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Geophysical study of palaeo-incisions in the Šventoji–Būtingė coastal area, north-west Lithuania

Dmitrij Gerok, Albertas Bitinas

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Abstract Palaeo-incisions (palaeo-tunnels, tunnel valleys, buried valleys, etc.) comprise the most prominent features in the sub-Quaternary surface covered by the Scandinavian continental ice sheets. An exception is the Scandinavian crystalline bedrock region. Palaeo-incisions are objects of Quaternary geology both from scientific and practical point of view and have been previously mapped along the Lithuanian coastal area using gravimetric and transient electromagnetic methods, complemented by traditional drilling. This paper presents an approach for high-resolution identification of the palaeo-incisions in the Šventoji–Būtingė coastal area of north-western Lithuania. Several geophysical methods have been tested, including shallow seismic reflection profiling, electrical tomography and ground-penetrating radar. A combination of shallow seismic reflection and electrical tomography profiling provides an optimal survey strategy for high-resolution investigations of palaeo-incisions.

Keywords *• Palaeo-incision • Gravimetric survey • Seismic survey • Electrical tomography • Ground-penetrating radar • Lithuanian coastal area*

✉ *Dmitrij Gerok (dmitrij.gerok@corpi.ku.lt), Albertas Bitinas, Klaipėda University, Coastal Research and Planning Institute, 84 H. Manto St., LT-92294 Klaipėda, Lithuania*

INTRODUCTION

The term *palaeo-incision* means hidden buried valleys imprinted into the surface of pre-Quaternary sedimentary bedrock. The palaeo-incisions, which often penetrate the entire sequence of Quaternary deposits, are filled in by Pleistocene glaciofluvial and glaciolacustrine sediments, or till. These subsurface structures are widespread in the countries previously covered by Scandinavian continental ice sheets, namely the Netherlands, Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Northwest Russia and Belarus. They are less common in Scandinavia. The terms palaeo-incision, palaeo-tunnel, tunnel valley, buried valley, etc. are in use with scientists in different countries, however, having the same meaning.

The first explanation of the origin of palaeo-incisions in the Baltic Region was based on the idea of lowering of the World Ocean level during the Quaternary glaciations in combination with neotectonic movements of continental plates resulting in changed conditions for the local base of erosion (A. Šliaupa 1981; Tavast 1981; Raukas, Tavast 1984; Baltrūnas 1997; A. Šliaupa 1997, 2004; Vaher *et al.* 2010). According to another opinion, palaeo-incisions are the result of glacier-derived water erosion caused by catastrophic releases of huge water masses under the high pressure during ice recession (Bitinas 1999; Satkūnas 2000, 2008). This hypothesis is based on the theory of melt-water circulation under continental ice sheet (Boulton, Hidmarsh 1987; Boulton *et al.* 1993; Piotrowski 1994, 1997; Boulton, Caban 1995; Boulton *et al.* 1995). J. Satkūnas (2000) particularly analysed palaeo-incisions in Lithuania and deduced that lowering of the global ocean-level is not sufficient to explain the intensive entrenching of palaeo-rivers and formation of palaeo-incisions. The palaeo-incisions of some generations had been determined to repeat each other in the same places. This fact is also confirmed by the results of marine seismic profiling in the Baltic Sea

(Sviridov 1984; Bjerkeus *et al.* 1994) and in the North Sea (Wingfield 1989).

Studies of palaeo-incisions as objects of Quaternary geology contribute to a better understanding of ice sheet dynamics and sedimentation processes during glaciations. The distribution of palaeo-incisions is irregular and complicated. Thus, the present day schemes and maps of sub-Quaternary surfaces in Lithuania with evidences of paleo-incisions are merely indicative. Some schemes and maps are based on drilling data but they contain very little geophysical information (A. Šliaupa 2004) (Fig. 1). In 2004, a detailed sub-Quaternary surface analysis was performed in order to locate palaeo-incisions in western Lithuania by geological methods (Grigelis, J. Bitinas 2004). However, because the inner structure of the palaeo- incisions differs radically from the surrounding deposits or rocks, geophysical methods are apt to contain the most appropriate tools for investigation of their morphology and distribution.

The objective of the present study is to put forward new geophysical prospecting techniques for high resolution investigations of the palaeo-incisions. Furthermore to evaluate the data of previous geophysical activities, and to select the most appropriate geophysical method, or complex of methods, for future investigations in the region. For this selection a focus is given to survey costs and efficiency. The geophysical acquisitions described in this paper have been performed as a part of the Klaipėda University project "The development of Technologies and Environment Investigations in Lithuanian Marine Sector".

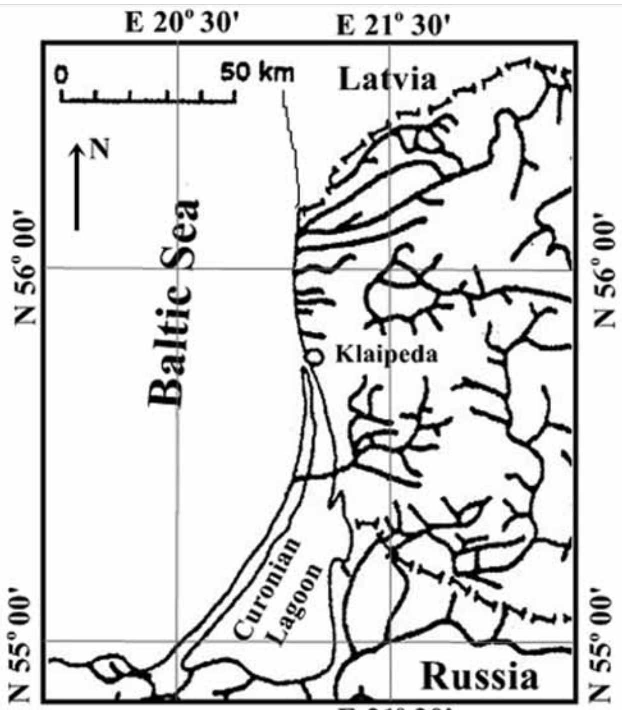

Fig. 1 A view of the palaeo-incision system imprinted on the sub-Quaternary relief of western Lithuania (after A. Šliaupa, 2004).

GEOLOGICAL SETTING

Palaeo-incisions represented as buried valleys are most often filled with Quaternary sandy-clayey deposits in various combinations. The shape of these geological structures looks slightly similar to river valleys. Commonly these structures are of U- or V-shape in perpendicular profile, with the angle of slopes reaching 40^o–45^o. The width of palaeo-incisions varies from a few meters (Piotrowski 1994) to the several hundred metres or to 5 kilometres according to different estimations (A. Šliaupa 2004; Smit, Bregman 2012; Atkinson *et al*. 2013). The depths of palaeo-incisions vary from several metres to 300 metres, their bottom could reach 300 metres in absolute values (Dutch sector of the North Sea), the width could exceed the depth about 10 times (Huuse, Lykke–Andersen 2000; Smit, Bregman 2012). The length of palaeo-incisions may reach 100 kilometres (Janszen *et al*. 2012).

The prevailing relative depth of the palaeo-incisions is about 40–70 metres in the Lithuanian coastal area; merely a few of them are deeper as e.g. a palaeo-incision reaching an altitude of -147 metres in the vicinity of Šventoji. The deepest palaeo-incision in this area was recorded in a borehole drilled in the Nemunas Delta area; its bottom reached an altitude of –269 metres (A. Šliaupa 2001).

METHODS

A complex of geophysical methods, namely shallow seismics, electrical tomography and ground-penetrating radar (GPR), have been applied for the first time in the Baltic Region to locate palaeo-incisions. The practical aspects and the efficiency of the geophysical methods, and their combination, have also been evaluated for the first time during these investigations.

The Palanga–Šventoji area along the Lithuanian coast was chosen as a key-area for the present detailed experimental investigations (Fig. 2). This area was selected because it contains a number of boreholes, which aided in locating the palaeo-incisions.

Transient electromagnetic survey

Maps of palaeo-incisions have been compiled from transient electromagnetic survey data collected in western Lithuania 1993 (A. Bitinas *et al*.; data in the archive of the Lithuanian Geological Survey) (Fig. 3) and also in Denmark 2006 (Smit, Bregman 2012). The existence of palaeo-incisions, as revealed using transient electromagnetic survey data, has been confirmed by a few wells drilled for water supply purposes in the present key-area. A relatively dense network of palaeo-incisions, and their actual existence confirmed by drilling data, was the main reason to select this area for the present investigation.

The geological sequence of well No. 19623 is used as a key-section for choosing theoretical physical properties of rocks (Tables 1, 2).

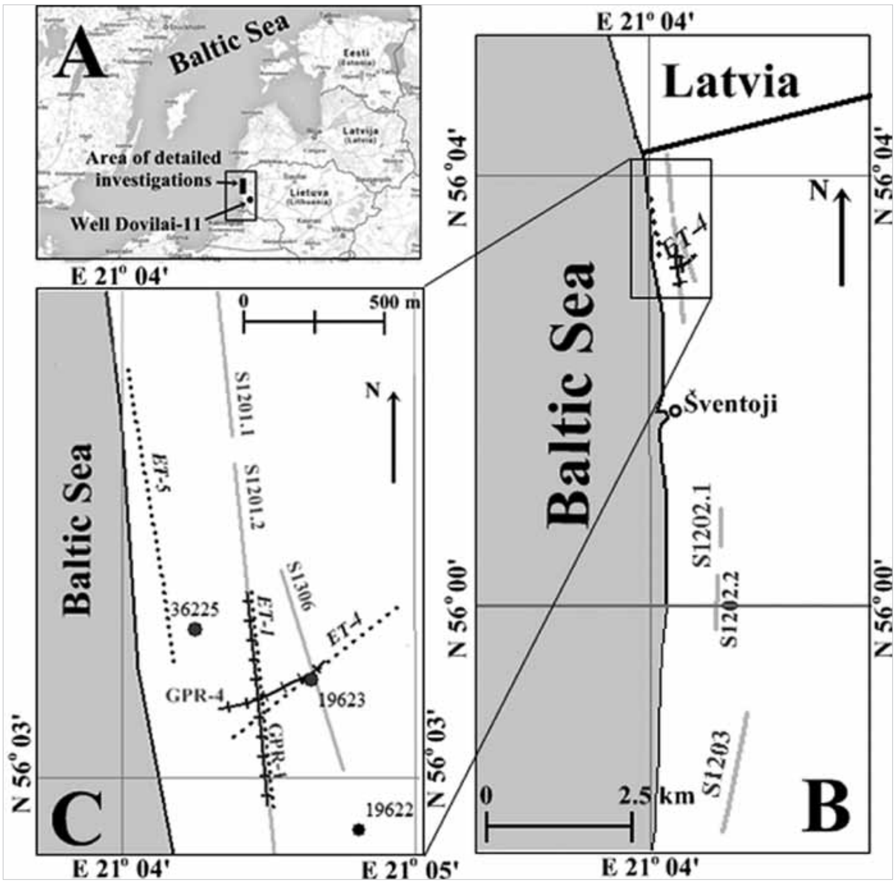

Fig. 2 **A.** The study area. **B.** Location of seismic lines. **C.** Location of electrical tomography lines (*ET*- dotted lines), location of ground-penetrating radar lines (GPR-lines with perpendicular dashes) and S1306 – seismic line. Filled circles – wells. Compiled by D. Gerok, 2013.

Gravimetric survey

A detailed gravimetric survey was performed in the Dovilai area (Klaipėda District) by L. Korabliova in 1996–2000. This survey was part of the integrated geological mapping at the scale of 1:50 000 carried out by the Lithuanian Geological Survey. The objective of the present investigation is to test the use of these gravimetric survey data for identification of palaeo-incisions in the particular geological setting that exists in this part of the Lithuanian coastal area. Thus, a palaeo-incision is contoured along one gravimetric profile in the Dovilai area and confirmed by the sequence in the well Dovilai-11 (Fig. 4). The geophysical model of the Quaternary thickness and the uppermost part of the pre-Quaternary sedimentary bedrock was carried out by L. Korabliova (A. Bitinas *et al.* 2000; data in the archive of Lithuanian Geological Survey). Based on these data, the geological section along the mentioned gravimetric profile and via well Dovilai-11 has been compiled by the present authors.

The Upgraded Quartzitic Land Gravimeter (GNU-KV) equipment is used during the investigations. The root-mean square precision of this gravimeter is 0.02 mGal, the range of measurements is 80-8000 mGal, the sensitivity is 0.001 mGal and the duration of measurement is 3 minutes. The distance between survey points is 100 metres.

Table 1 Physical properties of rocks in the well No. 19623. * – Vertical seismic profiling (VSP) data from well Girkaliai-2; ** – interval velocity of Kretinga region by seismic data; *** – after R. Šečkus (2002). Compiled by D. Gerok, 2013.

Strati-graphic unit	Rocks	V_p, m/s	***r, Ω · m
Q	Moraine deposits filled with water	*1710	30–100
T_1	Clay	**1900–2300	4–15
P_2	Limestone	**2500–3000	90–5000

V_p, m/s – p-wave velocity, metres per second
r, Ω · m – resistivity, Ohm*metres

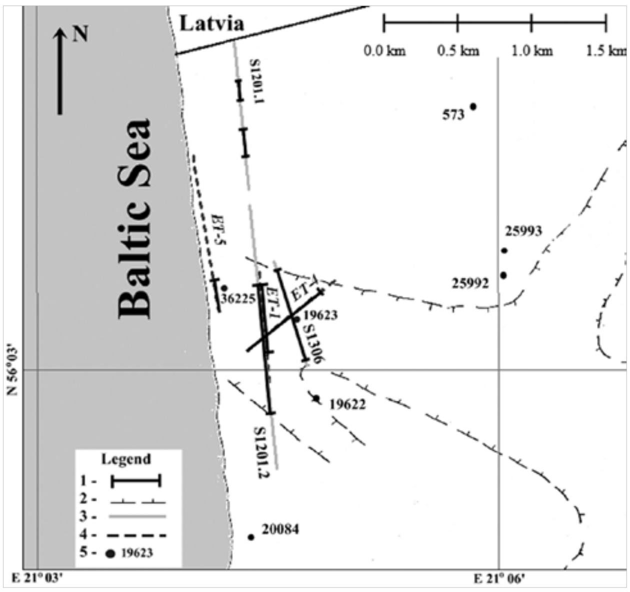

Fig. 3 Comparison between the transient electrical survey results (1993) and the present study. 1 – palaeo-incisions (2012–2013); 2 – palaeo-incisions (1993); 3 – seismic lines; 4 – lines of electrical tomography; 5 – wells. Compiled by A. Bitinas and D. Gerok, 2013.

Table 2 Relative permitivity (ε) and seismic velocity of p-waves (m/s) in well No. 19623 (numbering by Lithuanian Geological Survey database). * – after Ayalew *et al.* 2007; ** – after Vladov, Starovoytov 2004; *** – after R. Šečkus 2002. Compiled by D. Gerok, 2013.

Top of layer	Bottom of layer	Age	Rock	Relative permittivity (ε)	Seismic velocity of p-waves (m/s)	***r, Ω · m
0	0.5		Peat	*11		
0.5	4		Sand	**4–9		
4	8		Peat	*11		
8	11		Sand	**4–9		
11	16		Loam	**9–25		
16	21		Gravel with sand	**4–9		
21	83	Q	Sand	**4–9	≤ 1710	30–100
83	95		Gravel with sand			
95	104		Loam			
104	124		Sandy loam			
124	129		Gravel with sand			
129	135		Loam			
135	162	P_2	Limestone		2500–3000	90–5000
162	174		Marlstone			
174	190	C_1–D_3	Sandstone			
190	210		Marlstone			
210	240	D_3	Dolomite			

Electrical tomography

A high resistivity contrast, and an estimated penetration depth of c. 150 m, was obtained in the present survey area (see Fig. 3). A favourable productivity of c. 750 metres per day with a team of two persons, and previous positive experiences using the transient electromagnetic survey method in Lithuania and Denmark, are the reasons to select electrical tomography as one of main survey methods for investigation of palaeo-incisions in Lithuania. The *"Allied Tigre 128"* equipment (manufacturer *UAV Survey inc.*) was used for the present electrical tomography measurements. The field settings were 1 measurement per 10 seconds and c. 2600 measurements per profile. The time to measure one profile was c. 8 hours, plus 2–3 hours to prepare the equipment. The acquisition parameters were: electrode spacing 6 metres (128 electrodes in all), electrical field source – 36W with current rate 0.5–50 mA.

Resistivity inversion with the *Res2Dinv* software (manufacturer *Geotomo Software SDN. BHD.*) was performed by Dr. R. Šečkus for all the electrical profiles (Fig. 5).

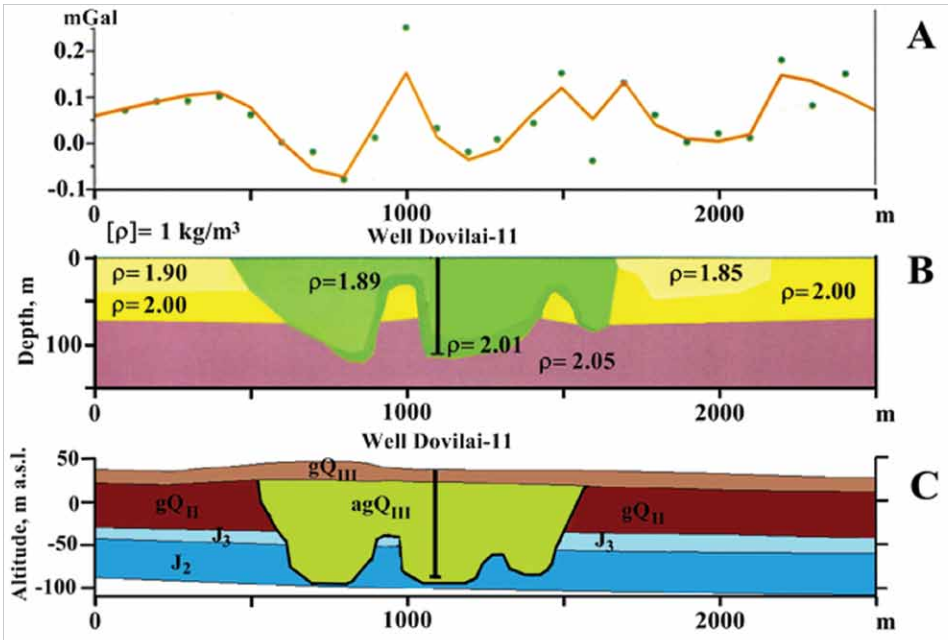

Fig. 4 Results of the gravimetric survey. **A.** Field data (dots) and the calculated model (polyline). **B.** The geophysical model; ρ – density. **C.** Geological interpretation, gQII – glacial deposits of Middle Pleistocene; gQIII – glacial deposits (till) of the Last Glacial (Upper Nemunas, Late Weichselian); ag III – aqua-glacial deposits of the Last Glacial inside the palaeo-incisions. Geophysical measurements and model according to L. Korabliova (2000, unpublished). Geological model compiled by A. Bitinas and D. Gerok, 2013.

Shallow seismics

Seismic common middle point method (CMP) was chosen after analysing the contrast of seismic velocities

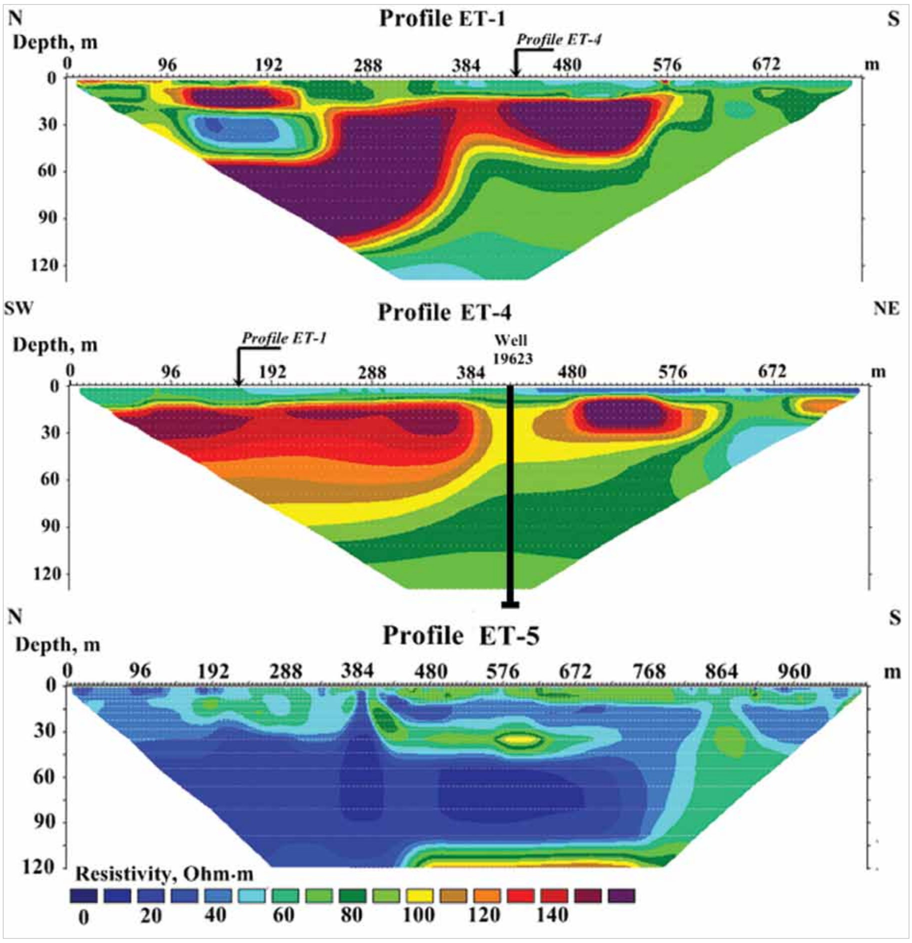

Fig. 5 Results of the electrical tomography: inverse model resistivity sections. **A.** Profile ET-1. **B.** Profile ET-4. Vertical line – well No. 19623. **C.** Profile ET-5. Compiled by D. Gerok, 2013.

better than 0.1 meter was used for the positioning.

in geological layers (Table 1). The depth reached with the CMP method is about 1/2–3/2 of the maximum offset (Boganik, Gurvich 2006). Field tests in the present work area showed that the maximum offset we can use in Lithuania, with a 5 kg sledge hammer as seismic source, is 200–300 metres. Therefore, the estimate depth of the method, as deployed in the present work, is between 100 and 450 metres.

To reach a survey productivity of 500–1000 metres per day with a team of 4 persons, without sacrificing the data quality, the present authors chose the following seismic acquisition parameters: symmetric spread with the maximum offset of 200 meters, seismic station spacing 5 metres (max 61 channels), seismic source spacing 10 metres and seismic source grouping of 16 (seismic source grouping of control profile is 32 and seismic station spacing is 10 metres across the well).

The CMP seismic investigations were performed using a Wireless Seismic Acquisition System with 100 geophones, namely GS-ONE (manufacturer *OYO Geospace*). The length of the seismic record was 500 ms, the sampling rate 0.5 ms and the frequency range 0–2000 Hz. The synchronization between the seismic source and receivers was provided by a built-in GPS. A Magellan ProMark 3 GPS navigator with an accurancy better than 0.1 meter was used for the positioning.

Ground-penetrating radar (GPR)

A potentially rather high contrast of relative permittivity ε exists in the upper part of the geological sequence within the study area (see Fig. 1; Table 2). This fact gave us an opportunity to try using ground-penetrating radar (GPR). However, the maximum estimated depth of this method with the presently used antenna of 300 MHz is only about 20 metres (Vladov, Starovoytov 2004). On the other hand, the productivity of the measurements might reach as much as 20–25 kilometres per day managed by only one person. The present authors carried out a test survey using a Latvian built instrument "GPR Zond-12e" (manufacturer *Radar Systems Inc.*) to determine potential secondary identification features of the palaeo-incisions. Thus, the method should be sufficient to identify potential areas of palaeo-incisions. In the future it should be possible to do more precise measurements, although with less productivity, in these areas. In our case the length of the record was 500 ns and a generator of 400V was used as a source.

The geophysical fieldwork in the present area was performed from the summer of 2012 to the spring of 2013. The productivity of the fieldwork is presented in Table 3.

RESULTS AND INTERPRETATION

The seismic data processing was performed using *Landmark ProMax* software with the following procedures: trace editing and killing, summing, true amplitude recovery, air blast attenuation, surface wave noise attenuation, F-K filtering, predictive deconvolution, bandpass filtering (35–40–100–120 Hz), velocity analysis, autostatics, DMO and migration. All the seismic sequences are the result of final data processing. The datum of all the profiles is -10 metres in absolute values.

Using geological information from wells 573, 19622, 19623, 20084, 25992 and 25993 (see Fig.

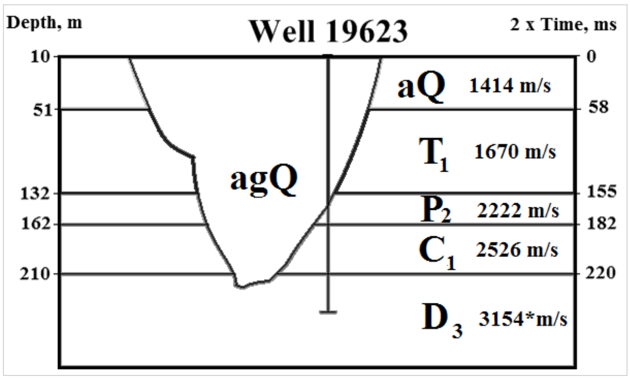

Fig. 6 Interpretational scheme of control seismic line S1306. * – VSP data from well Girkaliai-2. Compiled by D. Gerok, 2013.

3), the geological sequence for the control profile S1306 (Fig. 8) has been accepted. The interpolated data from all above mentioned wells except for No. 19623 (Table 2) have been used to establish top depths of Quaternary and Triassic deposits. The geological information from the well No. 19623 has furthermore been used to establish depths of deeper geological layers (Fig. 6).

Basing on this information, data of all the seismic profiles are associated with the geological knowledge of the study area. Subsequently, the authors tried to locate palaeo-incisions and interpret seismic data. This is a delicate matter when using merely the seismic information. The Quaternary part of geological sequence has a very complicated structure. Thus, it is quite hard to locate the top Triassic level in e.g. the profile S1201.2 (Fig. 7A). It is partly identified as a reflector of very low quality at 60–100 ms.

A delicate matter is to locate the extensional limit of the palaeo-incisions, i.e. the boundary between Quaternary and Triassic rocks. Analysing the profile S1201.2 it is possible to understand that there is a palaeo-incision here, because the tops of the high-contrasted borders of the Permian (120–140 ms) and the Carboniferous (160–180 ms) are broken between positions 650 and 1300 (Fig. 7A). But the interpretation is difficult without additional information in the uppermost interval down to 120 ms. The present authors tried to use turning ray tomography as an aid in the processing of the seismic data to solve that problem (Fig. 7B). This procedure is based on using a first break picking, but the quality of the first breaks is rather poor due to a peat layer in the uppermost part of the sequence. An indicative result was obtained from along the profile S1201.2 (Fig. 7B) and some additional information was extracted from the profile S1306. There are effects of decreasing fold before the position 100 and after the position 1400. Further, there is a zone of low velocities between positions 500 and

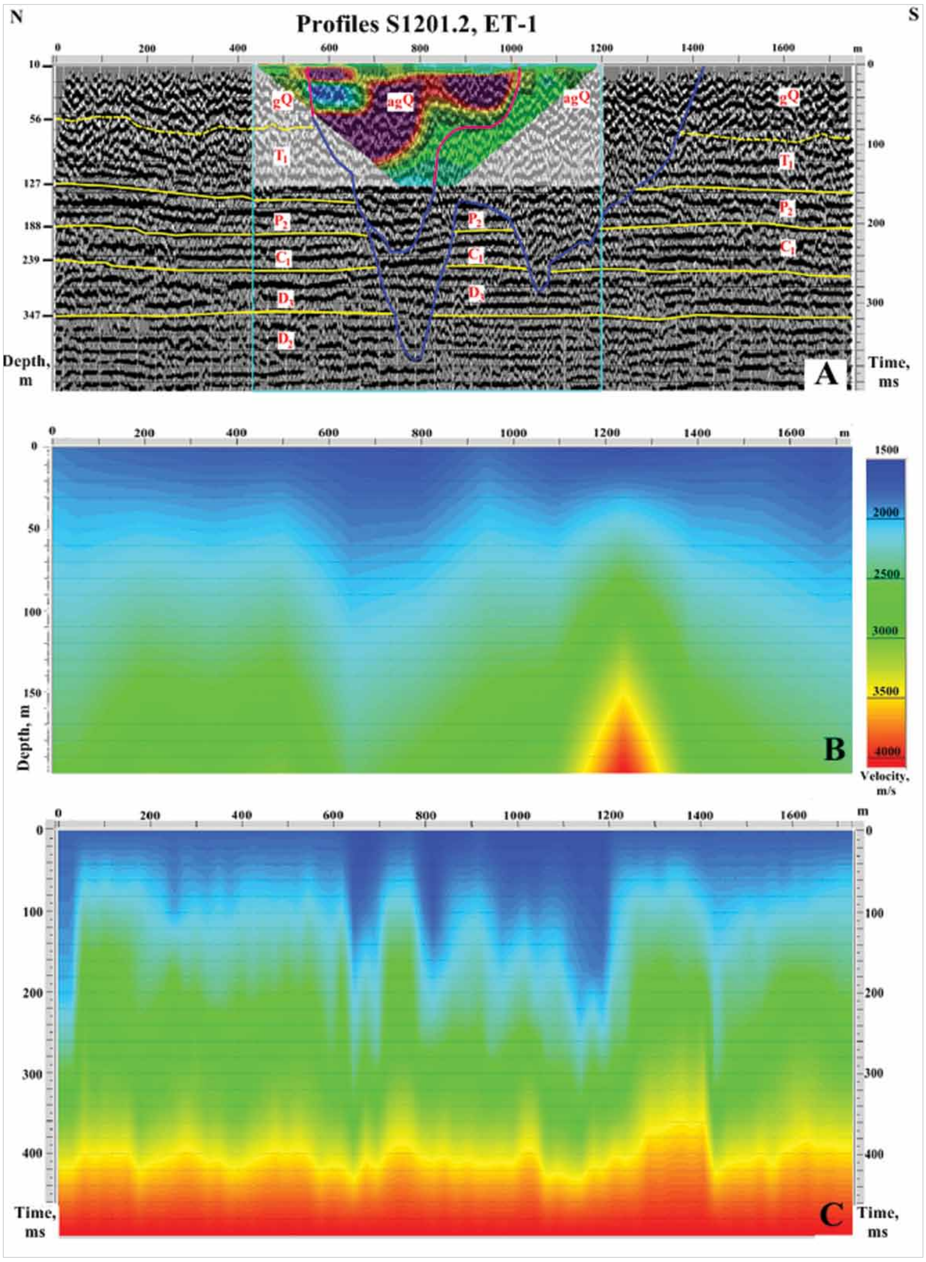

Fig. 7 A. Combined geophysical interpretation of lines S1201.2 and ET-1. Magenta line – palaeo-incision by electrical tomography data; blue line – palaeo-incision by seismic data; dashed yellow line – estimated geological border; yellow line – geological border. gQ – glacial deposits, agQ – aqua-glacial deposits. **B.** Interval velocity sequence of line S1201.2. **C.** RMS velocity sequence of line S1201.2. Compiled by D. Gerok, 2013.

1250 of profile S1201.2 (Fig. 7B). The quality of the turning ray tomography procedure as applied to all the other profiles of the survey proved not to be good enough to use for data interpretation, i.e. turning ray tomography refraction statics causes seismic sequence of bad or very bad quality.

The root-mean-square (RMS) velocity sequences have been used to better understand the geological structure of the sequences down to 120 ms. Analysing these velocity sequences, it is possible to observe some zones of decreasing velocities, namely between the positions 300 and 650 along the profile S1201.1, between the positions 600 and 1200 and at position 1450 along the profile S1201.2 (Fig. 7C). No low velocity zones were observed along the profiles S1202.1 and S1202.2. Low velocities were observed between positions 350 and 650 along the profile S1203, near the position 150 and between positions 450–650 along the profile S1306. Correlating the velocity sequences, seismic sequences and turning ray tomography, the authors interpret the occurrence of palaeo-incisions along the profiles S1201.1, S1201.2 and S1306 (Table 4).

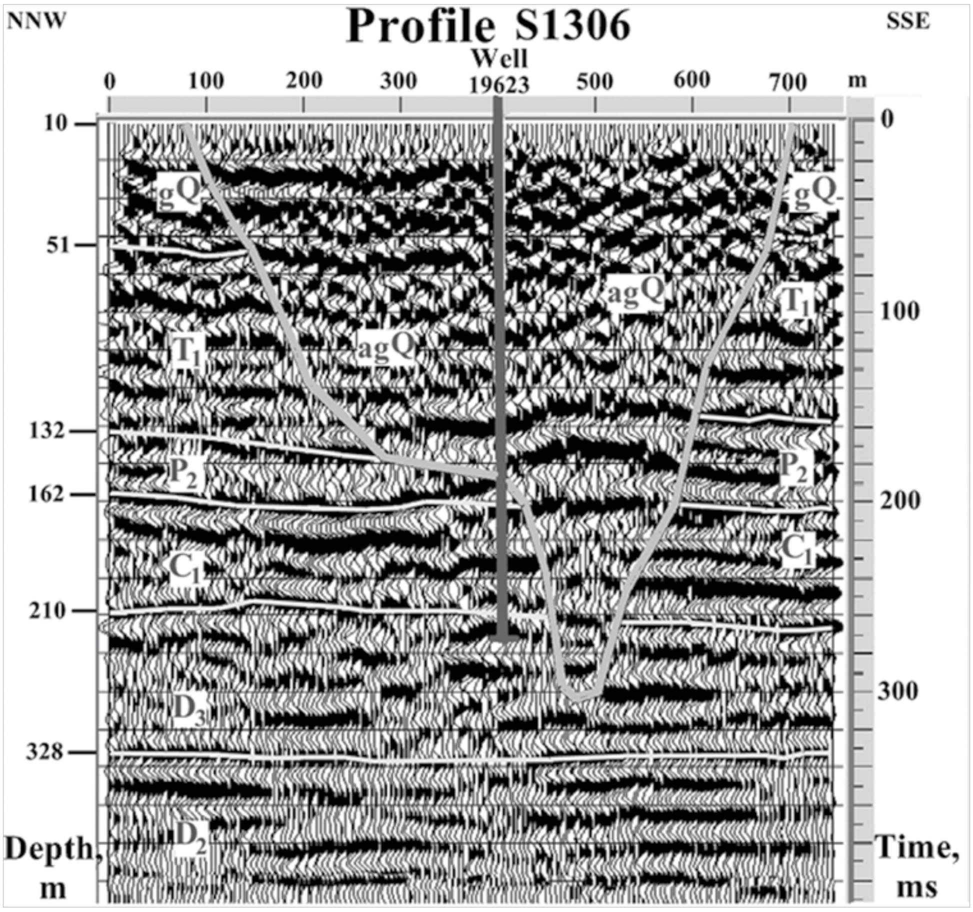

Fig. 8 Interpretation of seismic line S1306. Unconformable bold line – palaeo-incision by seismic data, dashed sub-horizontal line – estimated geological border, sub-horizontal line – geological border. gQ – glacial deposits, agQ – aqua-glacial deposits. Vertical line – well No. 19623. Compiled by D. Gerok, 2013.

The results of the ground-penetrating radar measurements were negative this time. Thus, the present authors did not detect any secondary identification features of palaeo-incisions with the GPR method.

As a next step in the interpretation, the resistivity and inverse resistivity sections of the electrical method were analysed. The well No. 19623 is located in the centre of the electrical profile ET-4 (Fig. 5B). This well is cased in its upper part with the metallic tube.

Table 3 Production of geophysical measurements. Compiled by D. Gerok, 2013.

Geophysical method	Profile index	Length, m	Duration, h	Total length, m	Productivity, m/man-hour
Shallow seismic	S1201.1	947.5	12.0	6882.5	51
	S1201.2	1747.5	19.0		
	S1202.1	597.5	5.0		
	S1202.2	897.5	9.0		
	S1203	1947.5	18.0		
	S1306	745.0	4.0		
Electrical tomography	ET-1	762.0	14.0	2580.0	28
	ET-4	762.0	12.0		
	ET-5	1056.0	20.0		
GPR	GPR-1	762.0	0.5	1182.0	1478
	GPR-4	420.0	0.3		

Table 4 Correlation of all the seismic information for lines: S1201.1, S1201.2, S1203, S1306. Compiled by D. Gerok, 2013.

Line	The position of estimated palaeo-incision, m	The position of interpreted palaeo-incision, m	Sequence	Remark
S1201.1	200–350, 650–700	250–400, 580–770	Seismic	High-contrasted seismic features (150–200 ms) are broken
	300, 650		Velocity	Zone of low RMS velocity
S1201.2	420–550, 670–1450	550–1420 (Fig. 7, A)	Seismic	High-contrasted seismic features (120–260 ms) are broken
	600–1200, 1450		Velocity	Zone of low RMS velocity
	500–1250		Turning ray tomography	Zone of low interval velocity
S1306	250–700	80–700 (Fig. 8)	Seismic	Seismic features (20–60 ms) are broken, high-contrasted seismic features (140–260 ms) are broken
	150, 450–650		Velocity	Zone of low RMS velocity
	300		Turning ray tomography	Zone of low interval velocity

This may be the reason of the lower resistivity values obtained between 390 and 440 m along the profile ET-4 (Fig. 5B). We interpret the changes of resistivity between 576 and 650 m as the slope of a palaeo-incision. The resistivity of the palaeo-incision body, 80–160 Ω · m, is higher than that of the enclosing rocks. Thus, the zone of resistivity 80–160 Ω · m along the profile ET-1 is also interpreted as palaeo-incision (Fig. 5A).

A different situation is met along the profile ET-5 (Fig. 5C). It is located nearby the sea coast, merely10 metres from the water, so the geological section might be saturated with salt water inducing a lower resistivity in the geological layers. The well number 36225 is located near the profile ET-5 (Fig. 1C). Its depth is 116 metres and there are only Quaternary deposits here. Using both the geological and geophysical information it is possible to interpret the changes of resistivity between 864 and 900 metres as the slope of a palaeo-incision (Fig. 5C). It is similar regarding the shape of the resistivity change to the northern slope of the buried valley along the profile ET-1 (Fig. 5A).

The combination of shallow seismics (positions 460–1222 along profile S1201.2) and electrical tomography (profile ET-1) has been used to obtain the location of the palaeo-incision with an enhanced resolution (Fig. 7A). Correlation by depth has been done using the geological interpretation (see Fig. 6). The upper part was interpreted using resistivity data (magenta line in Fig. 7A). The principle of interpretation is described above. The deeper part was obtained using seismic data (blue line in Fig. 7A). The main principle is to use the levels in the seismic sequence, where the phase of the reflection shifts or where it increases in strength. These places are considered to reveal the borders between the palaeo-incisions and the surrounding bedrock.

DISCUSSION

During this detailed study the results of the following geophysical methods have been evaluated in the Palanga–Šventoji coastal area: transient electromagnetic survey, land shallow seismic survey, profiling by electrical tomography, profiling with ground-penetrating radar (GPR), and also gravimetric survey in the Dovilai area, Klaipėda District.

The depth penetration of the shallow seismic method proved sufficient to locate even the deepest parts of a palaeo-incision, but it proved difficult to describe in any detail the upper geological boundaries due to the quality of seismic sequence there. Sometimes turning ray tomography procedure and sections of root-mean-square velocities allowed us to solve this problem. A seismic source grouping of 32, which was used for the control profile (Fig. 8), showed a superior result compared with a grouping of 16 (Fig. 7A). Probably in the future it is also necessary to increase the CDP fold using smaller source spacing for the better results. Under these conditions it is possible to use only the shallow seismic method to locate the buried valleys. The productivity will be about 25 metres per man-hour in this case.

Electrical tomography, as authors supposed, can be used to locate the slopes of palaeo-incisions. It proved impossible to get the full information of the palaeo-incision shapes using the equipment we had, however. It should be deeper for better result. Using this method alone is not sufficient to identify the location of palaeo-incision, i.e. if the profile is located along a palaeo-incision or if the width of the palaeo-incision is greater than the profile. Longer profiles and deeper penetration might help to solve this problem.

The present interpretation does not depend on any older results based on the transient electrical survey method. In view of the experience with electrical tomography and according to similar results obtained with during previous, as well as recent, geophysical investigations, resistivity methods seem to be rather reliable for locating palaeo-incisions.

The combination of electrical tomography and shallow seismic soundings has shown good results: electrical tomography allows a description of the upper part of the geological sequence, and shallow seismics reveals information of the deeper parts (Fig. 7A). Using the combination of resistivity and seismic methods with the parameters described above makes it possible to locate palaeo-incision reliably. These methods complement each other in this case.

Gravimetric surveys previously performed in the Lithuanian coastal area, with the results mentioned above for the Dovilai area, shows that the method is useful and it could be added as an additional method into the mentioned complex of geophysical methods for palaeo-incisions prospecting.

CONCLUSIONS

An area with a known palaeo-incision (confirmed with the well No. 19623) has been selected to compare the efficiency of different geophysical methods in exploring target objects. Knowing the geological situation in the chosen area the present authors have tried to improve the resolution and quality of palaeo-incision interpretation. The area has been investigated with all three of the above-mentioned geophysical methods, namely shallow seismics, electrical tomography and ground-penetrating radar (GPR). The shallow seismic survey and electrical tomography have been used for a combined geophysical interpretation resulting in an enhanced detection of the target structures. Another reason for using the two methods in combination is to compare their independent usage exploring buried palaeo-incisions. The GPR was used to determine secondary shallow identification features of palaeo-incisions. However, the experience with the GPR method was negative in our case and there are no results described here. Probably, it is possible to determine secondary identification features of palaeo-incisions by using more powerful or lower frequency (deeper) GPR antenna.

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