Annales Societatis Geologorum Poloniae (2009), vol. 79: 391–402.

SALINITY OF QUATERNARY SEDIMENTS AND HALOPHYTES AT STARUNIA PALAEONTOLOGICAL SITE AND VICINITY (CARPATHIAN REGION, UKRAINE)

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Mościcki, W. J., Toboła, T. & Zarzyka-Ryszka, M., 2009. Salinity of Quaternary sediments and halophytes at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 391–402.

Abstract: Interdisciplinary geophysical, geochemical and botanical studies were performed to recognize the problem of salinity of Quaternary sediments in the place, where woolly rhinoceroses were discovered at the beginning of the 20th century. Geoelectric methods (high resolution geoelectric research with electromagnetic conductivity meter) enabled construction of maps of the distribution of conductivity of near-surface sediments. Variation of conductivity with depth was recognized with penetrometer-based geoelectric measurements. Measured conductivity mainly depends on the level of mineralization (salinity) of underground water filling the pores and voids of poorly consolidated Quaternary sediments and partly underlying Miocene strata. Several samples were taken from geological boreholes. The analysis of these cores enabled estimation of salt (chloride ion) content in the solid phase of sediments. This content varies from place to place and with depth in an unpredictable way. The highest values reached 8.5 wt%. Generally, on the basis of a qualitative comparison, the salinity data gained from sampled cores correlate with distribution of apparent conductivity obtained with geoelectric methods. Nevertheless, in some places there is a discrepancy between geophysical and geochemical data, especially for penetrometer versus borehole data. It may be partly explained by an unavoidable difference in location of the geological borehole and penetrometer site (technically this cannot be the same place). During botanical field studies a group of vascular plants growing on saline soils (halophytes) was found. Halophytes indicate a higher salt concentration in the soil. Their aggregations are extremely rare in the Carpathian region. The pattern of halophytes distribution reflected the presence of saline water sources, and their flows and soils affected by them. Generally, the distribution of halophytes showed a good correlation with the distribution of high-conductivity anomalies determined with the surface geoelectric survey.

Key words: salinity, geoelectric electromagnetic survey, penetrometer-based resistivity profiling, botanical studies, halophytes, Starunia, Carpathian region, Ukraine.

Manuscript received 7 May 2009, accepted 29 September 2009

INTRODUCTION

At the beginning of the 20th century, rare specimens of woolly rhinoceros and mammoth were discovered at Starunia (Alexandrowicz, 2004 and references therein), a little village located near Ivano-Frankivsk in the western Ukraine (Fig. 1). Although there was some scientific activity in the past focused on that area, the more intense, interdisciplinary studies were conducted at the beginning of the 21st century. Historical background and results of these works are described in detail in a monograph (Kotarba, 2005) and in this volume (Kotarba, 2009). Among the targets of the realized scientific projects was recognition of the salinity of near-surface sediments. There are a few aspects of the problem: salinity of underground waters, salt content in sediments, and influence of salinity on contemporary vegetation. To study these problems, interdisciplinary geoelectric, geochemical and botanical studies were performed.

Quaternary sediments in the area of Starunia lie on top of the Lower Miocene salt-bearing Vorotyshcha beds of the Boryslav-Pokuttya Unit (Sokołowski *et al.*, 2009). Depending on local hydrogeological conditions, there were numerous saline and mineral water occurrences in the unit (Duliński *et al.*, 2005). A surface outflow of saline water (chloride ion content more than 1,000 mg/l) connected with Nadzieja-1 well is presently observed in the study area. Another outflow of brine takes place from "mud volcanoes", an interesting phenomenon, probably of neotectonic origin.

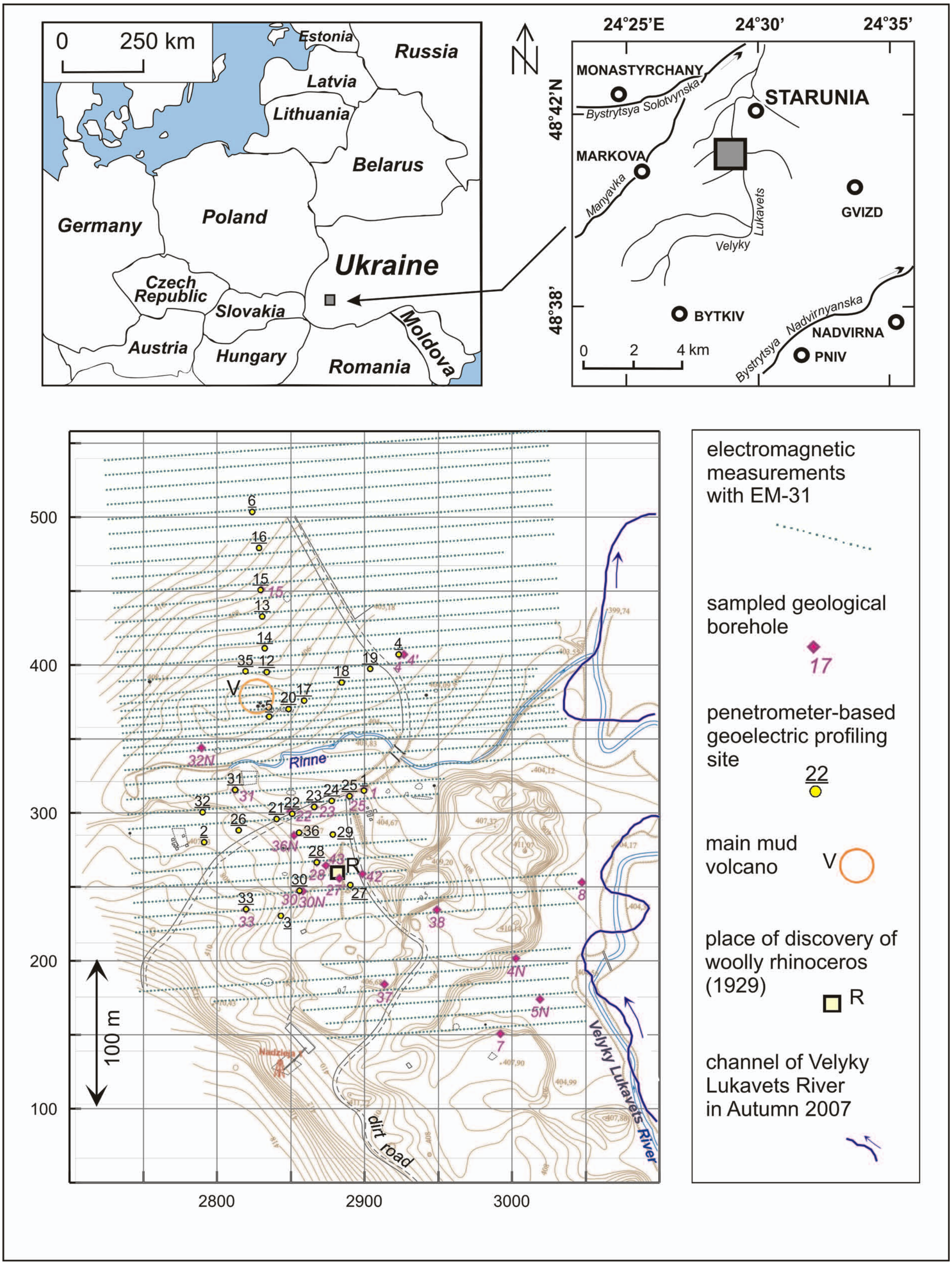

Fig. 1. Location map of the study area. Nadzieja-1 – old well

Distribution of water in the Quaternary sediments depends on their lithology and compactness, which show distinct variations in that area (Mościcki & Sokołowski, 2009). An important role is also played by anthropogenic transformations of the near-surface strata connected with former earth wax mining activity in this area (Alexandrowicz, 2004).

Halophytes are good indicators of an increased concentration of salt in soil or water. This is due to their salt tolerance. Obligatory halophytes can colonize places inaccessible for most of vascular plant species. Up to now, the knowledge about saline vegetation in the Carpathian region is insufficient because of the rarity and smallness of areas of appropriate habitats, as well as lack of comprehensive studies. In the Polish Carpathians they are extremely rare, and their species composition is much poorer than in other inland and coastal saline habitats (Kornaś, 1966). The same situation takes place in the Ukrainian Carpathians and the south-western part of the Ukraine, where only single locations of the halophytic vegetation are known (Zapałowicz, 1911; Kornaś, 1966; Trzcińska-Tacik & Woch, 2005; Dubyna *et al.*, 2007). There was only one halophyte species reported so far from the ozokerite mine in the Starunia area – *Spergularia salina* J. Presl & C. Presl (as *Lepigonium salinum* Ser. widespread on the spoil heaps; Łomnicki, 1914).

METHODS OF THE RESEARCH

Geophysical methods

The results of two geoelectric methods were used in this study: electromagnetic terrain conductivity measurements (ETCM) and penetrometer-based resistivity profiling.

The first one is a surface method utilizing the phenomenon of electromagnetic (EM) induction in fair conductive geological media. ETCM method is recognized as valuable geophysical tool for studying underground water pollution (*e.g.*, Mościcki & Antoniuk, 2002). In the Starunia area, electric resistivity (reciprocal of conductivity) of sediments is very low (Mościcki, 2009), which guarantees a strong induction signal, *i.e.* conditions are generally favourable for the method (within some limits). In this study EM measurements were carried out with the Geonics EM31 equipment (www.geonics.com). Two modes of coils orientation were applied: horizontal dipole (HD) and vertical dipole (VD). They differ in depth of investigation and depth-sensitivity characteristics. The HD mode enables an estimation of mean conductivity of sediments to the approximate depth of 3 m, while for VD mode it is about 6 metres. In the Starunia case, there are a few places with extremely high conductivity superficial soils/sediments. In such cases the value of conductivity measured with EM31 may be underestimated because the upper limit of the measuring range of the equipment is 1000 mS/m (= 1 Ωm). Apparent conductivity measurements were made along 42 lines oriented east-west, most of them 300 m long and separated from each other 5 to 10 m. The distance between adjacent measuring points along the lines was 2.5 m. Each line was repeated twice: first with HD mode and then with VD mode.

Penetrometer-based resistivity profiling is an invasive method used for measuring variations in electric resistivity of loose sediments with depth (*e.g.*, Antoniuk & Mościcki, 1994). A special geoelectric probe is progressively pushed (or hammered) into the ground and resistivity is measured in a nearly continuous manner. A mobile GEOPROBE (www.geoprobe.com) system with small size Wenner array probe (76 mm total length) for measuring sediments resistivity was used in this study. High vertical resolution can be achieved as the measuring depth step is less than 2 cm. The method was applied in 30 sites selected after analyzing the results of surface geoelectric surveys and following suggestions inferred from the earlier geological and geochemical works. The penetration depth depended on local conditions. In most sites it was of about 14–16 m, and in each case the penetration finished probably in Miocene sediments (Mościcki & Sokołowski, 2009).

Geochemical methods

As an indicator of total salinity (degree of salinity) of the sediments, the content of chloride ions was used. During the field campaign, 113 samples of sediments were taken from 23 geological boreholes. The depth of sampling was in the range from 0.2 to 12.9 m. The salinity of the samples was determined on the basis of a chemical analysis. The Mohr method with the limit of detection 0.15 wt% was applied. The detailed procedure of sample preparation and analyses was presented in another paper (Kotarba *et al.*, 2009).

Botanical methods (vegetation studies)

Field investigations were carried out in the area of the abandoned ozokerite mine in Starunia in May and August 2008. The study area is part of the Velyky Lukavets River valley (*ca*. 0.25 km^2; Fig. 1). Most of the area is occupied by post-industrial anthropogenic habitats (*e.g.*, waste heaps, remnants of mine shafts) with spontaneous vegetation affected by brine springs, and mud volcanoes with oil and saline water flows. Contemporary vegetation has developed since the early 1960s, when the mine was closed (Alexandrowicz, 2005), and around mud volcanoes, since their formation in 1977 (Adamenko *et al.*, 2005).

In the study area, a list of vascular plants was made and the contribution of halophytes was estimated. The halophytes were indicated according to Wilkoń-Michalska (1963), Lindacher (1995) and Zarzycki *et al.* (2002), and their salt tolerance was given according to Lindacher (1995). They were classified into habitat groups (phytosociological classes) according to Matuszkiewicz (2001) and Zarzycki *et al.* (2002). In the selected habitats phytosociological relevés were made according to the standard Braun-Blanquet method. The simplified map of vegetation with distribution of halophytic habitats was prepared. The nomenclature of plant names follows Mirek *et al.* (2002) and phytosociological units are given according to Matuszkiewicz (2001) and Wilkoń-Michalska (1963).

RESULTS AND DISCUSSION

Geoelectric data

The first geophysical sign of probable high salinity of near-surface sediments were the results of reconnaissance DC resistivity soundings (Mościcki, 2005). This survey revealed distinct low-resistivity pattern (LRP), well visible on apparent resistivity maps. This resistivity anomaly was confirmed and more precisely contoured during later geoelectric field works (Mościcki, 2009).

It should be emphasized that very low electric resistivity is not a *direct* indicator of salinity/mineralization, as the electric resistivity may be low in the case of clayey rocks, too (Kobranova, 1989). Nevertheless, according to available hydrogeological information, the presence of saline waters in the region is obvious (Duliński *et al.*, 2005) and in such a case the salinity of underground (or pore) water filling unconsolidated Quaternary sediments may be the most important reason for their low resistivity (high electric conductivity). In the following text the term *conductivity* will be preferred rather than *resistivity*, as conductivity is proportional to pore-water conductivity (mineralization or salinity). If sediment is well-sorted quartz sand in saturation zone, it is possible to estimate an effect of pore water salinity on sand conductivity. For example, if brine has NaCl concentration of 100 g/l it may have a specific conductivity (σ_{brine}) above 10^4 mS/m. Then, on the basis of the Maxwell model (McNeil, 1980) of well-sorted (uniform grain-size) sand, the conductivity of the sand is σ_{brine}/(2.4 to 5.3), depending on porosity factor. For clayey sediments resultant conductivity might be even higher.

Precise estimation of the horizontal extent of the mentioned LRP was possible by means of detailed electromagnetic induction profiling with EM31 equipment (Mościcki, 2009). The data obtained with EM31 enabled construction of apparent conductivity maps covering the most interesting part of the study area. These maps are shown in Fig. 2A, B. Map in Fig. 2A represents contours for horizontal dipoles (HD) measuring mode of EM31. In this case "mean" conductivity of sediments (which depends on spatial distribution of specific conductivity and on measuring characteristics of the method used) are measured to the depth of about 3 m. The map in Fig. 2B was constructed for vertical dipole (VD) mode measurements and depth of investigation of about 6 m may be assumed for that case. The highest values of apparent conductivity, s_a, were observed for HD mode in the places, where surface occurrences of salt water outflows were noticed. Measured values were higher than 700–800 mS/m in the vicinity of "mud volcanoes" and in NE surroundings of the Nadzieja-1 well. The comparison of these two maps is indicative of general rise of conductivity with depth.

Variations of sediment conductivity with depth was estimated from the penetrometer-based resistivity profiling. Measured resistivity data (in Ωm) were transformed to conductivity values (mS/m), which are more convenient for discussing the salinity problems. Vertical profiles of conductivity were presented in Fig. 3 together with geological and geochemical data.

Geochemical data

The content of Cl^- ion in the whole population of samples displays variability in the range from 0 to 8.54 wt%. In almost one third of the samples, chloride is below the limit of detection (0.15) (Fig. 4 and Table 1). These samples can be recognized as Cl-free. Most of the Cl-free samples belong to boreholes Nos 1, 4, 4' and 25, which are located in the north-eastern and central part of the study area (Fig. 2A, B). Their location corresponds to the area of the lowest apparent conductivity. Other Cl-free samples mainly come from the boreholes 4N, 7 and 8, which are located in the south-eastern part of the area where conductivity is relatively low, too. As to the other boreholes, only in a few samples Cl^- ion presence was not detected.

Most of the samples, in which Cl^- ion content was above the detection limit, show values below 1 wt% (Fig. 4). It is worth mentioning that values higher than 2 wt% were observed in all 13 samples taken from borehole No. 22, where the highest values (8.54 and 7.13 wt%) were noticed, too. The remaining samples with Cl^- content above 2 wt% were taken from boreholes: 32N (3 samples), 7 (2 samples) and 28 (1 sample).

Except the boreholes, in which samples do not have chloride ion above the limit of detection, the remaining boreholes show large diversity of mean contents in the range from 0.16 to 4.11 wt% (Table 1). In most of them, the mean value does not exceed 1 wt%. There are samples with mean value above 1 wt% from 7 boreholes only (namely, Nos 7, 22, 27, 28, 31, 32N and 43). These boreholes are located along the NW–SE belt of high electric conductivity zone (Figs 2A, B and 6).

Botanical data

The area of the abandoned ozokerite mine in Starunia has a typical post-industrial spontaneous vegetation, with a mosaic of ruderal, semi-natural and natural habitats (Fig. 6). Most of the area is occupied by anthropogenic habitats: waste heaps, remnants of mine shafts and boreholes. In the most disturbed central part, except for areas not colonized by vascular plants, two types of habitats are widely distributed: dry habitats on waste heaps were colonized by community with *Calamagrostis epigejos*, while moist places were occupied by reed swamps (*Phragmitetum australis*), which occurred along the Rinne Stream and Velyky Lukavets River as well. Other plant communities occupied small areas and were scattered (*e.g.*, patches of sedge or *Typha* swamps, fens, wet meadows), however, fresh meadows and pastures dominate on the slopes of the valley.

Among the most interesting habitats are halophytic plant communities, including aggregation of salt-tolerated vascular plant species. Contemporary flora of vascular plants in the studied area counted 230 species. Among them, 80 species are considered in Europe as salt-tolerant (Wilkoń-Michalska, 1963; Lindacher, 1995; Zarzycki *et al.*, 2002). They showed different salt tolerance and frequency in saline habitats. Halophytes indicating higher salt concentration in the soil are given in Table 2.

The most salt-tolerated vegetation is represented by communities from the order *Glauco-Puccinellietalia* and *Asteretea tripolium* class: *Puccinellio-Spergularietum salinae* with *Spergularia salina*, *Puccinellia distans*, and *Lotus tenuis*, and community with *Triglochin maritimum* connected with flows and wetter parts of halophytic habitats. Dips filled with water in the vicinity of salt water sources were occupied by *Scirpetum maritimi* with dominating *Schoenoplectus tabernaemontani* from the *Phragmitetea*

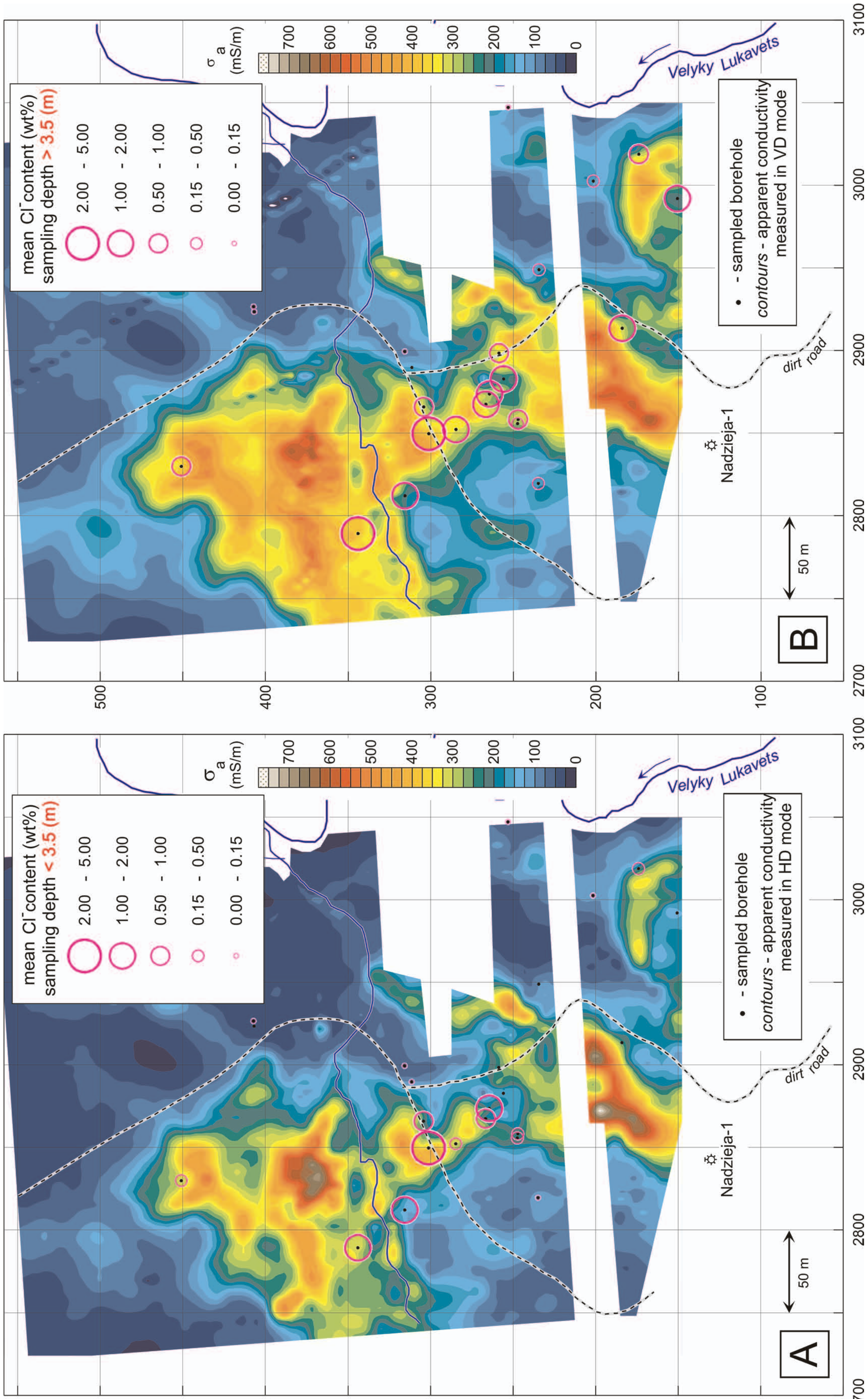

Fig. 2. (**A**) apparent conductivity contours based on electromagnetic induction profiling with Geonics EM31 – HD mode and mean content of Cl^- ions in samples taken from depth range 0–3.5 m; (**B**) apparent conductivity contours based on electromagnetic induction profiling with Geonics EM31 – VD mode and mean content of Cl^- ions in samples taken from sediments deeper than 3.5 m

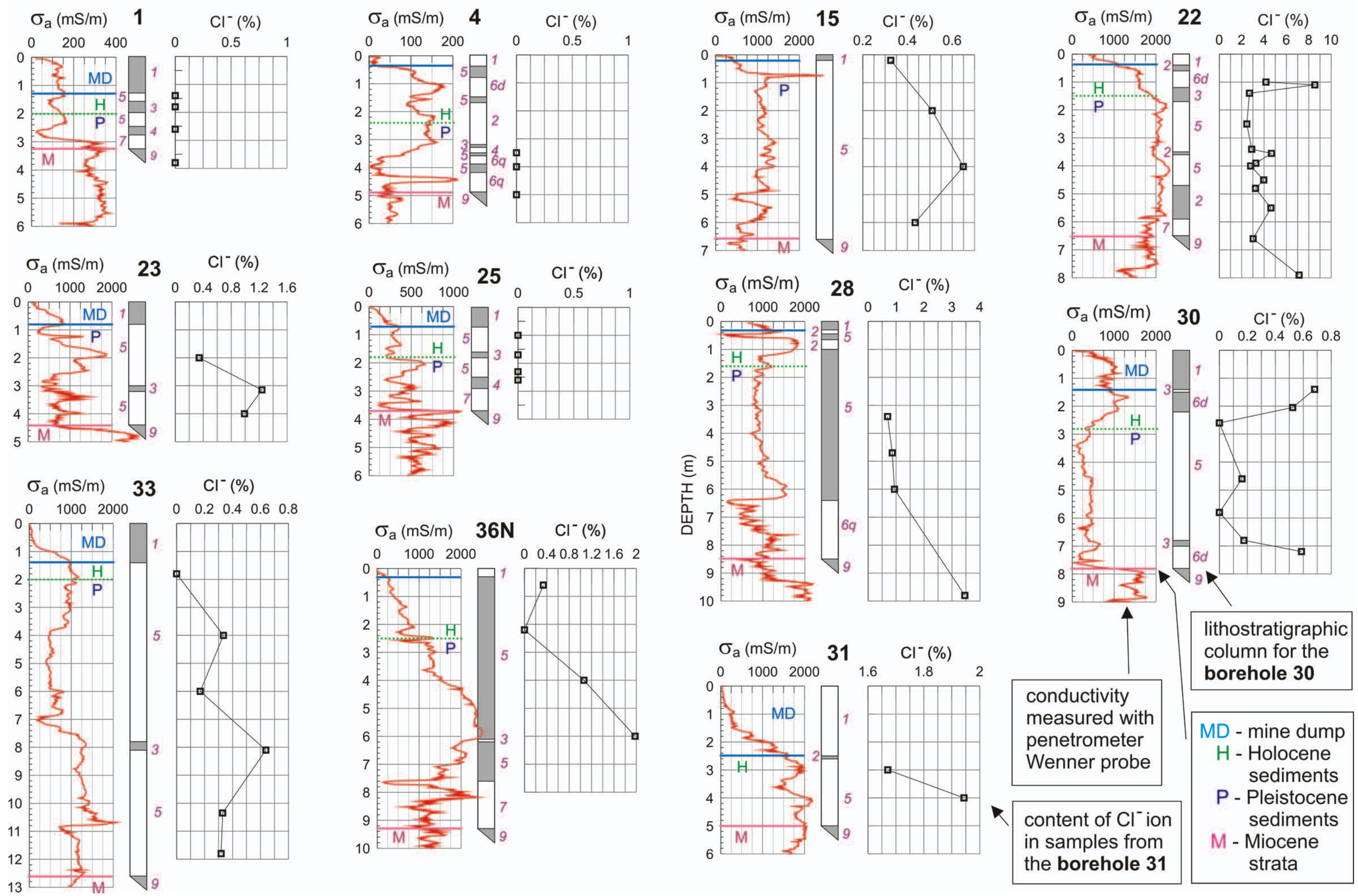

Fig. 3. Distribution of conductivity of sediments with depth from penetrometer-based measurements, lihostratigraphic profiles interpreted from cores, and Cl^- ions content in analysed samples. Symbols: 1 – mine dump, 2 – peat, 3 – peat mud, 4 – biogenic mud, 5 – clayey mud, 6d – mud saturated by bitumine, 6g – coarse and clastic saturated by bitumen, 7 – gravel, 8 – sand, 9 – Miocene salt-bearing strata

class. Communities from the *Molinio-Arrhenatheretea* class, occurring on the soils affected by salt water, are represented by *Blysmo-Juncetum compressi* from *Trifolio fragiferae-Agrostietalia stoloniferae* order, and *Arrhenatheretum elatioris lotetosum tenuifolii* from the order *Arrhenatheretalia*.

To characterize the distribution of halophytic plant communities, the studied area was divided into two parts: I and II (Fig. 6). In part I, halophytic plant communities from the class *Asteretea tripolium* occur around Nadzieja-1 well, other boreholes and old shafts, in the vicinity of the brine spring east of the Nadzieja-1 well, and along salt-water flowing from these sources between spoil heaps to the Rinne Stream and Velyky Lukavets River. In part II, halophytic habitats form a mosaic with meadows from the *Molinio-Arrhenatheretea* class, *Phragmites australis* swamps (class *Phragmitetea*), and ruderal plant communities (*e.g.*, community with *Calamagrostis epigejos*), where halophytes are also present (especially in the meadows and pastures). Halophytes are light-demanding species and, there-

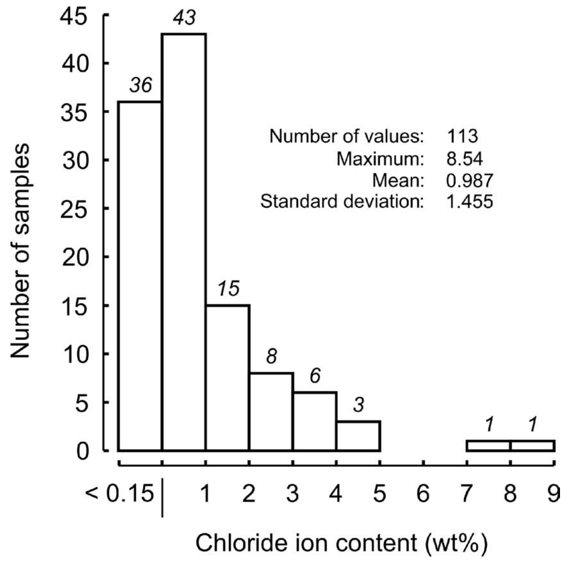

Fig. 4. Histogram of the chloride ion content in the samples

Table 1

Results of chemical analyses of samples from boreholes

Borehole	Depth (m)	Cl⁻ (wt%)	Borehole	Depth (m)	Cl⁻ (wt%)	Borehole	Depth (m)	Cl⁻ (wt%)	Borehole	Depth (m)	Cl⁻ (wt%)
1	1.40	0.00	7	5.20	2.62	25	1.00	0.00	32N	1.00	0.17
	1.80	0.00		6.55	2.04		1.70	0.00		2.00	1.31
	2.60	0.00		9.30	0.00		2.30	0.00		3.00	2.09
	3.80	0.00		10.40	0.00		2.60	0.00		4.00	3.09
4	3.50	0.00	8	0.50	0.18	27'	8.00	0.85		5.00	2.57
	4.00	0.00		1.50	0.18		9.50	1.43	33	1.80	0.00
	5.00	0.00		2.50	0.17	28	3.40	0.70		4.00	0.33
4'	1.00	0.00		3.50	0.00		4.70	0.86		6.00	0.17
	1.30	0.00		3.80	0.00		6.00	0.94		8.10	0.64
	1.40	0.00	15	0.20	0.33		9.80	3.46		10.35	0.33
	2.00	0.00		2.00	0.51	30	1.40	0.68		11.80	0.32
	3.00	0.00		4.00	0.65		2.05	0.52	36N	0.60	0.34
	3.70	0.00		6.00	0.43		2.60	0.00		2.20	0.00
	4.00	0.00	22	1.00	4.17		4.60	0.16		4.00	1.06
	4.65	0.00		1.10	8.54		5.80	0.00		6.00	1.98
	4.85	0.00		1.40	2.70		6.80	0.18	37	6.00	1.06
4N	1.40	0.17		2.50	2.46		7.20	0.59	38	11.00	0.51
	2.50	0.00		3.40	2.89	30N	2.90	0.42		12.90	0.00
	3.50	0.00		3.55	4.66		4.60	0.68	42	3.70	1.85
	4.15	0.00		3.90	3.26		5.00	0.68		3.80	0.76
	6.30	0.00		4.00	2.80		6.00	1.03		4.60	0.77
	6.40	0.51		4.50	3.97		7.20	0.51		6.45	0.70
5N	2.10	0.16		4.80	3.24		7.30	0.69		8.40	0.00
	2.70	0.20		5.50	4.61		8.20	0.00		8.50	0.17
	3.70	0.00		6.60	3.02		8.80	0.68	43	3.30	1.68
	4.70	0.37		7.90	7.13	31	3.00	1.67		4.50	0.86
	5.50	0.93	23	2.00	0.34		4.00	1.94		5.40	1.02
	6.50	1.18		3.15	1.24					6.70	1.04
				4.00	0.99					7.70	1.39

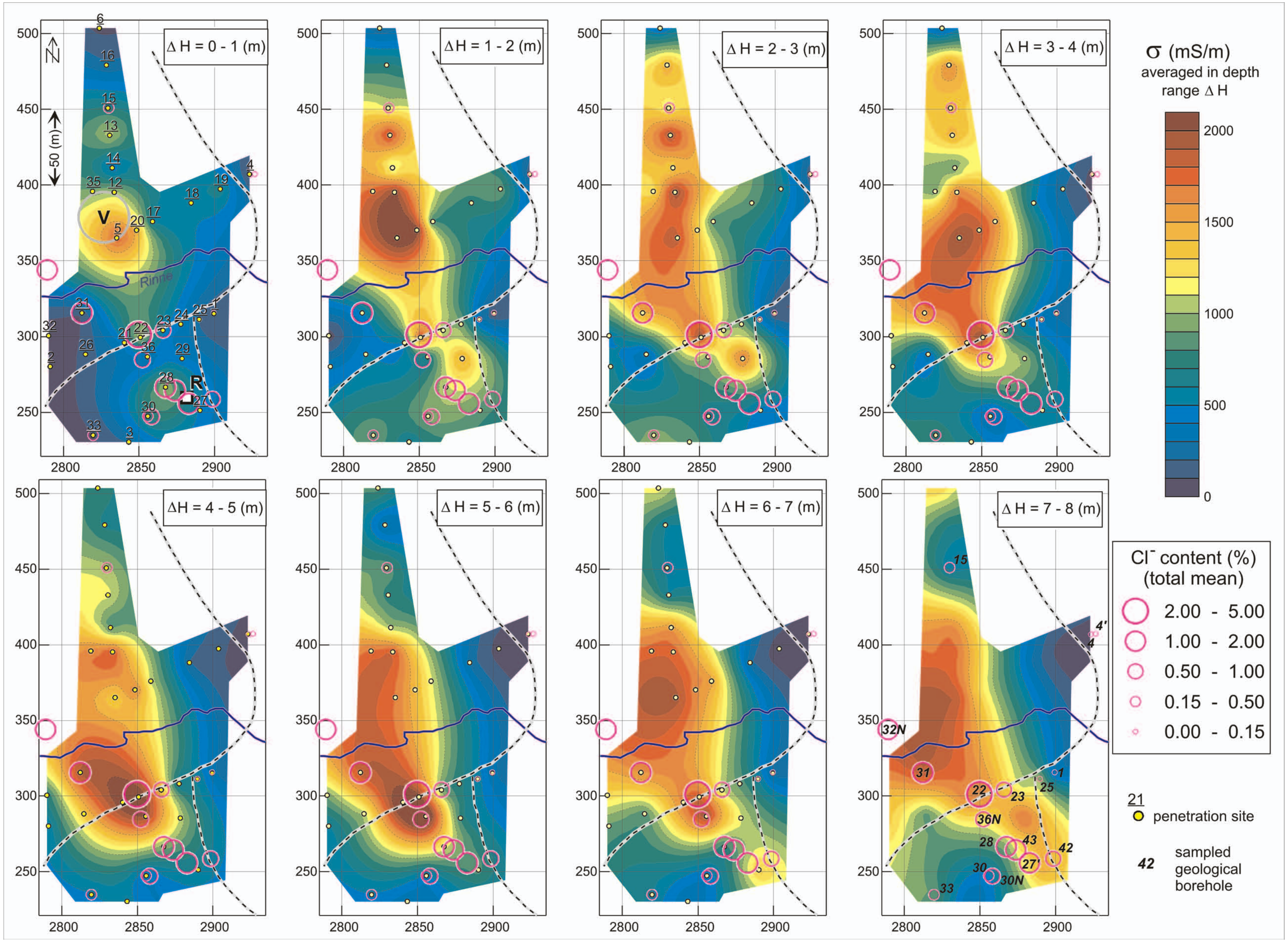

Fig. 5. Contours of mean conductivity of sediments in 1 m wide depth windows and chloride ion content data with location of sampled boreholes. Each map was drawn for different depth window. Salinity data – mean values for all samples from a given borehole

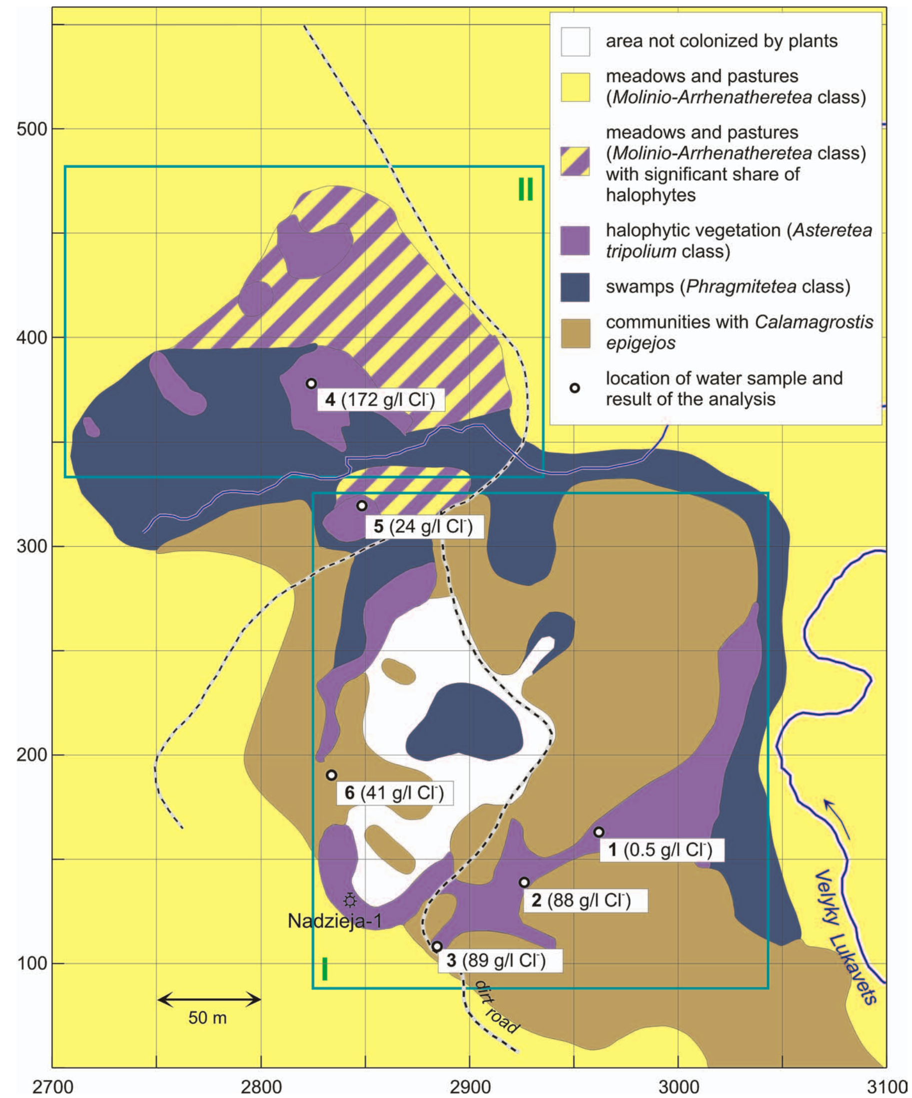

Fig. 6. Vegetation map of the study area. I and II – two main areas of distribution of halophytes, 1–6 – location of water samples analyzed for chloride ion content

fore, swamps with extremely expansive and tall *Phragmites australis* can reduce their distribution on the soils with lower salt concentration. Smaller patches of halophytic vegetation in the upper part of the slope were connected with saline spring (the most western patch), as well as old boreholes (Jadwiga, Kaufmann 1), and the biggest one occurred around main mud volcano. Generally, the pattern of halophytes distribution reflect presence of salt water sources, and their flows and soils affected by them. The Rinne Stream collects saline water flowing from the above mentioned sources, but no water halophyte was noted.

Vegetation of saline soils represent three types of distribution: (*i*) concentric (around saline source, *e.g.*, around mud volcano in part II, springs on slopes of the valley in both parts of the study area, and places inundated by saline water), (*ii*) linear (along narrow salt water flows meandering between waste heaps in part I), and (*iii*) scattered (on dry waste heaps in part I). On the vegetation map (Fig. 6), areas occupied by all types were marked together as communities from the class *Asteretea tripolium*. In the first two types of vegetation distribution, characteristic zonation of plant communities depending on the salinity of soil was observed. In the linear type of distribution, a stream of saline water was occupied by communities with *Triglochin maritimum* and other obligatory halophytes, on the edges appeared single non-halophilous plants together with halophytes, and the next were plant communities with dominance of non-halophilous plants. In the concentric type of distribution, there was a characteristic area with the lack of plants localized in the closest surrounding of saline flow, especially wide around the mud volcano and old shafts in part II, and much smaller around saline springs in both parts. Because of the mosaic character and small-area patches of saline vegetation, places uncovered by plants are not marked within halophytic patches in Fig. 6. The size of the area unoccupied by plants was related to salinity of water and capacity of the saline source. Vascular plants were not able to colonize this area because of too high salinity of outflows and soil. The salinity of water sampled from selected saline sources in September 2008 show value up to 178 g/l Cl^- ions in the mud volcano outflow (Fig. 6), whereas the obligatory halophytes noted in Starunia were able to grow on soil with much lower salinity. *Spergularia salina* colonized the most saline soils (more than 23 g/l Cl^- ions; Table 2), forming the first zone of vegetation. Next was the zone of *Puccinellio-Spergularietum*, where *S. salina* co-occurred with *Puccinellia distans*, *Lotus tenuis*, and other species, mainly facultative halophytes, and the last was zone of meadows, swamps or ruderal communities with halophytes. The number of halophytes gradually decreases with distance to saline source, while the number of non-halophilous species increases. Besides above mentioned types of distribution, halophytic vegetation also shows mosaic of patches with different plant communities.

COMMENTS

Although three different methods were applied in this study, the target was the same: document the salinity of sediments, underground water and soils (vegetation). Therefore, the results of individual methods, despite more or less obvious differences, complement one another.

In Fig. 2 apparent conductivity contours based on electromagnetic induction profiling method are set together with salinity results obtained from chemical analyses of core samples. Fig. 2A presents the distribution of conductivity and salinity within top 3–3.5 metres of the near-surface sediments, while Fig. 2B gives a comparison of data from deeper strata. There is generally a good correlation between salinity and conductivity data, especially for deeper sediments, *i.e.* for s_{VD} and salinity for depth > 3.5 m (Fig. 2B). When analyzing differences one should bear in mind that salinity data from cores are "point data", while apparent conductivity from surface profiling are "spatially averaged data", so only qualitative comparison can be made for these data sets. The situation is a bit different in the case, where results of botanical studies (Fig. 6) are compared with shallow conductivity data (Fig. 2A). Both data are presented in the form of surface maps, although depth range for both types of information is different. There are places of good correlation between presence of halophytes and higher apparent conductivity of near-surface sediments. This mainly occurred in the vicinity of the mud volcano and north of that point. In no other parts of the study area such obvious relations can be observed. Therefore, it may be guessed that in other places, except mud volcano and its vicinity which are colonized by halophytes, the higher amount of salt is present only in the thin top soil layer. Such local soil enrichment in salt can be an effect of local intense outflows of brines or seasonal floods.

Distribution of salinity with depth can be assessed from Fig. 3, where vertical profiles of conductivity, results of sample analyses and lithostratigraphy of sediments are set together. Generally higher Cl^- ion content is confirmed by higher conductivity value. For most places where Cl^- ions presence was not detected the conductivity is relatively low, too. Nevertheless, there are many exceptions to these "rules". The main reason lies in a different location of the boreholes and penetration sites (technically it is not possible

Table 2

Halophytes noted in Starunia with their salinity tolerance, according to Lindacher (1995)

Species	Phytosociological unit *
> 23 g/l Cl^- ions	
Spergularia salina J. Presl & C. Presl	*Asteretea tripolium* (*Puccinellio-Spergularietum salinae*)
16–23 g/l Cl^- ions	
Triglochin maritimum L.	*Asteretea tripolium*
12–16 g/l Cl^- ions	
Puccinellia distans (Jacq.) Parl.	*Asteretea tripolium* (*Puccinellio-Spergularietum salinae*)
Juncus gerardi Loisel.	*Asteretea tripolium*
7–9 g/l Cl^- ions	
Carex distans L.	*Molinio-Arrhenatheretea* (*Blysmo-Juncetum compressi*)
5–7 g/l Cl^- ions	
Lotus tenuis Waldst. & Kit. ex Willd.	*Asteretea tripolium*, *Molinio-Arrhenatheretea* **
Trifolium fragiferum L.	*Molinio-Arrhenatheretea* (*Blysmo-Juncetum compressi*)
3–5 g/l Cl^- ions	
Schoenoplectus tabernaemontani (C. C. Gmel.) Palla	*Phragmitetea*
Triglochin palustre L.	*Molinio-Arrhenatheretea (Blysmo-Juncetum compressi)*
0.5–3 g/l Cl^- ions	
Melilotus altissima Thuill.	*Artemisietea vulgaris*
0–1 g/l Cl^- ions	
Achillea millefolium L.	*Molinio-Arrhenatheretea*
Blysmus compressus (L.) Panz. ex Link	*Molinio-Arrhenatheretea* (*Blysmo-Juncetum compressi*)
Carex cuprina (I. Sándor ex Heuff.) Nendtv. ex A. Kern.	*Molinio-Arrhenatheretea* (*Blysmo-Juncetum compressi*)
Carex nigra Reichard	*Scheuchzerio-Caricetea nigrae*
Centaurium pulchellum (Sw.) Druce	*Molinio-Arrhenatheretea* (*Blysmo-Juncetum compressi*)
Juncus articulatus L. emend. K. Richt.	*Scheuchzerio-Caricetea nigrae*
Juncus compressus Jacq.	*Molinio-Arrhenatheretea* (*Blysmo-Juncetum compressi*)
Potentilla anserina L.	*Molinio-Arrhenatheretea* (*Blysmo-Juncetum compressi*)
Sonchus arvensis L. subsp. *uliginosus* (M. Bieb.) Nyman	*Phragmitetea*
Typha angustifolia L.	*Phragmitetea*
Typha latifolia L.	*Phragmitetea*

For the last group (0–1 g/l Cl^- ions) only examples are given. * – according to Matuszkiewicz (2001) and Zarzycki *et al*. (2002), ** – in the study area to make two holes in the same place) and high heterogeneity of the geological medium. For more general assessment of depth/surface variability of sediments, electric properties the conductivity values were averaged in 1 m wide depth windows for each penetration site. Then, these mean values of conductivity were used for making maps of different depths – depth slices, shown in Fig. 5. Information about core samples salinity was added to these maps.

CONCLUSIONS

Three different methods were applied in the area of the abandoned ozokerite mine at Starunia to assess salinity of the sediments, underground water and soils (vegetation).

Electromagnetic terrain conductivity measurements with Geonics EM31 enabled the determination of the surface extent of high-conductivity Quaternary sediments, which may be identified with sediments filled with saline water.

In the vicinity of saline water outflows specific vegetation was noted, with halophytes indicating increased salt concentration in the soil. Their range partly correlates with surface distribution of apparent conductivity of the near-surface sediments.

The distribution of salinity with depth was investigated directly by chemical analysis of sediment samples taken from boreholes and indirectly by penetrometer-based conductivity measurements. The highest chloride ion concentration reported in samples reached nearly 8.5 wt%. Both near-surface sediments and deeper strata (including Miocene) are highly saline, what is quite visible on the conductivity maps for different depths.

Acknowledgements

Financial support from the Ministry of Science and Higher Education (grant No. 139/UKR/2006/01) is kindly acknowledged. Review comments and suggestions by Jan Bromowicz and Jerzy Fijał of the AGH University of Science and Technology in Kraków were very helpful. We would like to express our gratitude to Paul Lillis of U.S. Geological Survey in Denver for his critical comments, which improved this paper.

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