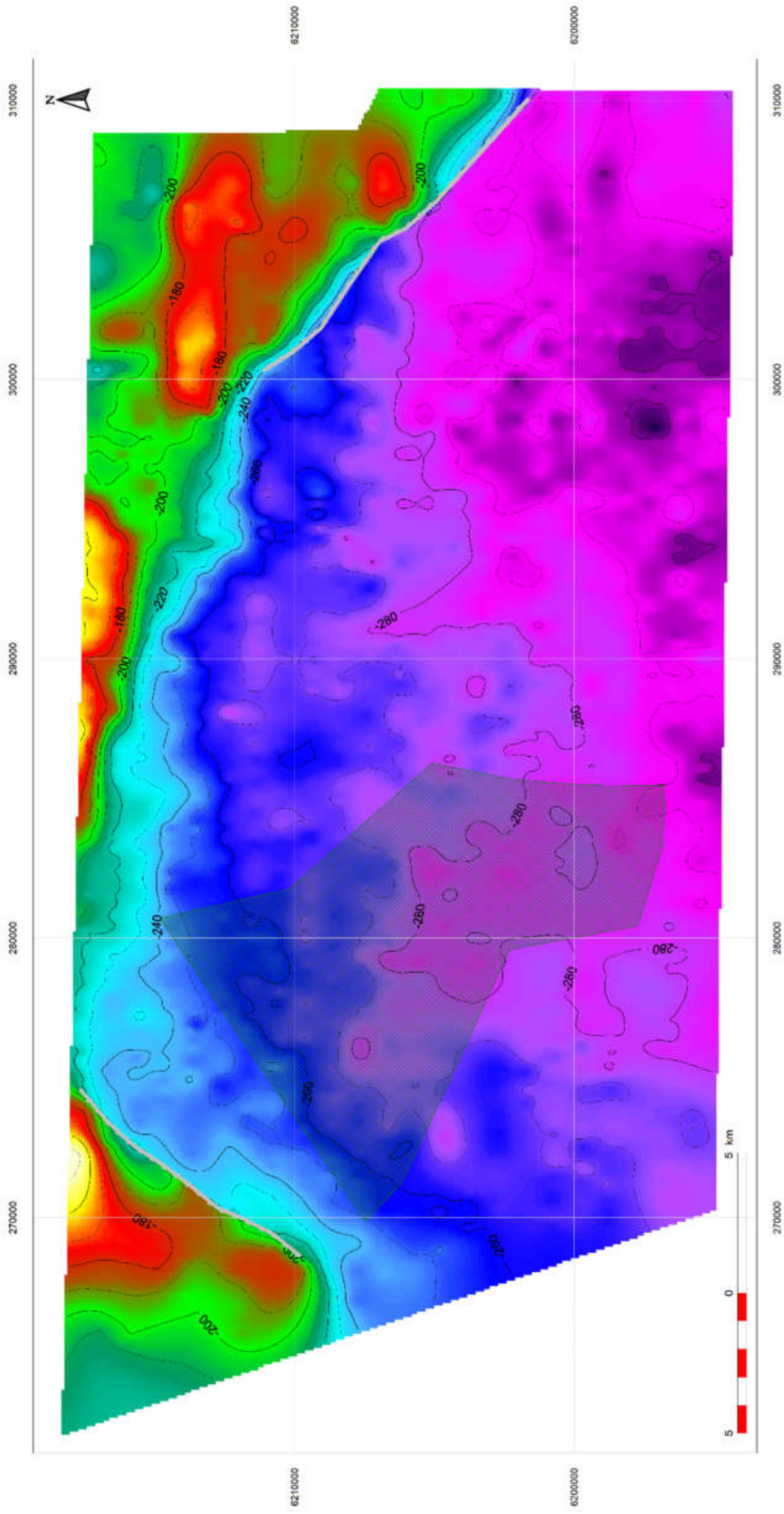


Figure 9. Top Devonian structural depth map (tectonic faults - gray, anticipated WPP area – hatched)

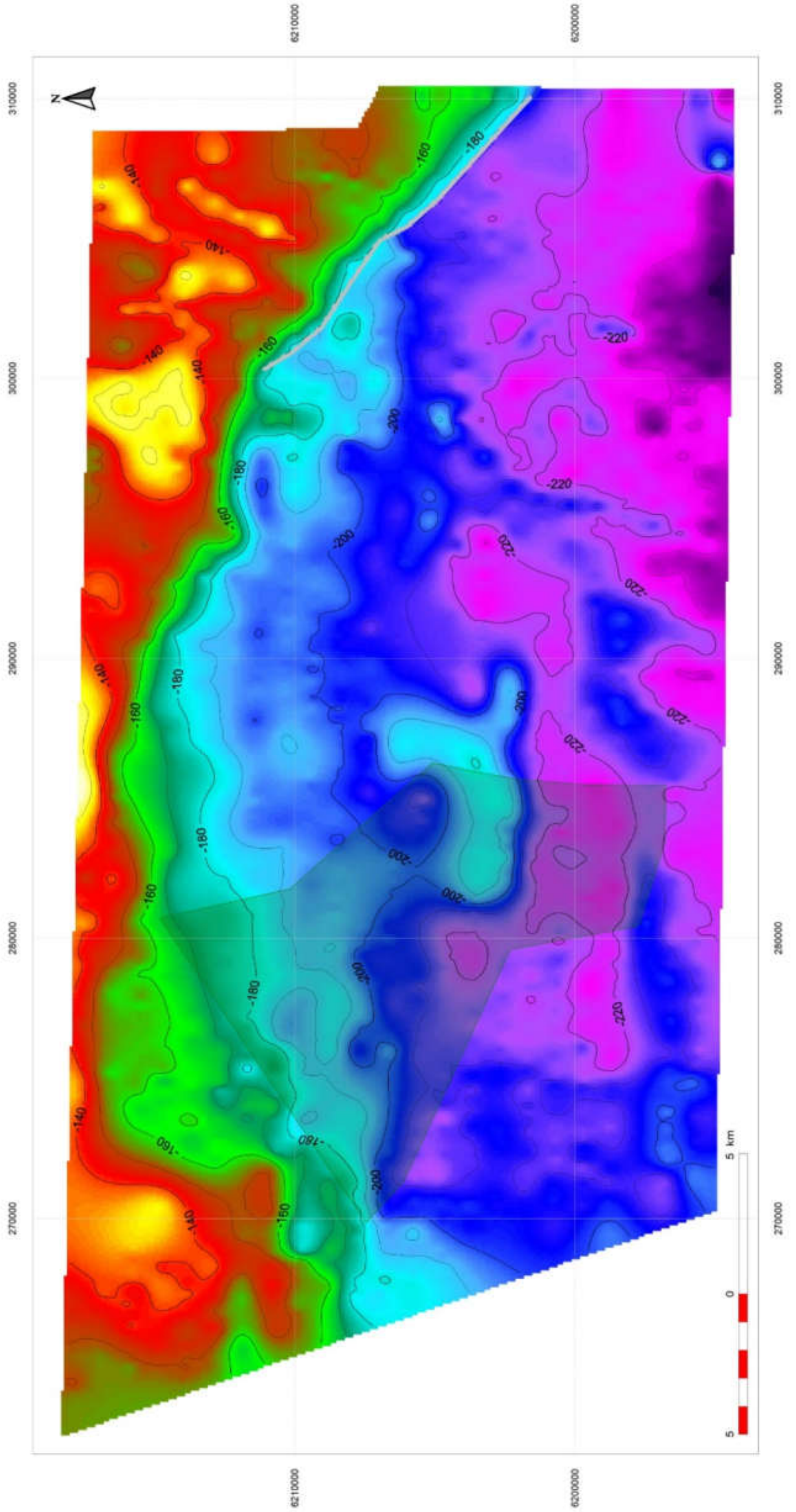


Figure 10 Top Permian structural depth map (tectonic faults - gray, anticipated WPP area – hatched)

III. 3. Geological features of structural depth maps

Top Ordovician (O3). In a major part of the research area (including the territory of the planned wind park), top Ordovician deepens continuously from -1850 m depth in the northern part to 2100 m depth in the south.

Tectonic activity took place in the NE and NW parts of the study area. In the NE edge, a very high amplitude (up to 700 m) tectonic fault is observed. It limits structure E2 (its crestal part rises to -1200 m abs. a.) from the east. Additionally, E2 is divided by several more smaller amplitude faults. The size and closure of the structure to the north remained unclear since the structure extends to the N beyond the study area into the territory of Latvia.

In the NE part of the research area, a series of smaller amplitude faults are also observed, the southernmost of which (after comparing the data with the onshore Ordovician structural maps) is a continuation of one of the largest Telšiai tectonic faults observed in the onshore territory of Lithuania. In the NE part of the survey area 2 top Ordovician structures were mapped (named D11 and D13 according to previous survey data). Since the surface of the main oil-bearing top Cambrian horizon repeats top Ordovician structural elements, therefore structures D11 and D13 shall be considered promising for oil extraction. The D11 structure has a structural closure at -1770 m SS contour, its area reaches 40 km^2, amplitude - 50 m, and volume - 715 million. m^3, and D13 - at -1935 m SS contour, where its area is 16.5 km^2, amplitude - 30 m, and volume - 197 million. m^3.

Top Devonian (D3). Observed from -180 m SS. in the north up to -280 m SS in the south. The structural map is clearly influenced by the 2 deep faults (Telšiai and east of E2), which are still observed in the Devonian, thus they were tectonically active in the post-Devonian period as well. The amplitudes of both faults do not exceed 30-40 m

Top Permian (P). In principle, it repeats the peculiarities of the Devonian structural surface and subsided from -140 m SS in the north to -220 m SS in the south. If the fault delimiting structure E2 from E is no longer observed on the Permian surface, the Telšiai fault is still observed in the Permian, where its amplitude reaches up to 20 meters. The surface of the Triassic overlying the Permian rocks is not observed in the seismic data, so there is no way to accurately confirm the age of this fault. In any case, it is the youngest tectonic fault in the study area, although it is about 10 km east of the planned wind park area.

III. 4. The position of planned WPP area in relation to deep geological structures

A generalized diagram of main geological structures and their position in relation to the planned Wind farm park is presented in Fig. 11. The scheme clearly shows that the planned territory of the Wind farm park does not fall either on the identified tectonic faults or on the discovered Ordovician/Cambrian structures that could be potential for petroleum exploration and production. The closest detectable tectonic fault to the planned VE park is located 3-5 km from the border of the NE park territory.

Tectonic faults are shown in red and gray in the diagram. Tectonic faults that were active during the Caledonian orogenic period and were not active later than the Early Devonian are highlighted in gray. The youngest faults are highlighted in red, which cross practically the entire sedimentary cover and are extinguished in Permian or even younger sediments (this cannot be accurately assessed based on the available material, as no reflection of the Triassic ridge is observed). Taking this into account, attention must be paid to these faults when assessing the seismicity of the area. The list of the main faults and their parameters is provided in the table 2, their location is presented in fig. 11.

Table 2. List of tectonic faults and their main parameters

Fault ID	Age	Max amplitude at ordovician, m	Lateral direction
Telsiai	younger than Permian	150	NW -SE
1	Permian	700	SW-NE
2	Permian	350	W-E
3	Early Devonian	80	SW-NE
4	Early Devonian	100	SW-NE
5	Early Devonian	100	NW -SE
6	Early Devonian	70	NW -SE

Ordovician/Cambrian structures potential for petroleum exploration and production are found on the NE and NE edges of the study area and are more than 5 km away from the proposed VE park in different directions. The structures have been named after the results of large-scale marine 2D seismic surveys conducted by the Polish company Petrobaltic in 1980-1990. Structure E2 extends to the north and exits the boundaries of the study area, so its closure, area and volume remain undefined. Structures D11 and D13 fall completely into the territory of the Lithuanian offshore area and may act as a target areas planning tenders for the use of hydrocarbon resources. Structure D11 is characterized by an extremely large area and volume, and it is adjacent to the same Telšiai fault, near which some of the largest onshore oilfields have been discovered and exploited: Girkaliai, Genčiai, Kretinga and Nausodis. Table 2 below provides a comparison of the area and volume of Structures D11 and D13 with the area and volume of onshore oilfields calculated from the lowest closure contour. As we can see from the calculations, D11 is practically twice as large in both volume and area as all the oil-bearing land structures combined. In order to estimate the preliminary petroleum resources of the D11 structure, an exploration well must be drilled.

Table 3. Comparison of the area and volume of onshore oilfields and potential petroleum structures in the Baltic Sea D11 and D13

Structure name	Area, km^2	Volume, million. m^3
Genčiai	3.6	85
Kretinga	3.6	24
Girkaliai	5.4	107
Nausodis	10.8	252
D11	40	715
D13	16.5	197

III. 5. Presentation of maps in digital formats

Interpreted structural time and depth maps are presented in digital media in XYZ and .jpg formats in LKS-94 coordinate projection.

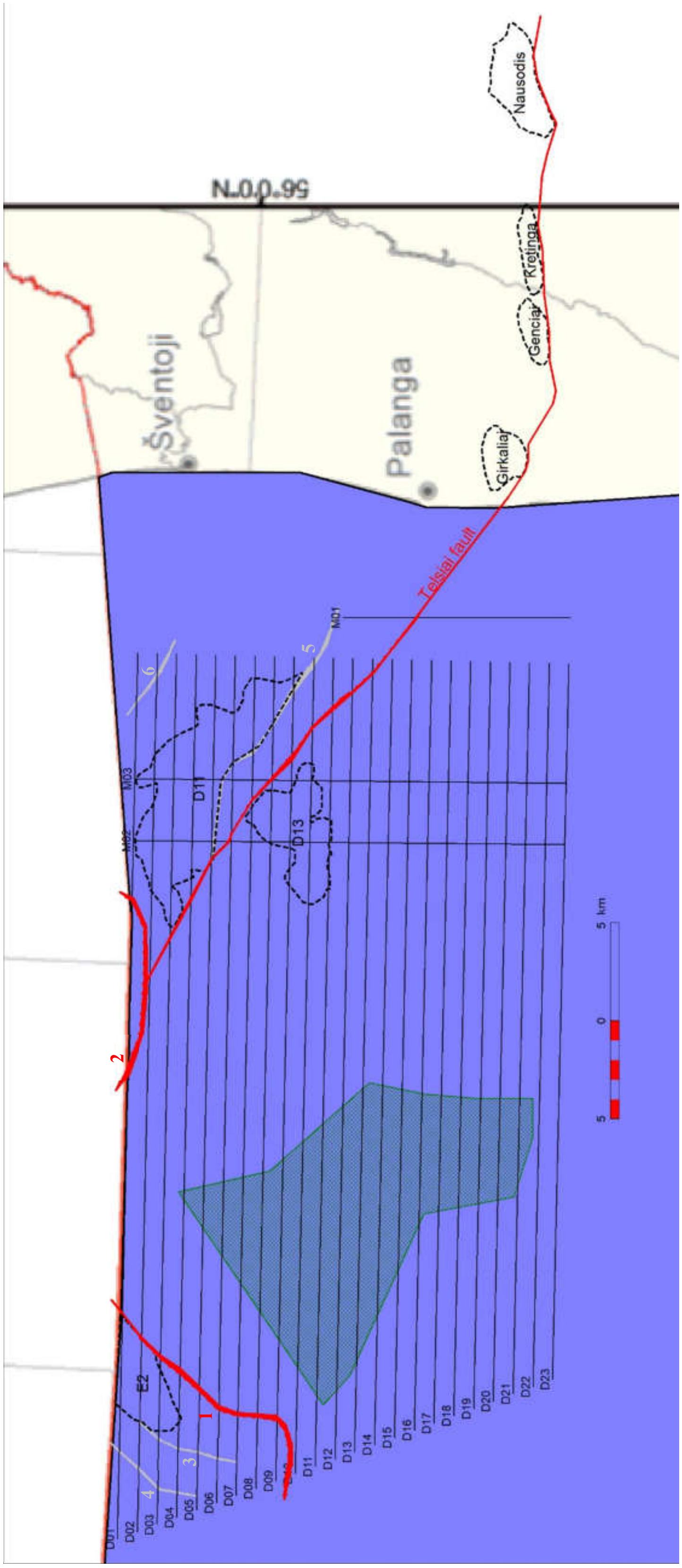


Figure 11. Location of planned WPP territory in relation to deep geological structures (Early Devonian tectonic faults - gray, Permo Triassic tectonic faults - red, petroleum potential structures - black dotted line)

IV. Recommended locations for deep boreholes

Locations of deep boreholes defined in the IInd report have been checked against deep seismic profiles and remain the same as recommended earlier – i.e. deep boreholes G1 and G2 were planned to drill a different geological section based on seismic data. seismic setting shows that borehole G1 should be drilled in the Quaternary paleo incision, reaching a depth of more than 80 m from the seabed, while borehole G2 falls into the Quaternary sedimentary zone with a lower thickness which is common in most of the research area. The recommended position of deep (G1 and G2) boreholes up to 100 meters locations (in LKS-94 coordinate projection) is provided bellow:

G1 X:273094,9 Y:6207391,7

G2 X:282672,6 Y:6203028,7

V. Conclusions

- the planned WPP territory does not fall either on the identified tectonic faults or on the discovered Ordovician/Cambrian structures that could be potential for petroleum exploration and production
- The closest tectonic faults to the planned WPP park are located 3-5 km to NW and 10 km to E from the border of WPP territory. The attention must be paid to these faults when assessing the seismicity of the area
- following Ordovician/Cambrian structures potential for petroleum exploration were mapped: D11 structure having an area of 40 km^2, and volume of 715 million. m^3, and D13 – with an area of 16.5 km^2 and volume of 197 million. m^3. Preliminary petroleum resources in these structures may be evaluated after drilling of exploration well.