Annales Societatis Geologorum Poloniae (2009), vol. 79: 219–241.

INTERDISCIPLINARY STUDIES AT STARUNIA PALAEONTOLOGICAL SITE AND VICINITY (CARPATHIAN REGION, UKRAINE) IN THE YEARS 2006–2009: PREVIOUS DISCOVERIES AND RESEARCH, PURPOSES, RESULTS AND PERSPECTIVES

Maciej J. KOTARBA

Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland; e-mail: kotarba@agh.edu.pl

Kotarba, M. J., 2009. Interdisciplinary studies at Starunia palaeontological site and vicinity (Carpathian region, Ukraine) in the years 2006–2009: previous discoveries and research, purposes, results and perspectives. *Annales Societatis Geologorum Poloniae*, 79: 219–241.

Abstract: The discovery of large Pleistocene mammals in 1907 and 1929 in the Starunia ozokerite mine, about 130 kilometres southeast of Lviv, Ukraine, was a spectacular scientific event on a world scale. A unique combination of brine and oil, into which the animals had sunk, resulted in the near perfect preservation of woolly rhinoceros. In 2004, investigations in Starunia were restarted by Polish and Ukrainian scientists. This issue of *Annales Societatis Geologorum Poloniae* contains 18 papers which present the results of field and laboratory studies in the Starunia area completed by Polish scientists in the years 2006–2009. Interdisciplinary studies were realized by eleven thematic working groups on: Quaternary lithology and sedimentology, palaeobotany (palynology and analysis of macrofossils), botany (analysis of halophytes), palaeozoology (malacological analysis), radiocarbon dating, microbiology, surface and near-surface geochemistry, organic geochemistry (bitumen content and its fractions, biomarkers and stable carbon isotopes) and inorganic geochemistry (chloride ion analysis), geoelectric survey (DC resistivity soundings, electromagnetic terrain conductivity measurements, resistivity imaging, penetrometer-based resistivity profiling and azimuthal pole-dipole DC resistivity soundings) and microgravimetric survey. Results of these studies enabled recognition of the geological setting and sedimentary environment of Quaternary sediments, which hosted the Pleistocene fossils, and to determine the most favourable area of about 1,000 square metres for subsequent prospecting for extinct mammals within Pleistocene sediments in Starunia.

Key words: Starunia, abandoned ozokerite mine, palaeontological site, woolly rhinoceros, Pleistocene, Carpathian region, Ukraine.

Manuscript received 17 July 2009, accepted 15 September 2009

INTRODUCTION

The discovery of large Pleistocene mammals in the Starunia ozokerite (earth wax) mine was a spectacular scientific event on a world scale (*e.g.*, Alexandrowicz, 2002, 2004, 2005a, b). The Starunia palaeontological site is located in the Ukrainian Carpathians, in the Velyky Lukavets River valley, about 35 kilometres south of Ivano-Frankivsk (formerly Stanisławów) and about 130 kilometres southeast of Lviv (formerly Lwów) (Fig. 1). The initial discovery was made in 1907 when remains of mammoth and rhinoceros were excavated (Bayger *et al.*, 1914). Later, in 1929, the Polish Academy of Arts and Sciences (Polska Akademia Umiejętności – PAU) organized a scientific expedition to the site, which discovered a nearly complete woolly rhinoceros carcass at a depth of 12.5 metres (Fig. 2). A unique combination of oil and brine, into which the animal had sunk, was responsible for almost perfect preservation of this specimen. Together with this discovery the remnants of two more rhinoceroses have been found at this site, along with numerous specimens of other Pleistocene fossil fauna and flora.

These specimens are now displayed at museums in Ukraine and in Poland: those found in 1907 are exhibited at the Natural History Museum of the National Academy of Sciences of the Ukraine (the former Dzieduszycki Family

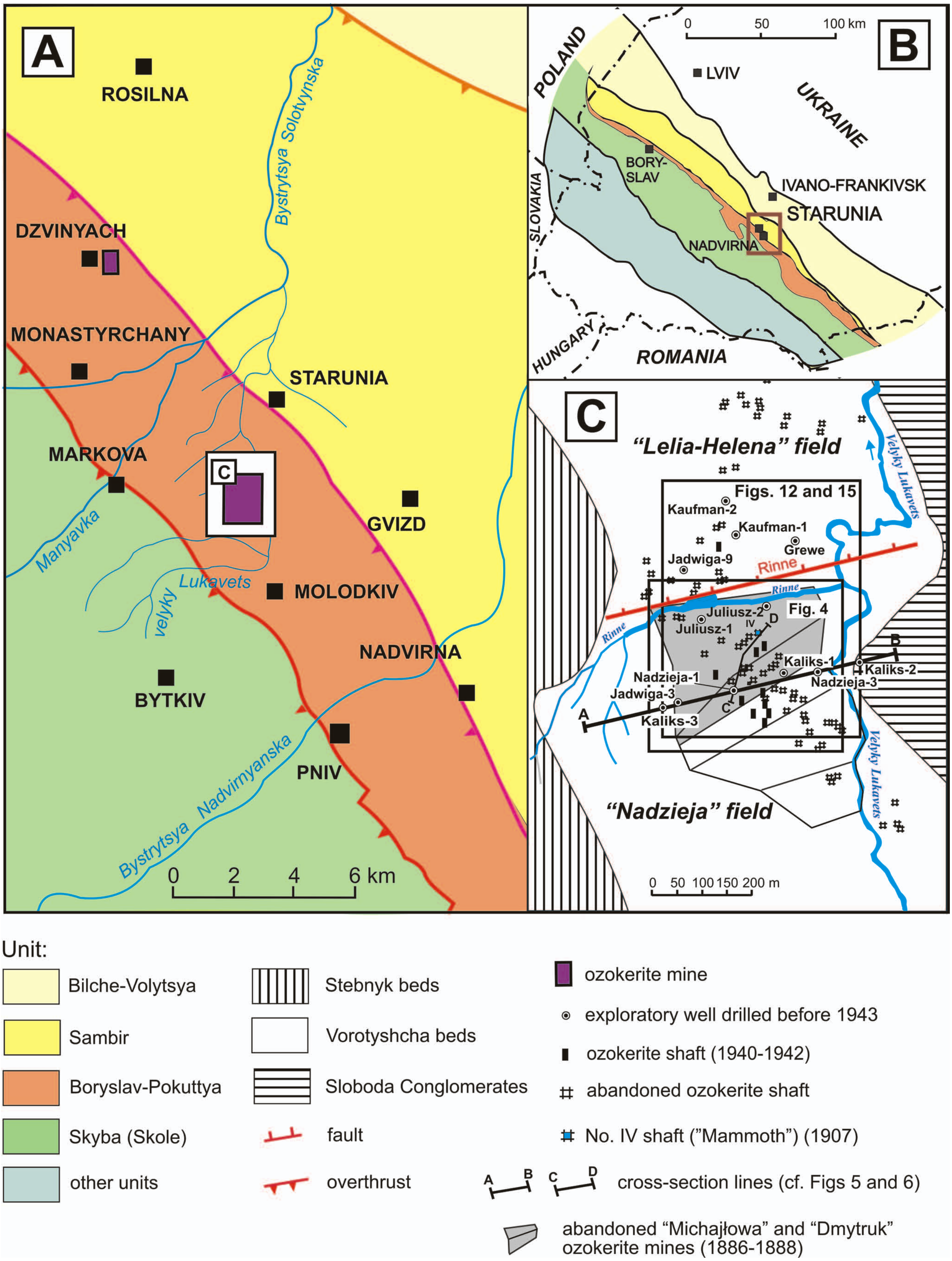

Fig. 1. (**A** and **B**) Sketch-maps showing major tectonic units of the Ukrainian Outer Carpathians and Carpathian Foredeep Basin in the Dzvinyach – Nadvirna area after Adamenko *et al.* (2005a) and Kotarba & Stachowicz-Rybka (2008), and (**C**) geological map of the Starunia ozokerite deposit after Mitura (1944) with author's modification

Museum) in Lviv, Ukraine (Kubiak & Drygant, 2005; Chornobay & Drygant, 2009), whereas specimens excavated in 1929 are displayed at the Natural History Museum and at the Institute of Systematics and Evolution of Animals of the Polish Academy of Sciences, both in Kraków, Poland (Kubiak & Drygant, 2005; Kubiak, 2009).

This paper presents an outline of geology, general remarks about petroleum occurrence, history of ozokerite production and discoveries of large, extinct Pleistocene vertebrates as well as previous scientific investigations in the Starunia area. Special attention was paid to programme, purposes and results of comprehensive, interdisciplinary investigations carried out in the years 2006–2009. Consideration was given to preservation and conservation of yet-to-be discovered woolly rhinoceroses and/or mammoths in this area, apart from discoveries from 1907 and 1929.

Fig. 2. The "second" woolly rhinoceros after conservation works in the Natural History Museum in Kraków. Photo by P. Witosławski

OUTLINE OF GEOLOGY AND PETROLEUM OCCURRENCE

The Ukrainian Carpathians belong to the largest petroleum provinces of Central Europe, constituting one of the oldest petroleum-producing regions in the world. Exploitation of oil and natural gas began in 1854 and 1921, respectively (*e.g.*, Kotarba & Koltun, 2006). The Carpathian ozokerite deposits: Boryslav, Volanka, Truskavets-Pomiarki, Dzvinyach, Starunia and a few minor accumulations hosted in the Boryslav-Pokuttya Unit of the Carpathian Foredeep (Koltun *et al.*, 2005) are among rare ozokerite occurrences in the world. These deposits are hosted by fractured and brecciated Miocene strata, over the hinge parts of the oil-bearing, anticlinal flysch structures (Bojko & Sozański, 2004).

The Carpathian thrust-and-fold belt consists of a number of nappes forming the Outer Carpathians and the inner part of the Carpathian Foredeep Basin, thrust generally towards the north-east. The Boryslav-Pokuttya Unit is the main oil reservoir of the Carpathian Province (*e.g.*, Kotarba & Koltun, 2006; Ślączka *et al.*, 2006). In the Starunia area and its vicinity, two tectonic units of the Carpathian Foredeep occur: the Sambir and the Boryslav-Pokuttya units as well as the external part of the Skyba Unit, the latter belonging to the Outer Carpathians (Fig. 1). Lithostratigraphic columns of these units are presented in Fig. 3. Tectonically, the Boryslav-Pokuttya Unit represents a stack of superimposed nappes, each of them comprising the flysch sequence covered by the molasse. The Oligocene Menilite beds rest upon the top of the flysch succession and are considered to be the most important hydrocarbon source rock with relatively high organic matter content (up to 20 wt%; Kotarba & Koltun, 2006). The salt-bearing Lower Miocene Vorotyshcha beds provide a seal for the hydrocarbon traps. To the south and southwest from the Starunia ozokerite deposit, both the Palaeogene and Neogene reservoirs of the Boryslav-Pokuttya and Skyba units host six oil and gas fields: Gvizd, Southern (Pivdenny) Gvizd, Monastyrchany, Pniv, Pasichna, and Bytkiv-Babche (Adamenko *et al.*, 2005a; Koltun *et al.*, 2005).

HISTORY OF OZOKERITE AND OIL EXPLOITATION, AND GEOLOGICAL SETTING OF THE STARUNIA DEPOSIT

Ozokerite mining at Starunia commenced in 1868 (Alexandrowicz, 2004; Adamenko *et al.*, 2005a). According to archival materials of the District Mining Bureau in Stanisławów collected at the State Municipal Archive in Ivano-Frankivsk (Kotarba & Stachowicz-Rybka, 2008), in 1886 there were 109 operating shafts in "Michajłowa" and "Dmytruk" Mines belonging to a dozen owners (Fig. 4).

In 1907 the "Michajłowa-Dmytruk" Mine was started by the "J. Campe and Co." mining enterprise based in Hamburg. The mining lot included cadastral parcels Nos 3324 to 3330 (Fig. 4) (Kotarba & Stachowicz-Rybka, 2008). In the years 1907–1908 several new shafts were sunk and the existing shafts were reconstructed (Mitura, 1944; Kotarba & Stachowicz-Rybka, 2008). The general map (Fig. 4) shows the locations of shafts and wells completed in the years 1886–1942. The later history of ozokerite mining in the Starunia area was described in detail by Mitura (1944), Alexandrowicz (2004, 2005a, b), Bojko and Sozański (2004), Adamenko *et al.* (2005a), and Kotarba and Stachowicz-Rybka (2008). Ozokerite mining was abandoned in 1960 (Bojko & Sozański, 2004).

In the Starunia area, ozokerite was discovered at depths ranging from 10 to about 500 metres. This lies within the salt-bearing Lower Miocene Vorotyshcha beds, which rest upon the flysch of the Boryslav-Pokuttya Unit. The Boryslav-Pokuttya Unit forms several, stacked slice-folds, each of them built of a flysch succession covered by molasse sediments. In the top part of the flysch succession, the Oligocene–Lower Miocene Menilite beds occur (Fig. 3). This unit comprises intercalated black claystones and mudstones, which are excellent hydrocarbon source rocks, and the Kliwa Sandstones, which are the hydrocarbon reser-

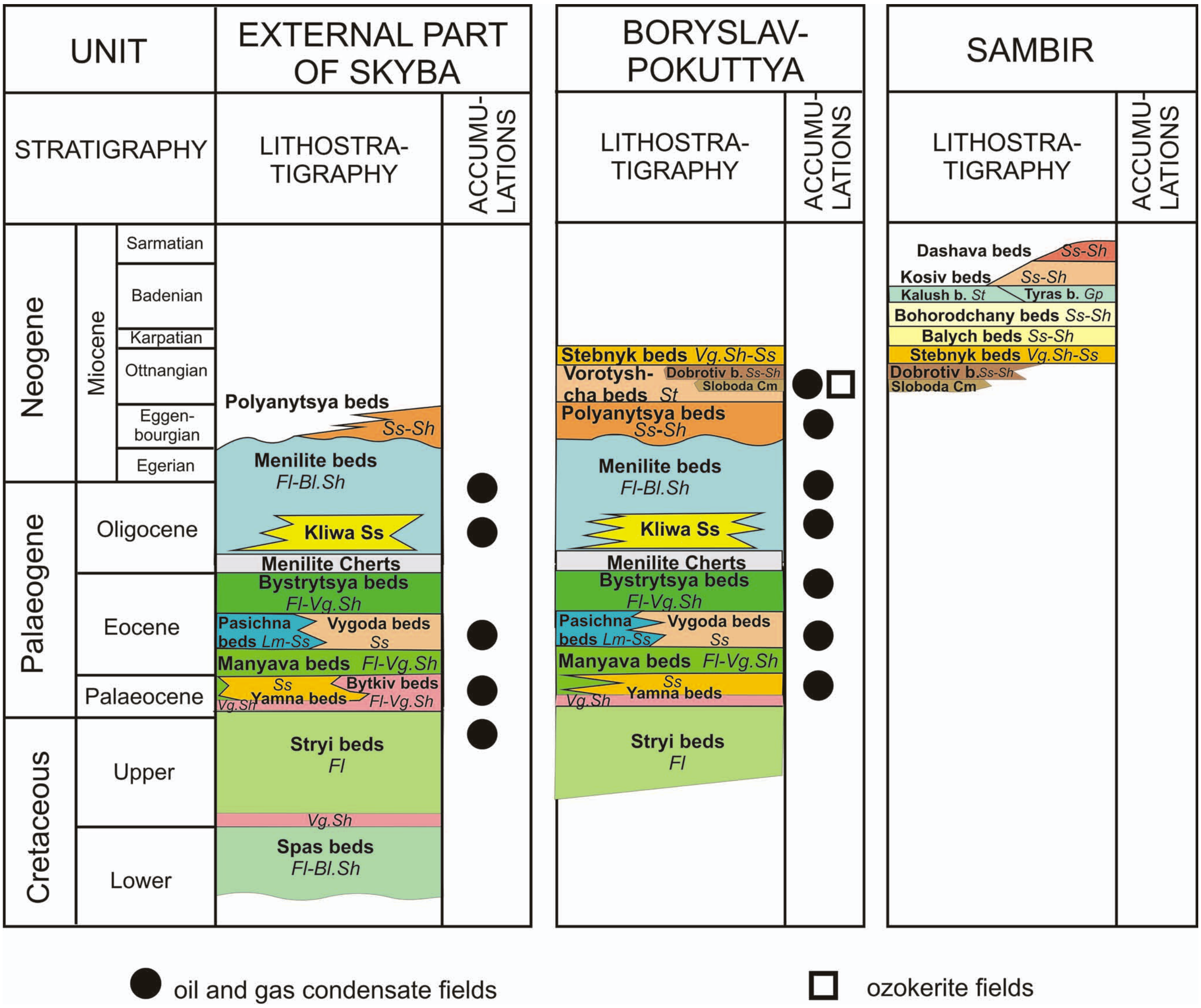

Fig. 3. Generalized lithostratigraphic columns of the Skyba, Boryslav-Pokuttya and Sambir units after Vialov *et al.* (1988), Andreeva-Grigorovich *et al.* (1986, 1997) and Kulchytsky & Sovchyk (1986), showing the distribution of flysch and molasse facies and ozokerite, oil and gas accumulations in the Starunia area. Fl – flysch; Bl.Sh – black shales; Vg.Sh – variegated shales; Ss – sandstones; Ss-Sh – sandstones and shales intercalations; Lm – limestones; St – salt-bearing strata, Cm – conglomerates; b. – beds

voirs. Another important reservoir horizon in the Starunia area is located in the Middle Eocene sandstones (Koltun *et al.*, 2005). The flysch succession of the Boryslav-Pokuttya Unit is covered by the Lower Miocene Polyanitsya beds (Fig. 3), which are absent from the Starunia fold, as well as the Vorotyshcha beds, which host rock-salt and potassium salt seams as well as ozokerite veins and nests (Fig. 5). Locally, the Vorotyshcha beds are replaced by the Sloboda Conglomerates and the Dobrotiv beds (Fig. 3). The youngest unit of the Lower Miocene complex is named the Stebnyk beds (Fig. 3). The salt-bearing Vorotyshcha beds, up to 500 metres thick, comprise claystones and mudstones intercalated by sandstones and thin-bedded marls with layers, lenses and veinlets of gypsum, pyrite, native sulphur, rock-salt and potassium salt (Mitura, 1944; Korin, 2005).

Ozokerite veins and layers, usually from 2 to 30 centimetres (rarely up to several metres) thick, occur exclusively within the salt-bearing Lower Miocene Vorotyshcha beds (Figs 5, 6). Common is also the so-called "ozokerite rock" (Fig. 6), which is composed of fragments of hard, calcareous sandstones and/or gypsum, all coated with ozokerite. The top surface of the Miocene Vorotyshcha beds in the Starunia area, which underlie Quaternary sediments, occurs at a maximum depth of 17 metres (Sokołowski *et al.*, 2009). In the area of the abandoned Starunia ozokerite mine, the Quaternary sediments are mainly developed as clayey muds with plant remains, peat, biogenic muds and peat muds (Sokołowski *et al.*, 2009; Sokołowski & Stachowicz-Rybka, 2009).

The Starunia ozokerite deposit is cut by the Rinne Fault (Mitura, 1944), which extends from the Rinne Stream to the south (*i.e.*, to the "Nadzieja" mining field) and to the north (to the "Lelia-Helena" mining field; Fig. 1C). The "Nadzieja" field is an eroded anticline whose axial surface is inclined to the southwest. The "Lelia-Helena" field is a full anticline (Mitura, 1944).

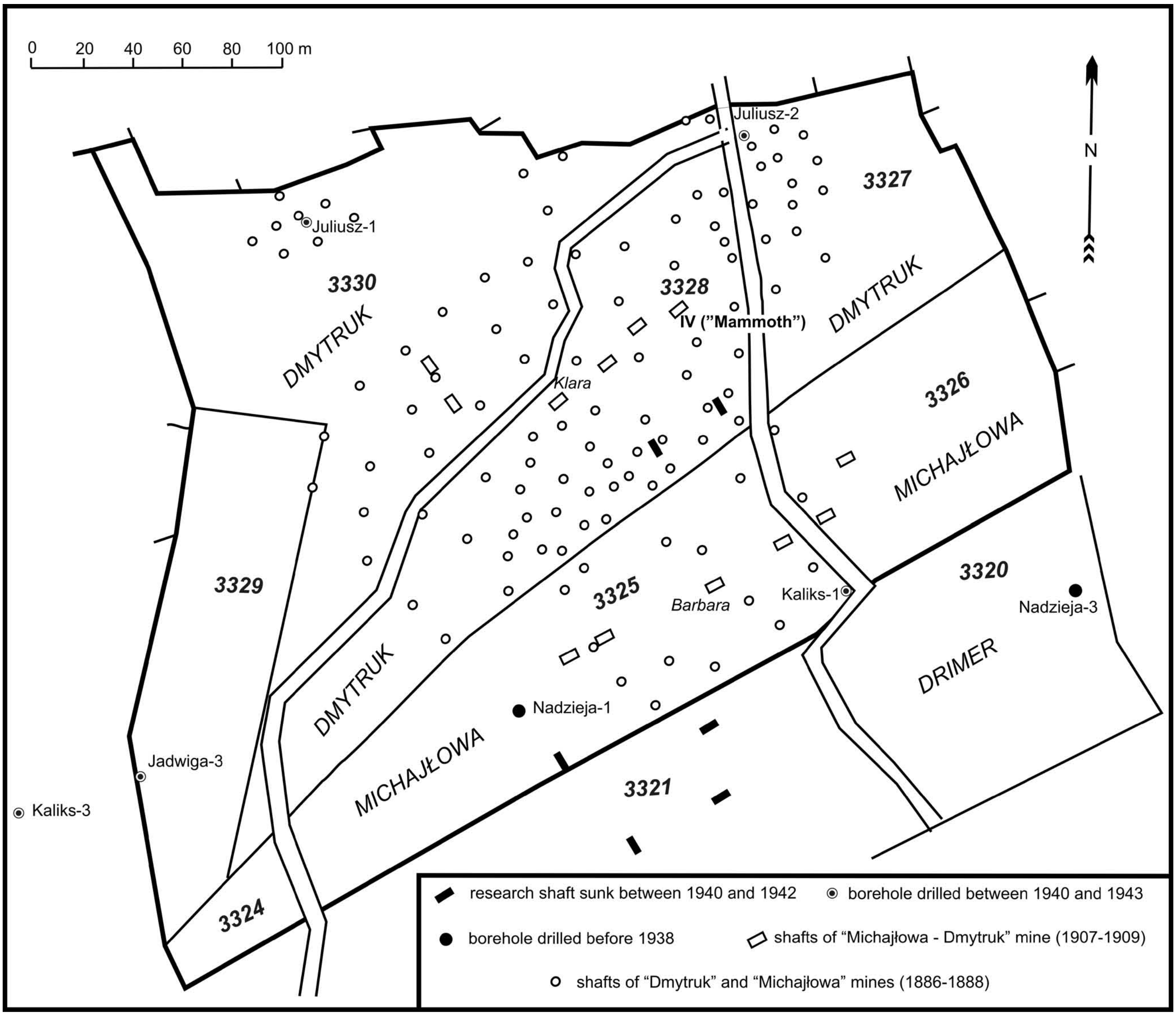

Fig. 4. Map of location of shafts and exploratory wells of abandoned "Michajłowa-Dmytruk" mine of "J. Campe and Co." mining enterprise on cadastral parcels Nos 3324, 3325, 3326, 3327, 3328, 3329 and 3330 in Starunia after Mitura (1944) and Kotarba and Stachowicz-Rybka (2008). *Dmytruk, Michajłowa and Drimer* – name of mining plots

Ozokerite reserves of the "Nadzieja" field were estimated at about 400,000 tons. Those of the "Lelia" field can be even larger (Mitura, 1944). Total production from the Starunia deposit between 1868 and 1960 is estimated at over 5,000 tons (Alexandrowicz, 2004), which means that the remaining mineable ozokerite reserves are still significant.

In the years 1885–1942, in the Starunia area, 20 exploration boreholes were drilled (Zubrzycki, 1938; Mitura, 1944). Industrial accumulations of oil and gas were encountered only in the Nadzieja-1 well. In 1929, daily oil production was 4,000 kg but decreased to only 300 kg in 1940 (Zubrzycki, 1938; Mitura, 1944). This well was closed just after the World War II due to technical failure.

In the years 1950–1970, several tens of boreholes were drilled in the Starunia area, which enabled the geologists to recognize in detail the structure of the Boryslav-Pokuttya Unit as well as led to localizing the Starunia and the Gvizd folds. In 1963, in the Gvizd fold, which borders the Starunia fold from the NE, the Gvizd oil deposit was discovered (Koltun *et al.*, 2005; Adamenko *et al.*, 2005a).

It was found that in the Starunia fold the Vorotyshcha beds were sliced, fractured and cracked during the Carpathian overthrust movements. As oil and gas were flowing from the flysch strata towards the surface and most of gaseous hydrocarbons were emitted to the atmosphere, liquid hydrocarbons saturated Quaternary sediments, and higher hydrocarbons formed veins of ozokerite. Therefore, in the rocks of the Starunia fold one of the largest world accumulations of ozokerite was formed, but the fold is not a prospective structure for further oil and gas exploration. However, oil, which still seeps at the surface forming "mud volcanoes", "oil eyes" and even small ponds (Kotarba *et al.*, 2005a), is one of the most important genetic factors of ozokerite deposits. Liquid hydrocarbons, which form the surface seeps and which saturate the relics of woolly rhinoc-

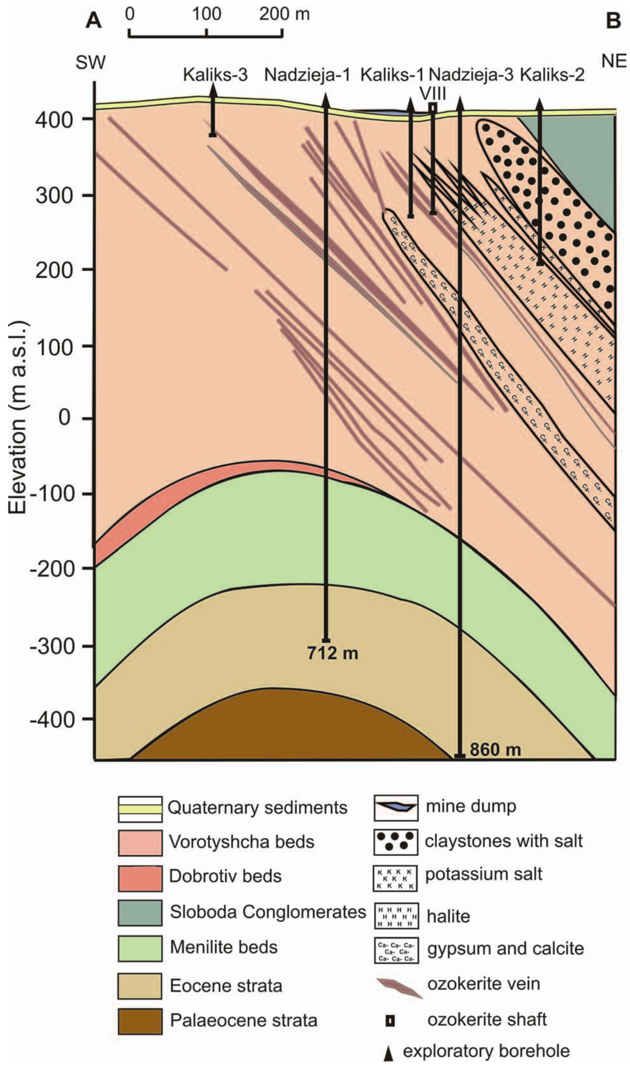

Fig. 5. Geological cross-section through the Starunia ozokerite deposit after Zubrzycki (1938), Mitura (1944) and Koltun *et al.* (2005). For location of cross-section see Fig. 1C

eroses are related to oil reservoirs in the Oligocene/Eocene Boryslav–Pokuttya Unit, *i.e.* the rock succession which builds the Starunia fold and adjacent structures: Bytkiv, Gvizd, Markova and Monastyrchany. These hydrocarbons were generated from the Oligocene Menilite beds (Kotarba, 2002; Kotarba *et al.*, 2005a, 2009b, c).

Lithostratigraphy and tectonics of the Starunia area and vicinity were studied and described by many Polish and Ukrainian authors, *e.g.*: J. Łomnicki (1911), M. Łomnicki (1908, 1914b), Nowak (1917), Nowak and Panow (1930), Mitura (1944), Rogala (1907), Tokarski (1930), Tołwiński (1927), Zuber (1885, 1888), and recently, Alexandrowicz (2004), Alexandrowicz *et al.* (2005), Koltun *et al.* (2005), Korin (1992, 1994a, 1994b, 2000, 2005), Kotarba and Stachowicz-Rybka (2008), Kotarba *et al.* (2008a), Monchak and Grodetska (1987), Sokołowski *et al.* (2009), Sokołowski and Stachowicz-Rybka (2009), and Stachowicz-Rybka *et al.* (2009a, b) (see also references therein). The first geological map was prepared by Zuber (1888), updated by J. Łomnicki (see Bayger *et al.*, 1914), and was reprinted in Kotarba (2005) and Kotarba *et al.* (2008a).

The occurrence and exploitation of ozokerite, oil and gas in Starunia were described by Windakiewicz (1875a, 1875b), Szajnocha (1881, 1892), Siegfried (1912), Bujalski (1928, 1929), Zubrzycki (1938), Mitura (1944), Baranovskiy and Sukharev (1959), Bojko (1967) and AOGFU (1998), and recently by Adamenko *et al.* (2005a), Alexandrowicz (2002, 2004, 2005a, 2005b), Bojko and Sozański (2004), and Kotarba and Stachowicz-Rybka (2008).

OCCURRENCE AND DISCOVERY OF SALTS AND BRINES

Brine and salt water springs are widely distributed in the Eastern Carpathians within the Quaternary sediments (Kuźniar, 1930; Korin, 2005). These are genetically related mainly to the salt-bearing Vorotyshcha beds and also to other salt-bearing Miocene formations (Duliński *et al.*, 2005; Kotarba *et al.*, 2009b; Mościcki *et al.*, 2009). Apart from oil, brines are one of the most important factors in preservation of the unique woolly rhinoceros and other fossilized vertebrates.

In the Starunia area, the Miocene Vorotyshcha beds succession includes both the rock-salt and the potassium salt seams (Korin, 2005). These salts were described from the Nadzieja-3 well (Fig. 5) before the World War II, when the rock-salt/potassium salt deposit was assessed, but never exploited (Zubrzycki, 1938; Mitura, 1944; Alexandrowicz, 2004). Brines exploited from dug wells and shafts called "salt windows" have been known from Starunia and vicinity since the Middle Ages (see Alexandrowicz, 2004, and references therein).

HISTORY OF DISCOVERIES AND PALEOZOOLOGICAL STUDY OF LARGE, EXTINCT PLEISTOCENE MAMMALS

Mammoth and woolly rhinoceros from 1907

In September 1907, the new mining enterprise: "J. Campe and Co." started ozokerite mining at the new "Michajłowa-Dmytruk" Mine. As early as in October and November 1907, during the deepening of No. IV shaft (later named "Mammoth"), the incomplete carcasses of a mammoth and a woolly rhinoceros (so-called "the first rhinoceros from Starunia") with preserved soft tissues were found at depths of 12.5 and 17.6 metres, respectively (Łomnicki, 1914a). Both specimens were transferred to the Dzieduszycki Family Natural History Museum in Lviv (present name: The Natural History Museum of the National Academy of Sciences of the Ukraine) (Kubiak & Drygant, 2005; Chornobay & Drygant, 2009).

Results of geological and palaeobotanical studies (Nowak & Panow, 1930; Szafer, 1930) revealed that sediments excavated from No. IV shaft are secondary, which may suggest that both the mammoth and the "first" rhinoceros were discovered earlier and dumped into this shaft. Such an explanation was proposed for the first time by Raciborski (1914a, b), who analyzed fragments of leafs and

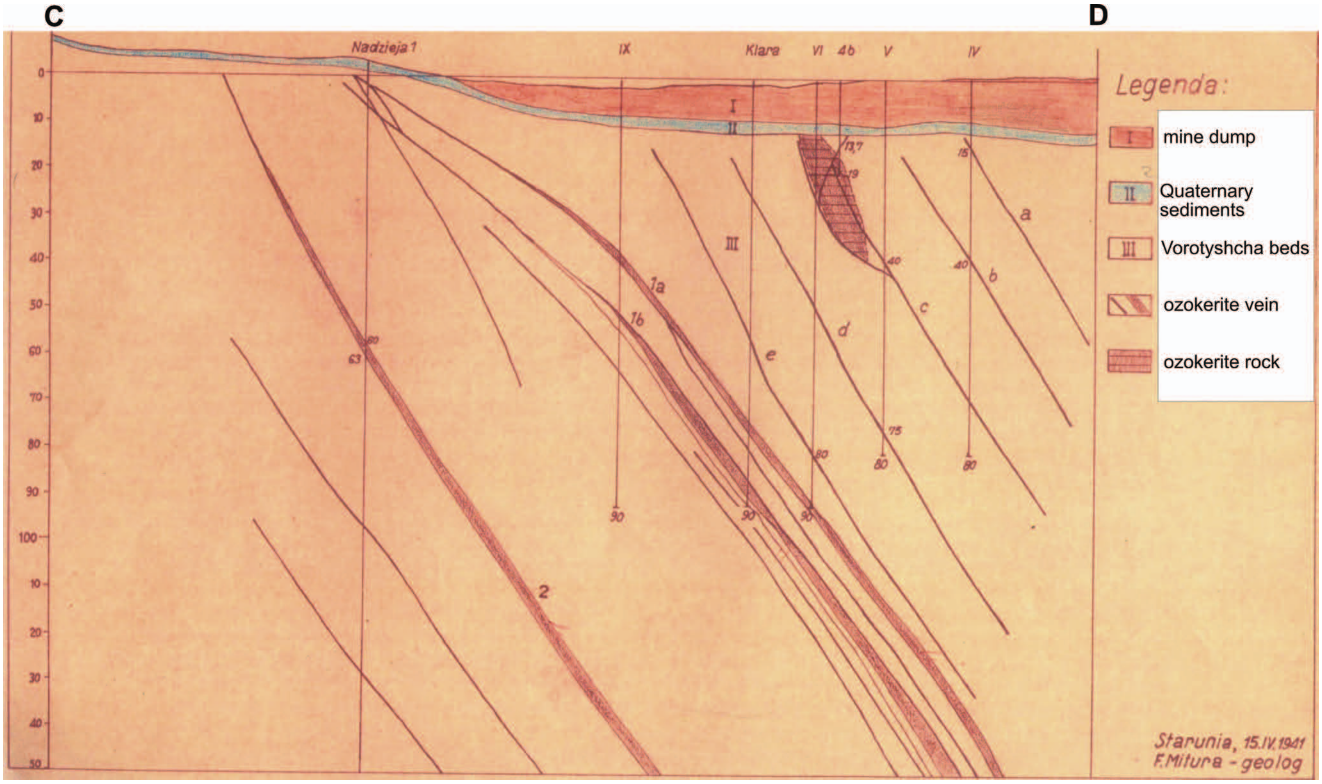

Fig. 6. Geological cross-section through "Dmytruk" mining plot of the Starunia ozokerite deposit after Mitura (1944). For location of cross-section see Fig. 1C

fruits found in sediments from the vicinity of mammoth and rhinoceros bodies. Moreover, the horn was found at a different depth than the body itself (Łomnicki, 1908), which supports the thesis that both the fossils and the hosting sediments were displaced earlier. Alexandrowicz (2004) suggested that this event might have taken place even about 20 years earlier (about 1887–1890).

In 1914, an extended monograph about the Starunia findings was published by Bayger *et al.* (1914), including 386 pages of text with separate atlas containing 67 tables. The fossils of mammoth and rhinoceros were studied by Lubicz-Niezabitowski (skeletons, 1914a, b) and Hoyer (soft tissue, 1914). In the vicinity of both vertebrates, numerous small fossils were found, mostly insects, gastropods and molluscs (M. Łomnicki, 1908, 1914c, d, e, f; J. Łomnicki & M. Łomnicki, 1914; Schille, 1914, Kulczyński, 1914). Remains of other vertebrates were investigated by Bayger (1914), Mierzejewski (1914) and Kiernik (1914).

Abandoned plans of excavations in 1907

Discovery of unique mammoth and woolly rhinoceros fossils in No. IV shaft resulted in a keen interest in this palaeontological site and generated a will to continue exploration. Two documents issued in late November and early December 1907 by eng. Franciszek Fałek, technical manager of the ozokerite mine in Starunia, were found in the State Archive in Lviv (Kotarba & Stachowicz-Rybka, 2008). These presented three very interesting variants of further exploration. Based upon available information, Fałek assumed that Pleistocene sediments in the depth interval from 14 to 25 metres had a high possibility of containing additional fauna. It must be emphasized that our drillings completed in the years 2007–2008 proved that the bottom of Pleistocene sediments recently occurs at a maximum depth of 17 metres (Sokołowski *et al.*, 2009).

The first variant (a) of the Starunia excavation, most labour-consuming and expensive, included the digging of benched excavation down to 25 metres depth with the squared lowest bench 25×25 metres and bank slopes 40–60°. The volume of removed rock was estimated as about 20,000 cubic metres.

The second, most interesting variant (b), proposed cutting of 10-metres-long gallery at the depth from 14 to 25 metres (Fig. 7). Eng. Fałek wrote (Kotarba & Stachowicz-Rybka, 2008): …"*Assuming that exploration would be made within the squared area 25 x 25 = 625 m^2, at the Quaternary/Miocene boundary […], the space to be explored is a layer of dimensions 25x25 metres and 10 metres thick. Hence, the parallel, galleries Nos 1, 2, 3 and 4 should be cut […] from a-b point, 1.70 metre high and 1.30 metre wide, which means that a layer 1,70 metre high would be searched at the beginning. Rock excavated from No. 2 gallery will be backfilled in No. 1 gallery, and that dug from No. 3 will be located in No. 2 gallery. Therefore, only the excessive part of extracted rock produced by loosening will be hoisted to the surface. When searching of the first layer is completed, the second search level will be developed at the backfilled surface with parallel galleries a, b, c, d, e, f, etc,* α, β, γ, δ. *Then, the next search levels will be cut up to 14 metres height. Obviously, this project requires two 25-metres-deep shafts for ventilation, haulage and crew move-*

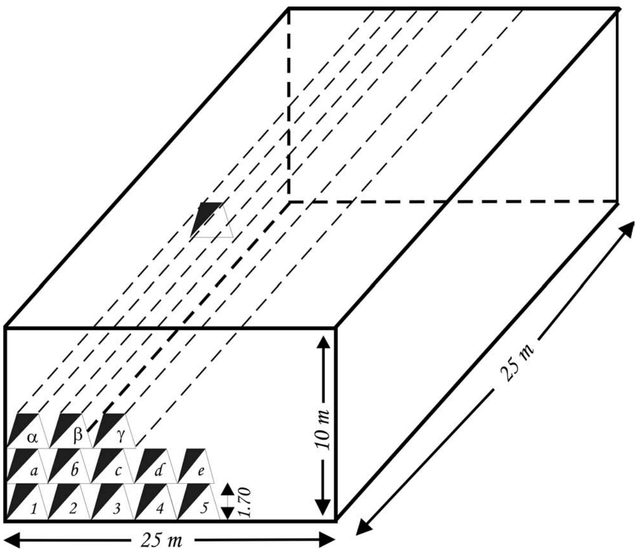

Fig. 7. Sketch map of planned mine galleries near No. IV ("Mammoth") shaft in Starunia prepared by Franciszek Fałek in 1907 (Kotarba & Stachowicz-Rybka, 2008); see text for symbols 1, 2…a, b...α, β...

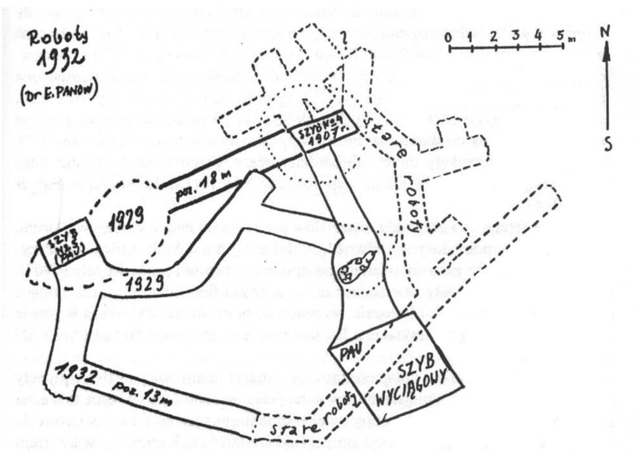

Fig. 8. Sketch map of location of shafts and mine workings in Starunia prepared by Eugeniusz Panow in 1932 (Alexandrowicz, 2004); "szyb" means "shaft"; "szyb wyciągowy" means "recovery shaft", "stare roboty" means "old underground workings" and "poz." means " mining level"

ments (…). It must be emphasized that, in my opinion, this search system is most rational and flexible in terms of available funds."...

In the third variant (c) two or more shafts should be sunk, distant from each other or, alternatively, small twin shafts should be dug from which galleries should be cut in all directions at any depth. Eng. Fałek wrote (Kotarba & Stachowicz-Rybka, 2008): …"*It is obvious that this system does not ensure any systematic searching work. Hence, any accurate cost estimation cannot be made without work plan, number of shafts, length of galleries, etc. The main advantages of scenarios (b) and (c) are that after sinking of two shafts the full work plan can be modified or adjusted to available funds at any moment.*"…

If any of these ambitious projects was completed in the years 1908–1911, the "second" woolly rhinoceros would undoubtedly had been discovered much earlier. Unfortunately, the lack of funds precluded any exploration. Small-scale underground works (only two days of excavations) were undertaken in 1911 under the supervision of Dr. W. Rogala (Kiernik, 1914). Partly, the plans made in 1907 (variant "c") came into being during the 1929 search.

Woolly rhinoceroses from 1929

Exploration and scientific research in Starunia could not be continued earlier than after the World War I, in independent Poland, when a special National Culture Fund was established in 1928 by the Prime Minister, Marshall Joseph Piłsudski.

In 1929, under the auspices of the Polish Academy of Arts and Sciences, the Committee for Starunia Research was established and new excavations were undertaken at the ozokerite mine in Starunia. First, a special shaft (further called "the PAU shaft") was sunk under the supervision of a young geologist, Mr. Eugeniusz Panow. On October 23rd, 1929, in a gallery cut about 4.5 metres from No. IV shaft, at a depth of 12.5 metres an extraordinary, almost fully preserved carcass of a female woolly rhinoceros was found (later named "the second woolly rhinoceros from Starunia"). Moreover, in this excavation, parts of the skeleton (without soft tissue) of "the third rhinoceros" were discovered (Stach, 1930) together with bones of "the fourth rhinoceros" (Kubiak, 1994, 2003). Then, soldiers from the Polish army engineers' corps sunk a special recovery shaft (4x4 m), through which the carcass of the woolly rhinoceros was raised to the surface on December 17th, 1929. On December 22nd, 1929, the fossil was transported to Kraków, to the Natural History Museum of the Polish Academy of Arts and Sciences on 17, Sławkowska Street. In 1995, the fossil was moved to the Natural History Museum of the Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, on 9, St. Sebastian Street in Kraków.

In the years 1931–1932, a small-scale underground exploration was run in Starunia around No. IV and the PAU shafts. The old sketch-map drawn by Mr. Panow (Alexandrowicz, 2004) shows old and new exploration workings together with localization of three shafts: No. IV ("Mammoth") from 1907, the PAU shaft, and the recovery shaft from 1929 (Fig. 8).

Earlier, in 1930, the monograph on "the second rhinoceros" was published in Polish as Volume 70 of the "Transactions of the Department of Mathematics and Natural Sciences, Polish Academy of Arts and Sciences" (Nowak *et al.*, 1930a). The publication contained five chapters and an unauthorized introduction, was also published in an English version as *Bulletin International de l'Académie Polonaise des Sciences et des Lettres de Cracovie, Ser. B* (Nowak *et al.*, 1930b). Since 1933, the Polish Academy of Arts and Sciences has published the scientific series named "Starunia". The first five volumes were devoted to the studies of the Starunia site (Gams, 1934; Kormos, 1934; Lengersdorf, 1934; Szafran, 1934; Zeuner, 1934).

Apart from large mammals, the enclosing clays supplied a large number of insect remnants, from which detailed studies were run on *Orthoptera* (Zeuner, 1934), *Diptera* (Lengersdorf, 1934), *Coleoptera* (Angus, 1973), and *Curculidonidea* (Kuśka, 1992). Many years later the beetle fauna from Starunia was described by Pawłowski (2003), whereas ecological aspects of gastropods and molluscs were investigated by Alexandrowicz (2003). Review of fossils encountered in Starunia was made by Hoyer (1915, 1937). Large mammals were described also by Niezabitowski-Lubicz (1911a, b), Kubiak (1969, 1971, 2003), Kubiak and Dziurdzik (1973), and Kubiak and Drygant (2005).

In autumn 1992, just 85 years after the first discoveries in Starunia, an international conference took place in Lviv concerning the history and further palaeontological and archaeological studies of Starunia site (Kubiak, 1994).

History of palaeobotanical research was presented in detail by Granoszewski (2002) and Stachowicz-Rybka *et al.* (2009a, b). Recently, Alexandrowicz (2004) published a book, which provides comprehensive information on the history of discoveries and scientific research in Starunia before 2003.

INTERDISCIPLINARY STUDIES IN THE YEARS 2004–2005

In 2004, after more than a 70-years-long break, geological, geophysical, geochemical and microbiological studies in Starunia were restarted. In May and again in October 2004, the Society of Research for Environmental Changes "Geosphere", in cooperation with the AGH University of Science and Technology in Kraków, Poland, the Ivano-Frankivsk National Technical University of Oil and Gas in Ivano-Frankivsk, Ukraine and the Institute of Geology and Geochemistry of Combustible Minerals of the National Academy of Sciences of Ukraine in Lviv, organized two scientific expeditions to Starunia. Their objective was to analyze the geological structure and the specific sedimentary environment, in which the Pleistocene mammals were found, and to assess the possibility of further findings of large mammals. The results were published as a monograph (Kotarba, *ed.*, 2005) which contained 18 thematic papers presenting the results of field and laboratory studies of the Starunia area (Fig. 9).

In the area of an abandoned ozokerite mine and in its vicinity, the following studies were accomplished: sedimentological and dendrochronological research of the Velyky Lukavets River Holocene terrace (Alexandrowicz *et al.*, 2005); geophysical (D.C. resistivity, gravity and shallow temperature) survey (Mościcki, 2005; Madej & Porzucek, 2005); near-surface geochemical survey (Kotarba *et al.*, 2005a; Dzieniewicz *et al.*, 2005); microbiological studies (Barabasz *et al.*, 2005); organic geochemical studies on hydrocarbon source rocks from outcrops and drill cores, and of oils and natural gases from deep accumulations and surface seeps (Kotarba *et al.*, 2005b); chemical, stable hydrogen and oxygen isotope analyses of surface and ground- waters (Duliński *et al.*, 2005); and radiocarbon dating of fauna remnants (Kuc *et al.*, 2005). Moreover, the monograph contains also papers presenting the purposes, programs and

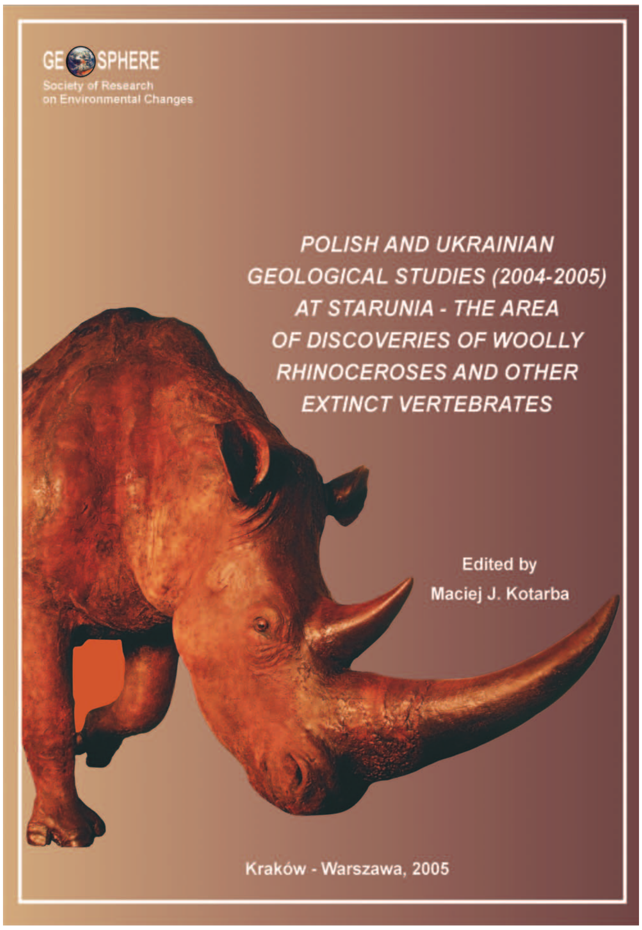

Fig. 9. Title page of the third Starunia monograph (Kotarba, *ed.*, 2005)

comprehensive results of two Polish scientific expeditions to Starunia in 2004 (Kotarba, 2005) and a spectrum of information related to historical and geological/geomorphological aspects of the area. Some of these are: the history of the Starunia palaeontological site and abandoned ozokerite mine (Alexandrowicz, 2005b); the history of petroleum exploration and production (Adamenko *et al.*, 2005a); geological setting and occurrence of oil and gas deposits (Koltun *et al.*, 2005); characterization of the salt-bearing Miocene Vorotyshcha beds (Korin, 2005), and geomorphological/neotectonic features of the area (Stelmakh, 2005). Archaeological sites in the Starunia area (Matskevyj, 2005) as well as the collections of remains connected with the discoveries of Pleistocene mammoth and woolly rhinoceroses from Starunia in Lviv and Kraków natural history museums were described by Kubiak and Drygant (2005). Moreover, the concept of an "Ice-Age park" in the Starunia area as an ecological and tourist centre was discussed (Adamenko *et al.*, 2005b).

The results of interdisciplinary studies carried out in the years 2004–2005 around the Starunia palaeontological site led to preliminary contouring of a Pleistocene water reservoir ("palaeomarsh"), into which large mammals might have sunk and in which their bodies might have been subsequently preserved (Kotarba, *ed.*, 2005; Kotarba *et al.*, 2008b).

Fig. 10. The geological drillings by means of the UGB-50 vibratory probe (12 cm diameter) and core description by T. Sokołowski. Photo by R. Stachowicz-Rybka

Fig. 11. The geological drillings by means of MDR–06 drilling probe with plexiglas inner tube (5 cm diameter). Photo by R. Stachowicz-Rybka

INTERDISCIPLINARY STUDIES IN THE YEARS 2006–2009 – PRESENTATION OF ACHIEVEMENTS

In the years 2006–2009, interdisciplinary studies were carried out in Starunia by eleven thematic working groups on: Quaternary lithology and sedimentology, palaeobotany (palynology and analysis of macrofossils), botany (analysis of halophytes), palaeozoology (malacological analysis), radiocarbon dating, microbiology, surface and near-surface geochemistry, organic geochemistry (bitumen content and their fractions, biomarkers and stable carbon isotopes) and inorganic geochemistry (chlorine ion analysis), geoelectric survey (DC resistivity soundings, electromagnetic terrain conductivity measurements, resistivity imaging, penetrometer-based resistivity profiling and azimuthal pole-dipole DC resistivity soundings), and microgravimetric survey. The leader of the Starunia team and coordinator of these studies was Maciej J. Kotarba from the Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology in Kraków, Poland. Three groups of works were completed: field, laboratory and interpretative ones.

The field work was focused on the area of about 12 hectares around the Starunia palaeontological site, which was selected from the results of studies from 2004–2005 (Kotarba, *ed.*, 2005). Four stages of field research were scheduled: first in April 2007, second in June 2007, third in October-November 2007, and fourth in May 2008.

The main purposes of the interdisciplinary studies were: (i) to contour and recognize the details of internal structure of Pleistocene sediments, (ii) to localize the Pleistocene lakes and marshes, (iii) to recognize lithofacies variability of Pleistocene sediments (particularly distribution of mud facies), (iv) to determine properties of depositional environment (oxidizing versus reducing) including saturation of sediments with salt and bitumen – the best conserving agents of Pleistocene mammals. It was expected that these data would enable evaluation of the possibility of further discoveries of well-preserved Pleistocene animal carcasses, and, eventually, also human bodies. It is well-known from archaeological records that in the Pleistocene at least 17 settlements of ancient hunters existed in Starunia and vicinity (Matskevyj, 2005). Hence, it is reasonable to expect that also humans might have sunk into the marsh and their bodies might have been preserved.

During the 2007 and 2008 campaigns, the geological drillings were carried out by the Polish Drilling Company ALGEO from Grabownica with the UGB-50 vibratory probe (12 cm diameter) (Fig. 10) and MDR–06 drilling probe with plexiglas inner tube (5 cm diameter) (Fig. 11). In total, 44 boreholes were drilled to depths from 4.6 (borehole No. 23) to 20.0 m (borehole No. 22). From the boreholes 421.1 m of core were recovered, of which 191.2 m from Quaternary sediments (108 m from Pleistocene and 82.9 m from Holocene strata), 109.9 m from Miocene strata, and 120.0 m from mine dumps. Moreover, 17 soundings were driven to depths from 3 to 6 m (Fig. 12).

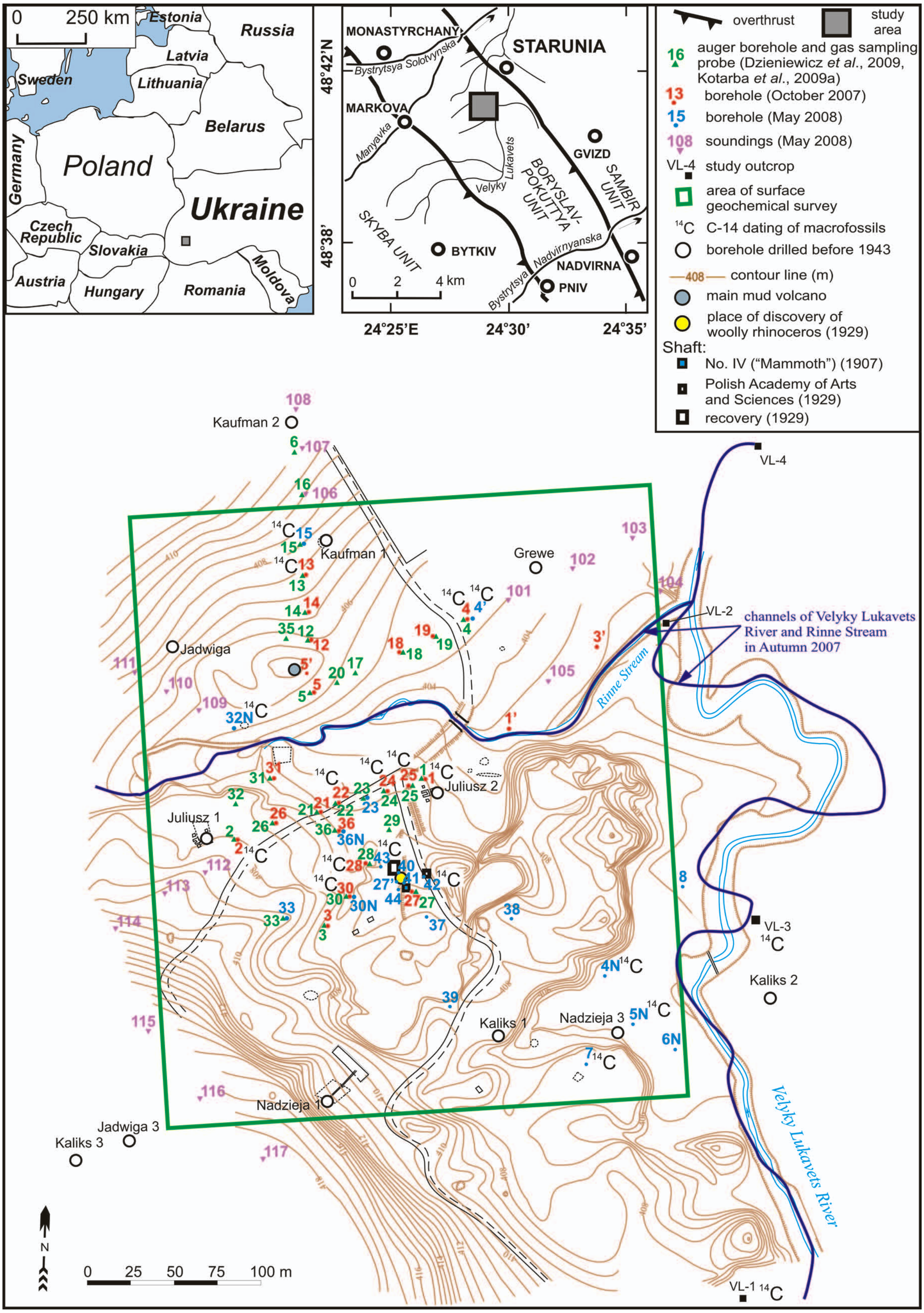

Fig. 12. Map of location of boreholes drilled for studies of Quaternary lithology and sedimentology, palaeobotany (palynology and analysis of macrofossils), palaeozoology (malacological analysis) (Sokołowski & Stachowicz-Rybka, 2009; Sokołowski *et al*., 2009; Stachowicz- Rybka *et al*., 2009a, b), radiocarbon dating (Kuc *et al*., 2009), microbiology (Barabasz *et al*., 2009), near-surface geochemistry (Kotarba *et al*., 2009a; Dzieniewicz *et al*., 2009), organic and inorganic geochemistry (Kotarba *et al*., 2009b, c; Mościcki *et al*., 2009), surface geochemical survey (Sechman *et al*., 2009), botany (analysis of halophytes), and geomorphology (Mościcki *et al*., 2009; Sokołowski, 2009) in the years 2007–2008

Fig. 13. DC resistivity soundings headed by W. J. Mościcki. Photo by M. Dzieniewicz

This paper is an introduction to the thematic volume of the *Annales Societatis Geologorum Poloniae*. Moreover, the volume contains 17 papers presenting the results of field and laboratory studies completed in the years 2007–2008 in the Starunia area.

Sokołowski (2009) describes a fragment of the valley between Molotkiv and Starunia, and its close vicinity. The area belongs to several morphostructural and geomorphic units of the Eastern Outer Carpathians and the Carpathian Foreland.

Sokołowski *et al.* (2009) describe the Upper Pleistocene and Holocene sediments represented by channel (gravel, sandy gravel), floodplain (mud, peat, biogenic mud) and slope (mud, sandy mud) deposits as well as by mine wastes. In the study area, 44 boreholes were drilled and 17 soundings were driven. The rock material taken from 7 boreholes (Nos 1, 4, 4', 6, 15, 22 and 28) and from outcrops (Nos VL-1 and VL-4) (Fig. 12) was used to describe the lithology of fine-grained Pleistocene sediments. From the lithological point of view, the most favourable conditions for preservation of large, extinct mammals still exist in the two selected areas, where the total thickness of Pleistocene muds exceeds 2 metres. The first area is located in the vicinity of boreholes Nos 2, 3, 21, 22, 23, 28, 30 33 and 36N, and the other, smaller one, exists around borehole No. 42.

Stachowicz-Rybka *et al.* (2009a) show the history of Pleistocene and Holocene vegetation of the Starunia area. Palynological analyses were made for three boreholes Nos 4', 22, and 28, and No. VL-1 outcrop (Fig. 12). The deposition of biogenic sediments has begun in the Middle Pleniglacial, in the Moershoofd Interstadial, and has lasted through the Hengelo/Denekamp Interstadial Complex, the Late Glacial and the Holocene.

Kuc *et al.* (2009) present results of radiocarbon dating of plant macrofossils from Pleistocene and Holocene sediments. Seventeen boreholes Nos 1, 2, 4, 4', 4N, 5, 7, 13, 15, 22, 24, 25, 28, 30, 32, 42 and 43, and two outcrops Nos V-1 and VL-3 were selected for radiocarbon dating of plant macrofossils (Fig. 12), and 36 samples were collected. Radiocarbon ages of microfossil samples originating from nearby the location of the "second" woolly rhinoceros suggest that the minimum age of sediments in which the mammals were found is in the range of ca. 35–40 ka BP.

Stachowicz-Rybka *et al.* (2009b) present the results of palaeobotanical and malacological studies of Pleistocene and Holocene sediments from the Starunia area. Plant macroremains analysis was carried out for rock material collected from cores (boreholes Nos 4', 22 and 28) and two outcrops (Nos VL-1 and VL-3) in the Velyky Lukavets River scarp (Fig. 12). Malacological analysis was carried out for mollusc shells and shell fragments obtained from cores of six boreholes Nos 4, 5, 14, 22, 28 and 43 (Fig. 12). In the Weichselian Middle Pleniglacial, the landscape was dominated by steppe and tundra plant communities, mostly various grass and sedge species. Areas of higher humidity were covered with shrub tundra with *Betula nana*. In the Late Weichselian, the open landscape dominated with the majority of steppe and steppe-tundra, at the presence of a dry, continental climate.

Sokołowski and Stachowicz-Rybka (2009) present the results of absolute age dating and biostratigraphical analysis carried out for alluvial sediments. The paper summarizes the results of palaeobotanical (palynology and analysis of macrofossils), malacological (Stachowicz-Rybka *et al.*, 2009a, b) and lithological studies (Sokołowski *et al.*, 2009), and the OSL and ^{14}C absolute age dating (Kuc *et al.*, 2009). The sediments built up three terrace levels. The highest one is likely to be associated with a short episode of valley broadening, which occurred in the Weichselian Late Pleniglacial. The lower one is most likely to be linked to the Holocene. The lower part of this terrace series contains coarse-grained channel sediments dated back to 120.6–58.9 ka BP (Eemian Interglacial? – Weichselian Early Pleniglacial – OIS 5e, 4 and 3) and overbank (distal floodplain) mud with intercalations of biogenic deposits (peat, peat muds and biogenic muds). The overbank deposits are dated from 48.2 to 11.1 ka BP (Glinde Interstadial? – Younger Dryas, OIS 3-2) and are overlain by Holocene (OIS 1) mud and biogenic sediments.

Mościcki (2009) shows the results of DC resistivity soundings (Fig. 13), electromagnetic terrain conductivity measurements, resistivity imaging and penetrometer-based resistivity profiling (Fig. 14) carried out in the Starunia area. Location of the geoelectric survey is shown in Fig. 15. Generally, resistivity of the near-surface zone is low and decreases with depth, down to at least 40 m. This may be a combined effect of salty water distribution within Quaternary sediments and upper part of Miocene strata. Locally, values of resistivity are extremely low, which is probably connected with the inflow of brines from the salt-bearing Miocene Vorotyshcha beds into Quaternary sediments, and with some additional anthropogenic effects resulting from mining activity at the end of the 19th and the first half of the 20th centuries.

Mościcki and Sokołowski (2009) present results of the DC azimuthal pole-dipole resistivity soundings and penetrometer-based resistivity profiling with simultaneous penetration-velocity measurements to study variability of environment in the vicinity of geological boreholes. No evident correlation was found between lithology of drilled sediments and geophysical data. Nevertheless, remarkable, horizontal and vertical variability of geophysical parameters was observed. The strongest recorded horizontal changes may reflect an existence of some sharp geologic boundaries in the study area. The measured physical properties of geological strata: electric resistivity and compactness (determined from penetration velocity) change also with depth, but correlation with geological structure was found only in a limited number of cases. Registered variability might have originated both from the complex geological arrangement of shallow layers and/or from transformations of near surface environment caused by past mining operations.

Porzucek and Madej (2009a) present the results of gravity surveying. The gravity measurements were carried out with the CG-3 Scintrex gravimeter. The objective of the survey was to recognize the geological structure of the near-surface zone, *i.e.* the Quaternary and Miocene strata. Detailed gravity surface surveys were made in two stages. In 2007, the survey covered an area of about 10 ha and measurements were made in a 12.5 m grid; in 2008, about 10 hectares of area was surveyed in 10 m grid (Fig. 15). Additionally, the G6 profile, about 500 metres long and transversely cutting the analyzed structure, was established. The assumed spacing of sites along the measurement line was 25 metres. For interpretation, the results of gravity survey carried out by Madej and Porzucek (2005) run along five profiles were used.

Porzucek and Madej (2009b) present the results of microgravimetric study carried out in order to recognize the anomalous areas of relatively low gravity values within the salt-bearing Lower Miocene Vorotyshcha beds. These areas are probably connected with migration zones of brines from the Vorotyshcha beds into Pleistocene muds and, thus, these may constitute zones where extinct animal remains can potentially be found. Apart from the gravity measurements presented in Porzucek and Madej (2009a), more detailed microgravity surveys were made in two areas of dimensions 130×110 m and 70×50 m (Fig. 15). The measurements were made in the accessible nodes of 6.25 m square grid.

Sechman *et al.* (2009) show the results of near-surface geochemical survey (depths 1.1 to 1.3 metres). The samples were taken within a rectangle, 300×350 m in area, using 12.5 m square grid (Fig. 12). In total, 689 measurement sites were sampled (Fig. 16). Molecular and isotopic compositions of soil gases enabled the authors to identify their origin and, particularly, to distinguish microbial gases generated within the near-surface zone from thermogenic gases migrating from deep accumulations.

Mościcki *et al.* (2009) present the results of geoelectric (high resolution geoelectric research with electromagnetic conductivity measurements), geochemical (chloride ion content), and botanical (distribution of halophytes) studies aiming at recognition of salinity of Quaternary sediments near the 1907 and 1929 discovery sites. Distribution of conductivity of near-surface sediments depends mainly on mineralization (salinity) of underground water filling the pores and voids of poorly consolidated Quaternary sediments and, partly, also the underlying Miocene strata. The area of geoelectric measurements is shown in Fig. 15. The salt (chloride ion) content in Quaternary sediments varies both horizontally and vertically in an unpredictable way. The highest values reached 8.5 wt%. In total, 113 core samples of sediments were taken from 23 boreholes Nos 1, 4, 4', 4N, 5N, 7, 8, 15, 22, 23, 25, 27', 28, 30, 30N, 31, 32N, 33, 36N, 37, 38, 42 and 43 (Fig. 12). Generally, when compared qualitatively, the salinity of sampled drill cores correlates with the distribution of apparent conductivity measured with geoelectric methods. Botanical field studies were carried out over the whole area of the abandoned ozokerite mine (see Fig. 12). A group of vascular plants growing on saline soils (halo- phytes) was found. Halophytes indicate higher salt concentrations in soils. Generally, the distribution of halophytes reveals a good correlation with the distribution of high-conductivity anomalies determined with the surface geoelectric survey.

Fig. 14. Penetrometer-based resistivity profiling made by workers of Geofizyka Toruń Company. Photo by W. J. Mościcki

Kotarba *et al.* (2009a) present results of molecular and isotopic analyses of near-surface gases collected by special sampling probe at 30 measurement sites (Fig. 12) from 0.8, 1.6, 2.4, 3.2 and 4.0 m sampling depths. Distribution of thermogenic methane and higher gaseous hydrocarbons in Quaternary sediments is variable and, generally, increases with depth. Microbial methane or mixture of microbial and thermogenic methanes also occur in the near-surface zone. Helium of crustal origin migrated through tectonic zones

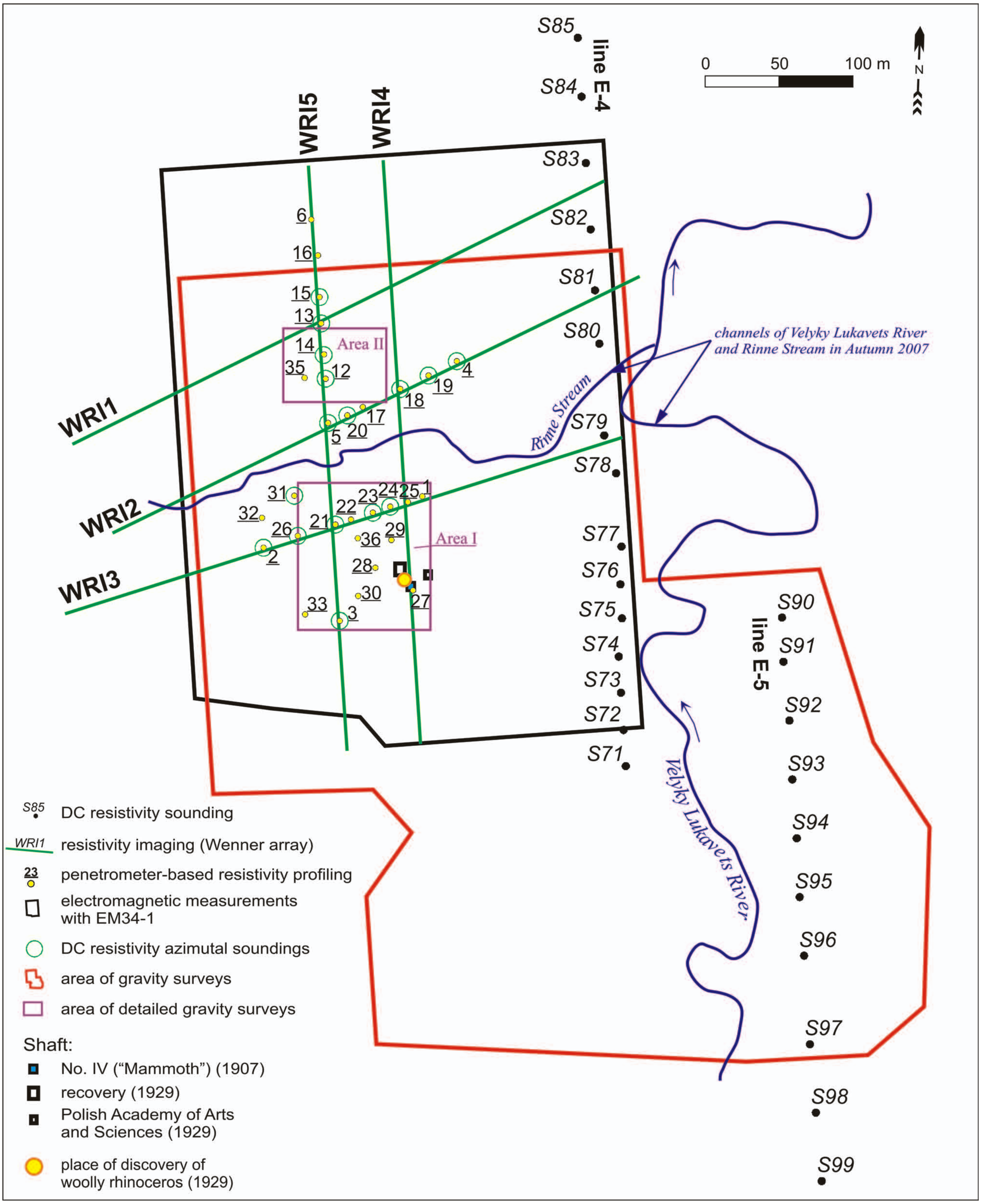

Fig. 15. Map of location of geoelectric and gravimetric surveys (Mościcki, 2009; Mościcki & Sokołowski, 2009; Mościcki *et al.*, 2009; Porzucek & Madej, 2009a, b) in the years 2007–2008

cutting the study area and was subsequently dispersed during migration through lithologically diversified Pleistocene and Holocene sediments. Carbon dioxide is of polygenetic origin (thermogenic, microbial and oxidation of hydrocarbons and Quaternary organic matter). Zones of thermogenic methane migration within Pleistocene sediments dominated by muds saturated with bitumens and brines provide the most favourable environment for preservation of large extinct mammals.

The paper by Dzieniewicz *et al.* (2009) present the results of the near-surface geochemical survey of adsorbed gases. Analyses of molecular and stable carbon isotope compositions of adsorbed gases were carried out in the two variants. The first included sampling of cuttings from 30 auger boreholes (Fig. 12) of diameters about 70 mm, at depths 4.8, 5.6 and 6.4 m. In total, 88 samples were collected. In the second variant, core samples were collected from 17 selected boreholes Nos 1, 1', 3, 4, 5, 12, 13, 14, 18, 19, 21, 24, 25, 27, 28, 30 and 31 (Fig. 12). In total, 78 samples were taken from various depths, down to 12 m. The results of molecular composition analyses of adsorbed gases indicated high saturation of near-surface sediments with the oil. Highest concentrations of alkanes were detected in the Miocene Vorotyshcha beds. Hydrocarbon migration from deep accumulations to the surface was relatively quick and proceeded along the faults and fractures. In the near-surface zone hydrocarbons were subjected to oxidation and dehydrogenation, which resulted in generation of unsaturated hydrocarbons and hydrogen.

Barabasz *et al.* (2009) present recent biological activity within Quaternary sediments. Core samples for microbiological analyses were collected from 15 boreholes Nos 4', 4N, 4N, 7, 8, 15, 23, 27', 39N, 32N, 33, 36N, 37, 42 and 43 (Fig. 12). The quantitative results regarding the occurrence of different physiological groups of microorganisms (methanogens, methanotrophs, vegetative forms of bacteria, fungi, ammonificators and acctinomycetes) show that their numbers vary significantly depending on the sampling site and depth, humidity and the organic matter content. The amount and diversity of the tested groups of microorganisms decreased with depth. Methanogens occurred in Pleistocene sediments, in boreholes Nos 4', 30N and 36N, and main groups of saprophytic microorganisms (bacteria, fungi and actinomycetes) were found in Holocene sediments.

Kotarba *et al.* (2009b) show the results of geochemical study of bitumens and salts saturating the Pleistocene and Holocene sediments. Both the bitumens (oil) and brine (chloride ion) were the preserving agents for the large, Pleistocene mammals, therefore, the muds of this age were given special attention. For geochemical study of bitumens and chloride contents, 113 core samples from boreholes Nos 1, 4, 4', 4N, 5N, 7, 8, 15, 22, 23, 25, 27', 28, 30, 30N, 31, 32N, 33, 36N, 37, 38, 42 and 43 (Fig. 12) were collected from Quaternary sediments, in which 55 samples were from Pleistocene strata and 46 from Holocene sediments. The main mass of organic carbon hosted in the Pleistocene muds is related to bitumens. The source of bitumens is oil migrating from deep accumulation reservoirs within the Boryslav-Pokuttya Unit. Taking into consideration the contents of the remaining preservatives, chloride and bitumens, the most favourable zone for fossils conservation and preservation is located close to boreholes Nos 22, 23, 28 and 36N, where the thickness of Pleistocene muds exceeds 2 metres.

Kotarba *et al.* (2009c) present results of biological markers and stable carbon isotopic analyses of bitumen impregnating Pleistocene and Holocene sediments around the Starunia palaeontological site. This was to find genetic links between these bitumens and oils from the nearest deep accumulations within the Boryslav–Pokuttya and Skyba units of the Carpathians. Moreover, there is evidence of secondary geochemical processes (oxidation and biodegradation) active within the hosting sediments, especially in Pleistocene muds. For biological markers and stable carbon isotope analyses, 56 core samples were collected from 19 boreholes Nos 1, 4, 4', 4N, 5N, 7, 8, 15, 22, 23, 25, 27', 28, 30, 30N, 31, 32N, 38 and 42 (Fig. 12). Bitumen within the near-surface rocks was not genetically connected with residual organic matter present in Quaternary sediments. All bitumens originate from oil-prone, type II kerogen with insignificant admixture of terrestrial, type III kerogen at the middle stage of low-temperature thermogenic processes (catagenesis). The oils occurring in deep accumulations in the Starunia area were the sole source of bitumen found in the near-surface sediments. The main factors differentiating the near-surface bitumens were: biodegradation, water washing and/or weathering. Additional influence of bitumens transport in brine was found. The most favourable conditions for preservation of large, extinct mammals within the Pleistocene muds exist in the vicinity of Nos 22 and 23 boreholes, where bitumens are best preserved.

Fig. 16. Near-surface geochemical surveys headed by H. Sechman. Photo by M. Dzieniewicz

Moreover, results of interdisciplinary studies in Starunia were presented during two international conferences. At the International Science-Technical Conference "IFNTUOG-40" on "Resources-saving Technologies in Oil and Gas Power Engineering", organized by the National Technical University of Oil and Gas in Ivano-Frankivsk, the members of the Starunia team gave five presentations:

Kotarba *et al.* (2008c, d), Mościcki (2008a), Porzucek and Madej (2008a), and Stachowicz-Rybka (2008a). At the Second International Scientific Conference "Natural and historical legacy of Starunia at 100th Anniversary of the Discovery of Mammoth and "First" Woolly Rhinoceros in 1907", organized by the Natural History Museum of the National Academy of Sciences of the Ukraine in Lviv, the Society of Research of Environmental Changes "Geosphere" in Kraków, the AGH University of Science and Technology in Kraków, and the National Technical University of Oil and Gas in Ivano-Frankivsk, the members of Starunia team presented nine lectures: Kotarba and Alexandrowicz (2008), Kotarba *et al.* (2008e), Kubiak (2008), Mościcki (2008b), Porzucek and Madej (2008b), Sokołowski (2008), Sokołowski and Stachowicz-Rybka (2008), Stachowicz-Rybka (2008b), and Stachowicz-Rybka *et al.* (2008).

RANGE OF PLEISTOCENE LAKE AND MARSH RESERVOIR, AND LOCATION OF SITES OF POTENTIAL OCCURRENCE OF LARGE EXTINCT MAMMALS

The deposition of Quaternary biogenic sediments started in the Weichselian Middle Pleniglacial, in the Moershoofd Interstadial, and lasted through the Hengelo/Denekamp Interstadial Complex and the Late Glacial, until the Holocene (Stachowicz-Rybka *et al.*, 2009a). The range of Pleistocene muds with *Betula nana* (Stachowicz-Rybka *et al.*, 2009b), in which unique specimen of woolly rhinoceros was found in 1929, probably covers the vicinity of boreholes Nos 21, 22, 23, 24, 25, 27, 28, 30, 30N, 36, 36N, 37, 40, 41, 42, 43 and 44 (Fig. 17). From the lithological point of view, the most favourable conditions for preservation of large, extinct mammals still exist in the two selected areas, where the total thickness of Pleistocene muds exceeds 2 metres (Fig. 17). The first area is located in the vicinity of boreholes Nos 2, 3, 21, 22, 23, 28, 30, 33 and 36N, and the other, smaller one exists around borehole No. 42 (Sokołowski *et al.*, 2009).

The unique combination of oil and brine saturating the Pleistocene muds produced specific conditions responsible for almost perfect preservation of these mammal specimens. The zone of decreased density in the near-surface Quaternary and Miocene beds (Fig. 17) was defined from the microgravity study (Porzucek & Madej, 2009a). This zone is probably connected with a layer within the Lower Miocene Vorotyshcha beds enriched in halite and ozokerite, from which large volumes of brines and oil ascended to Quaternary sediments (Kotarba *et al.*, 2009b). The area of apparent conductivity over 250 mS/m (Fig. 17), was determined with a geoeletric study (Mościcki *et al.*, 2009). Presumably, this zone may define the Pleistocene water reservoir and marsh area ("palaeoswamp"). General qualitative comparison demonstrates that chloride ion concentrations measured in sampled cores correlate well with the values of apparent conductivity obtained with geoelectric methods and with the distribution a group of vascular plants (halophytes) growing on saline soils (Mościcki *et al.*, 2009). Moreover, the sites of anomalous concentrations of methane, total C_2-C_5 alkanes and helium probably also correspond to the range of the Pleistocene lake and marsh ("palaeoswamp") area (Sechman *et al.*, 2009). Zones of thermogenic methane occurrence within Pleistocene sediments dominated by muds saturated with bitumens and brines provide the most favourable environment for preservation of large extinct mammals (Kotarba *et al.*, 2008b, 2009a).

Large quantities of microbial methane were generated within the Quaternary sediments of the Starunia area (Barabasz *et al.*, 2009; Kotarba *et al.*, 2009a; Sechman *et al.*, 2009). Unlike the sites of significant fluxes of thermogenic gases (hydrocarbons and carbon dioxide) and helium, such places would be less likely to be locations of future discovery of well-preserved large vertebrates because microbial methane was generated locally, in recent swamps. The highest quantities of methanogens occur recently in Pleistocene sediments in boreholes Nos 4', 30N and 36N (Barabasz *et al.*, 2009). Microbial methane generated in Pleistocene swamps escaped to the atmosphere (Kotarba *et al.*, 2009a).

Taking into consideration the contents of the main preservatives: chloride and bitumen, the most favourable zone for fossils preservation is located close to boreholes Nos 22, 23, 28 and 36N, where the thickness of Pleistocene muds exceeds 2 metres (Kotarba *et al.*, 2009b). Based on the results of biological markers and stable carbon isotopic composition of fractions of bitumens impregnating Pleistocene sediments (Kotarba *et al.*, 2009c), the most favourable conditions for preservation of large extinct mammals within the Pleistocene muds exist in the vicinity of Nos 22 and 23 boreholes, where bitumens are best preserved.

The results of all mentioned above investigations reveal that the most suitable area for future exploration for extinct mammals in Starunia exist within Pleistocene sediments, in the rectangular, 55×25 m area (*i.e.*, about 1,000 square metres) around boreholes Nos 21, 22, 23, 36 and 36N, where the bottom of Pleistocene muds occurs at the depth interval of 4.5 to 7.5 m (Fig. 17).

CONCLUSIONS

The complex investigations (lithology and sedimentology, botany, palaeobotany, palaeozoology, microbiology, radiocarbon dating, surface and near-surface geochemistry, organic and inorganic geochemistry, geoelectric and microgravimetric surveys) carried out in the years 2006 to 2008 around the Starunia palaeontological site were focused on contouring of the water reservoir and marsh ("palaeoswamp"), into which the Pleistocene mammals had sunk, as well as on the evaluation of possible new discoveries of large Pleistocene mammals, and even human remains. Accordingly, the content and origin of bitumen and salt, which are the main substances for extinct mammals' preservation within Pleistocene sediments were also studied. Interdisciplinary studies enabled the working groups to investigate geological setting and sedimentary environment of Quaternary sediments, which hosted the Pleistocene fossils and to recognize the most favourable area of about 1,000 square

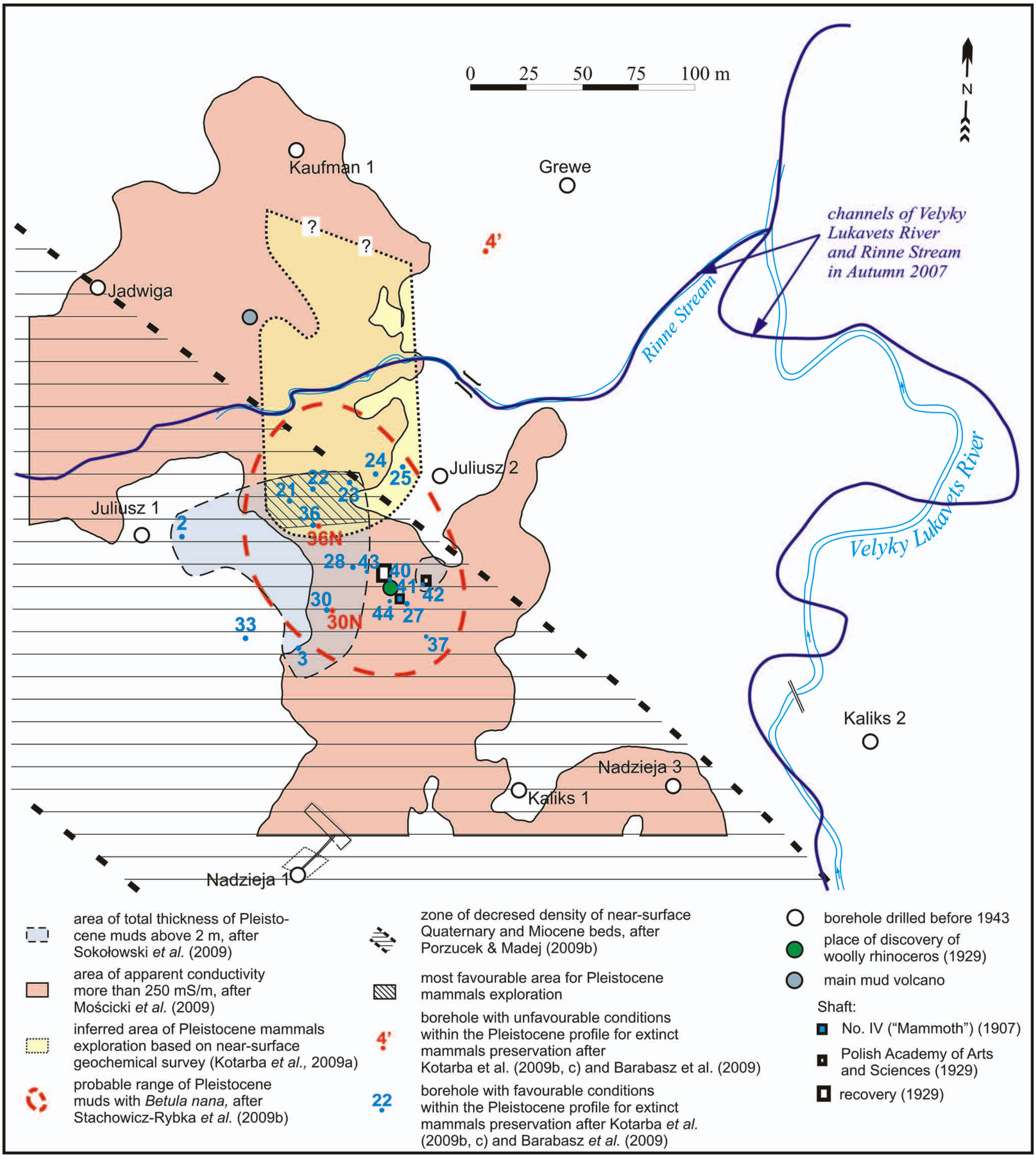

Fig. 17. Map of most favourable area for discoveries of extinct mammals based on results of interdisciplinary studies in the years 2006–2009

metres, where potential exists for future discoveries of extinct Pleistocene mammals. The bottom of the mud complex of Pleistocene sediments of the thickness exceeding 2 m occurs at the depth interval of 4.5 to 7.5 m. The results of interdisciplinary studies raise hopes for future discoveries of well-preserved remnants of large vertebrates. The next step should be the excavation project within the determined area. It seems likely that the best solution would be the first variant of the concept presented by Eng. Franciszek Fałek in 1907 (Kotarba & Stachowicz-Rybka, 2008), *i.e.* the 50×25 m excavation down to a depth of about 8 m. The volume of excavated rock is estimated as about 10,000 cubic metres.

The Starunia village is located in the picturesque area of the Carpathian region. From this site the snowy, 2,000-metres-tall, peaks of the Gorgany Mts., a part of the main Carpathian range, can be seen. The Starunia area has the following unique features: (i) discoveries of extinct rhinoceroses, mammoth and other fossil fauna and flora, some of them being unique specimens, (ii) abandoned ozokerite mine, (iii) mud volcanoes, oil and gas surface seeps, (iv) springs of brines and mineral waters, and (v) archaeological sites.

The Starunia area meets all the requirements of a geopark. Some years ago the UNESCO (Eder, 1999) proclaimed the idea of the world network of geoparks (www.worldgeopark.org). The concept of an international "Park of the Ice Age" as an ecological and tourist centre (Adamenko *et al.*, 2005b, 2009) is an important element of the planned Starunia (Ukraine) – Kraków (Poland) cross-border geotouristic route "Traces of large, extinct mammals, ozokerite, oil and salt" (Kotarba, 2009). In must be emphasized that before the World War II a Polish geologist J. Tokarski wrote about Starunia: "*...The problem is so important that the whole society should be involved and funds must be raised in the nearest future for purchasing the entire village as a world-class natural reserve...*" (Tokarski, 1930). Such a protected area in Starunia should exist after completion of excavations for the large, extinct Pleistocene vertebrates.

Acknowledgements

Financial support from the Ministry of Science and Higher Education in Warsaw (Grant No. 139/UKR/2006/01) is kindly acknowledged. Review comments and suggestions by Henryk Kubiak of the Polish Academy of Sciences in Kraków, and Wojciech Mayer of the AGH University of Science and Technology in Kraków were very helpful. I would like to express my gratitude to John Curtis of the Colorado School of Mines in Golden, and Mark Pawlewicz of U.S. Geological Survey in Denver for their critical comments, which improved this paper.

REFERENCES

Adamenko, O. M., Stelmakh, O. R., Zinchuk, M. S. & Kotarba, M. J., 2005a. History of petroleum exploration in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 53–60.

Adamenko, O. M., Krizhanivskiy, E. I., Vekeryk, V. I., Stelmakh, O. P., Mischenko, L. V., Zorina, N. O., Zorin, D. O. & Ambrozyak, M. V., 2005b. A concept of an international "Ice-Age Geopark" as an ecological–tourist center in Starunia former ozokerite mine, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 205–210.

Adamenko, O. M., Stelmakh, O. R., Zorin, D. O. & Radlovska, K. O., 2009. The ecological-tourist centre in Starunia (Ukrainian Carpathians). *Geoturystyka* (in press).

Alexandrowicz, S. W., 2002. Starunia jako symbol aktywności badawczej Polskiej Akademii Umiejętności). (In Polish). *Prace Komisji Historii Nauki Polskiej Akademii Umiejętności*, 4: 71–89.

Alexandrowicz, S. W., 2003. Krytyczny przegląd malakofauny z wykopalisk w Staruni. (In Polish). *Prace Komisji Historii Nauki Polskiej Akademii Umiejętności*, 1: 159–162.

Alexandrowicz, S. W., 2004. Starunia and the Quaternary research in the tradition and initiatives of the Polish Academy of Arts and Sciences. (In Polish, English summary). *Studia i materiały do dziejów Polskiej Akademii Umiejętności*, 3: 261 pp.

Alexandrowicz, S. W., 2005a. Historia i ostatnie lata działalności kopalni wosku ziemnego w Staruni. (In Polish). *Prace Komisji Historii Nauki PAU,* 7: 71–89.

Alexandrowicz, S. W., 2005b. The history of Starunia – a palaeontologic site and old ozokerite mine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 21–36.

Alexandrowicz, S. W., Alexandrowicz, W. P. & Krąpiec, M., 2005. Holocene terrace of the Velyky Lukavets River in Starunia: sediments and dendrochronology. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 95–101.

Andreeva-Grigorovich, A. S., Gruzman, A. D., Reifman, L. M. & Smirnov, S. E., 1986. Biostratigraficheskaya kharakteristika opornogo razreza menilitovoy svity po r. Chechva, Ukrainskie Karpaty. (In Russian). *Paleontologicheskiy sbornik*, 23: 83–89.

Andreyeva-Grigorovich, A. S., Kulchytsky, Y. O., Gruzman, A. D., Lozynyak, P. Y., Petrashkevich, M. I., Portnyagina, L. O., Ivanina, A. V., Smirnov, S. E., Trofimovich, N. A., Savitskaya, N. A. & Shvareva, N. J., 1997. Regional stratigraphic scheme of Neogene formations of the Central Paratethys in the Ukraine. *Geologica Carpathica*, 48: 123–136.

Angus, R. B., 1973. Pleistocene"Hellephorus (Coleoptera, Hydrophilidae)" from Borislav and Starunia in the Western Ukraine, with a reinterpretation of M. Łomnicki's species, description of a new Siberian species, and comparison with British Weichselian faunas. *Philosophical Transactions of the Royal Society London, Biological Sciences,* 265: 299–326.

AOGFU, 1998. *Atlas of oil and gas fields of Ukraine*. Fedyshyn, V. *et al*. (eds), Lviv, Ukrainian Oil and Gas Academy, v. 5: 710 pp.

Baranovskiy, N. F. & Sukharev, M. F., 1959. *Ozokeryt (dobycha, pererabotka i primenenje).* (In Russian). Izdatel'stvo Gostoptekh, Moskva, 203 pp.

Barabasz, W., Chmiel, M. J., Dzieniewicz, M. & Sechman, H., 2005. Microbiological characteristics and gaseous hydrocarbons, carbon dioxide and hydrogen distribution in the near-surface zone of the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 175–185.

Barabasz, W., Chmiel, M. J. & Ostafin, M., 2009. Microbiological characteristics of Quaternary sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 439–446.

Bayger, J. A., 1914. Żaba śmieszka. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 385–386.

Bayger, J. A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F., 1914. *Wykopaliska Staruńskie.* (In Polish). Muzeum im. Dzieduszyckich, Lwów, 15: 386 pp.

Bojko, G. Y., 1967. Uslovija obrazovanija Prykarpatskikh ozokeritovykh mestorozhdenij. (In Russian). *Geologija i geokhimija gorjuchikh iskopajemykh*, 12: 107–115.

Bojko, G. & Sozański, J., 2004. Ozokeryt. (In Polish and Ukrainian). In: Raczkowski, J. & Zarubin, J. (eds), *Nafta i gaz Podkarpacia. Zarys historii.* Instytut Nafty i Gazu, Kraków, Naukova Dumka, Kyiv: 345–360.

Bujalski, B., 1928. Pasieczna. (In Polish). In: Tołwiński, K. (ed.), *Kopalnie nafty i gazów ziemnych w Polsce*. *Biuletyn, Karpacka Stacja Geologiczna*, Borysław, 18: 17–24.

Bujalski, B., 1929. Bitków. (In Polish). In: Tołwiński, K. (ed.), *Kopalnie nafty i gazów ziemnych w Polsce*. *Biuletyn, Karpacka Stacja Geologiczna*, Borysław, 18: 28–37.

Chornobay, Yu. M. & Drygant, D. M., 2009. The Starunia collections in the Natural History Museum of the National Academy of Sciences of Ukraine in Lviv. *Geoturystyka* (in press).

Duliński, M., Różański, K. & Kotarba, M. J., 2005. Isotopic and chemical composition of surface and groundwaters in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses*. Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 187–194.

Dzieniewicz, M., Sechman, H. & Mościcki, J., 2005. Preliminary near-surface geochemical survey and shallow temperature measurements along the selected line in Starunia, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 147–155.

Dzieniewicz, M., Sechman, H. & Kotarba, M. J., 2009. Molecular and isotopic compositions of gases adsorbed to near surface sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 421–437.

Eder, W., 1999. "UNESCO GEOPARKS" – A new initiative for protection and sustainable development of the Earth's heritage. *Neues Jahrbuch für Geologie und Paläontologie*, 214: 353–358.

Gams, H., 1934. Die Moose von Starunia als Vegetations- und Klimazeugen. *Starunia*, 2: 1–6.

Granoszewski, W., 2002. Szczątki roślinne towarzyszące wykopaliskom mamuta i nosorożca włochatego w Staruni (Ukraina) w latach 1907–1929. (In Polish). *Wiadomości Botaniczne*, 45 (3/4): 29–34.

Hoyer, H., 1914. Części miękkie głowy nosorożca i skóra mamuta. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 269–340.

Hoyer, H., 1915. Die Untersuchungsergebnisse am Kopfe des in Starunia in Galizien ausgegrabenen Kadavers von *Rhinoceros antiquitatis* Blum. *Zeitschrift für Morphologie und Anthropologie*, 19: 19–492.

Hoyer, H., 1937. Fauna dyluwialna Polski. (In Polish). *Kosmos*, 63: 181–210.

Kiernik, E., 1914. Szczątki innych kopalnych kręgowców ze Staruni. (In Polish). In: Bayger, J. A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 341–355.

Koltun, Y. V., Adamenko, O. M., Kotarba, M. J., Dudok, I. V., Pavluk, M. I., Burzewski, W. & Stelmakh, O. R., 2005. Geological setting and petroleum occurrence of the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 61–77.

Korin, S. S., 1992. Tektonicheskie uslovija formirovanija struktury kalijnykh mestorozhdenij v Boryslavo-Pokutskom pokrove. (In Russian). *Otechestvennaja geologija*, 12: 20–25.

Korin, S. S., 1994a. Pro mozhlyvist' vykorystannja budovy solenosnykh vidkladiv Prykapattia dlia prognozuvannia naftonosnykh struktur. (In Ukrainian). *Geologiia i geokhimiia goryuchykh kopalyn,* 1–2: 89–93.

Korin, S. S., 1994b. Geological outline of Miocene salt-bearing formations of the Ukrainian fore-Carpathian area. (In Polish, English summary). *Przegląd Geologiczny*, 42: 744–747.

Korin, S. S., 2000. Occurrence of fossil animals in salt-bearing Vorotyshcha Formation: history and perspectives of further discoveries. (In Polish, English summary). *Przegląd Geologiczny*, 48: 305–306.

Korin, S. S., 2005. Miocene salt-bearing Vorotyshcha Beds in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 79–86.

Kormos, T., 1934. Knochenfragmente der in Starunia zusammen mit dem Wollnashorn gefundenen kleineren Wirbeltiere. *Starunia*, 5: 1–4.

Kotarba, M. J., 2002. Composition and origin of hydrocarbons saturating the remnants of woolly rhinoceros from Starunia, the Ukrainian Carpathians. (In Polish, English abstract). *Przegląd Geologiczny*, 50: 531–534.

Kotarba, M. J., 2005. Interdisciplinary Polish and Ukrainian studies on the Starunia extinct fauna site in the years 2004–2005. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 9–20.

Kotarba, M. J. (ed.), 2005. *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków, 218 pp.

Kotarba, M. J., 2009. Idea of Ukrainian-Polish cross-border geotouristic route "Traces of large extinct mammals, ozokerite, oil and salt": from Starunia to Kraków. *Geoturystyka* (in press).

Kotarba, M. J. & Alexandrowicz, S. W., 2008. Historia badań unikatowego stanowiska paleontologicznego w Staruni. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuś-*

cizna Staruni. Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 157–159.

Kotarba, M. J. & Koltun, Y. V., 2006. The origin and habitat of hydrocarbons of the Polish and Ukrainian Parts of the Carpathian Province. In: Golonka, J. & Picha, F. J. (eds), *The Carpathians and their foreland: geology and hydrocarbon resources. American Association of Petroleum Geologists Memoir*, 84: 395–442.

Kotarba, M. J. & Stachowicz-Rybka, R., 2008. Wyjątkowe stanowisko paleontologiczne i środowisko osadów plejstoceńskich, w których znaleziono nosorożce włochate w Staruni (Karpaty Wschodnie). (In Polish). *Przegląd Geologiczny*, 56: 442–452.

Kotarba, M. J., Dzieniewicz, M. & Sechman, H., 2005a. Geochemical survey, molecular and isotopic compositions, and genetic identification of near-surface gases from the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 157–174.

Kotarba, M. J., Więcław, D., Koltun, Y. V., Lewan, M. D., Marynowski, L. & Dudok, I. V., 2005b. Organic geochemical study and genetic correlations between source rocks and hydrocarbons from surface seeps and deep accumulations in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa– Kraków: 125–145.

Kotarba, M. J., Alexandrowicz, S. W. & Stachowicz-Rybka, R., 2008a. Historia i program dalszych badań geologicznych na obszarze byłej kopalni ozokerytu i stanowiska paleontologicznego w Staruni (In Polish). *Przegląd Geologiczny*, 56: 34–441.

Kotarba, M. J., Dzieniewicz, M., Mościcki, W. J. & Sechman, H., 2008b. Unique Quaternary environment for discoveries of woolly rhinoceroses in Starunia, fore-Carpathian region, Ukraine: Geochemical and geoelectric studies. *Geology*, 36: 567–570.

Kotarba, M. J., Adamenko, O. M. & Stelmakh, O. R., 2008c. Ukraine–Polish researches in Starunia in 2004–2005 on a place of finds of woolly rhinoceroses. *Abstracts of the International Science-Technical Conference "IFNTUOG-40" on "Resources-saving Technologies in Oil and Gas Power Engineering"*, National Technical University of Oil and Gas in Ivano-Frankivsk, 16-20 April 2008, Ivano-Frankivsk: 14.

Kotarba, M. J., Dzieniewicz, M. & Sechman, H., 2008d. Surface geochemical researches in Starunia. *Abstracts of the International Science-Technical Conference "IFNTUOG-40" on "Resources-saving Technologies in Oil and Gas Power Engineering"*, National Technical University of Oil and Gas in Ivano-Frankivsk, 16-20 April 2008, Ivano-Frankivsk: 19.

Kotarba, M. J., Dzieniewicz, M. & Sechman, H., 2008e. Powierzchniowe badania geochemiczne w Staruni w latach 2004–2007. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 161–163.

Kotarba, M. J., Sechman, H. & Dzieniewicz, M., 2009a. Distribution and origin of gaseous hydrocarbons and carbon dioxide in the Quaternary sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 403–419.

Kotarba, M. J., Więcław, D., Toboła, T., Zych, H., Kowalski, A. & Ptak, S., 2009b. Bitumen and salt contents within the Quaternary sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 447–461.

Kotarba, M. J., Fabiańska, M., Więcław, D., Kowalski, A. & Zych, H., 2009c. Biological markers and stable carbon isotope studies of bitumen impregnating Quaternary sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 463–480.

Kubiak, H., 1969. Über die Bedeutung der Kadaver des Wollhaarnashorns von Starunia. *Berichte der Deutschen Gesellschaft für geologische Wissenschaften, A, Geologie und Paläontologie,* 14: 345–347.

Kubiak, H., 1971. Datowanie radiowęglem ^{14}C szczątków nosorożca włochatego ze Staruni. (In Polish). *Wszechświat*, 10: 267–268.

Kubiak, H., 1994. Starunia – w 85 rocznicę pierwszych odkryć paleontologicznych. (In Polish). *Wszechświat*, 95: 295–299.

Kubiak, H., 2003. Nosorożce i mamut ze Staruni. (In Polish). *Prace Komisji Paleogeografii Czwartorzędu PAU*, 1: 19–20.

Kubiak, H., 2008. Mamut i nosorożec ze Staruni – tafonomia znalezisk 1907 i 1929. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 165–166.

Kubiak, H., 2009. The Starunia collections in the Institute of Systematics and Evolution of Animals, Polish Academy of Sciences in Kraków. *Geoturystyka* (in press).

Kubiak, H. & Drygant, D. M., 2005. The Starunia collections in Lviv and Kraków natural history museums and history of palaeontological studies. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 37–44.

Kubiak, H. & Dziurdzik, B., 1973. Histological characters of hairs in extant and fossil rhinoceroses. *Acta Biologica Cracoviensia*, Series Zoologia, 16: 55–61.

Kuc, T., Różański, K., Goslar, T., Kubiak, H. & Kotarba, M. J., 2005. Radiocarbon dating of remnants of woolly rhinoceroses and mammoth from Starunia, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses*. Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 195–203.

Kuc, T., Różański, K., Goslar, T. & Stachowicz-Rybka, R., 2009. Radiocarbon dating of plant remnants in Quaternary sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 289–296.

Kulczyński, W., 1914. Typ: Członkonogi. Gromada: Pajęczaki. Rząd: Roztocza. (In Polish). In: Bayger, J. A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*.

Muzeum im. Dzieduszyckich, Lwów, 15: 46–49.

Kulchytsky, Y. O. & Sovchyk, Y. V., 1986. To the problem of Paleogene–Neogene border in the Carpathians (In Russian, English summary). *Paleontologicheskiy sbornik*, 23: 89–99.

Kuśka, A., 1992. Revision of fossil "Curculionidea (Coleoptera)" from Borysław and Starunia near Lwów. *Polskie Pismo Entomologiczne*, 61: 89–95.

Kuźniar, C., 1930. Budowa złóż soli potasowych w niecce Kałuskiej. (In Polish). *Posiedzenia Naukowe Państwowego Instytutu Geologicznego*, 25: 16–21.

Lengersdorf, F., 1934. Dipteren aus den diluvialen Schichten von Starunia, *Starunia*, 4: 1–8.

Lubicz-Niezabitowski, E., 1914a. Słoń mamut. (In Polish). In: Bayger, J. A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 95–180.

Lubicz-Niezabitowski, E., 1914b. Nosorożec włochaty. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 181–268.

Łomnicki, J., 1911. O składnikach tektonicznych Podkarpacia nadwórniańsko-sołotwińskiego. (In Polish). *Sprawozdania Komisji Fizjograficznej Akademii Umiejętności*, 45: 8–17.

Łomnicki, J. & Łomnicki, M., 1914. Owady (Insekta). Rząd: Tęgopokrywe (Coleoptera). (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 52–85.

Łomnicki, M., 1908. Wykrycie mamuta (*Elephas primigenius* Blumb.) i nosorożca dyluwialnego (*Rhinoceros antiquitatis* Blumb.) w Staruni (pow. Bohorodczański). (In Polish). *Kosmos*, 33: 63–70.

Łomnicki, M., 1914a. Wykrycie mamuta i nosorożca dyluwialnego. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 1–8.

Łomnicki, M., 1914b. Stosunki topograficzne i geologiczne kopalni staruńskiej. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 9–24.

Łomnicki, M., 1914c. Gromada: Wije. Rząd Dwuparce. Rząd: Prostoskrzydłe. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 50.

Łomnicki, M., 1914d. Gromada: Owady. Rząd Ważki. Rząd: Prostoskrzydłe. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 51–52.

Łomnicki, M., 1914e. Owady (Insecta). Rząd: Półtępokrywe (Hemiptera) i Dwuskrzydłe (Diptera). (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 86–88.

Łomnicki, M., 1914f. Typ: Mięczaki (*Mollusca*). (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 41–45.

Madej, J. & Porzucek, S., 2005. Elements of geological setting of former ozokerite mine based on gravity survey in Starunia, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses*. Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 115–124.

Matskevyj, L. G., 2005. Archaeological sites in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses*. Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 45–51.

Mierzejewski, W., 1914. Łuszczak grubodziób. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*.Muzeum im. Dzieduszyckich, Lwów, 15: 357–384.

Mitura, F., 1944. *Geologia złoża wosku w Staruni*. (In Polish). Unpublished report, Archive of the Jagiellonian University, Kraków, 18 ms. pp.

Monchak, L. S. & Grodetska, G. D., 1987. Glybynna budova Boryslavs'ko-Pokuts'koy zony Peredkarpats'kogo progynu. (In Ukrainian). *Rozvidka i rozrobka naftovykh i gazovykh rodovyshch*, 22: 21–22.

Mościcki, W. J., 2005. Characterization of near-surface sediments based on DC resistivity soundings in the Starunia area, fore-Carpathian region, Ukraine. In: Kotarba, M. J. (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses.* Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 103–114.

Mościcki, W. J., 2008a. Surface geoelectric researches in Starunia. *Abstracts of the International Science-Technical Conference "IFNTUOG-40" on "Resources-saving Technologies in Oil and Gas Power Engineering"*, National Technical University of Oil and Gas in Ivano-Frankivsk, 16-20 April 2008, Ivano-Frankivsk: 17.

Mościcki, W. J., 2008b. Badania geoelektryczne w Staruni w latach 2004–2007. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 167–170.

Mościcki, W. J., 2009. Characterization of near-surface sediments based on combined geoelectric studies at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae,* 79: 333–342.

Mościcki, W. J. & Sokołowski, T., 2009. Electric resistivity and compactness of sediments in the vicinity of boreholes drilled in the years 2007–2008 in the area of Starunia palaeontological site (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 343–355.

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.

Niezabitowski-Lubicz, E., 1911a. Die Haut- und Knochen-überreste des in Starunia in einer Erdwachsgrube gefundenen Mammut-Kadavers (Elephas primigenius) (Vorläufige Mitteilung). *Bulletin International de l'Académie Polonaise des Sciences et des Lettres de Cracovie*, Ser. B, Cracovie, 4: 229–239.

Niezabitowski-Lubicz, E., 1911b. Die Überreste des in Starunia in einer Erdwachsgrube mit Haut und Weichteilen gefundenen Rhinoceros antiquitatis Blum. (tichorhinus Fisch.). *Vorläufige Mitteilung*, 4: 240–267.

Nowak, J., 1917. Kilka uwag w sprawie budowy Karpat wschodnich. (In Polish). *Kosmos*, 41: 148–154.

Nowak, J. & Panow, E., 1930. The geological conditions of the Starunia excavations. In: Nowak, J., Panow, E., Tokarski, J., Szfer, W. & Stach, J. (eds), The second wolly rhinoceros (Coelodonta antiquitatis Blum.) from Starunia, Poland. *Bulletin Internationale de l' Académie Polonaise des Sciences et des Lettres de Cracovie*, Ser. B, Cracovie: 1–7.

Nowak, J., Panow, E., Tokarski, J., Szafer, W. & Stach, J., 1930a. Drugi nosorożec z warstw dyluwialnych Staruni oraz charakter jego otoczenia (geologja, mineralogja, flora i fauna. (In Polish). *Rozprawy Wydziału matematyczno-przyrodniczego*, Polska Akademja Umiejętności, 70B, 1: 1–56.

Nowak, J., Panow, E., Tokarski, J., Szafer, W. & Stach, J., 1930b. The second woolly rhinoceros (*Coelodonta antiquitatis* Blum.) from Starunia, Poland. *Bulletin Internationale de l' Académie Polonaise des Sciences et des Lettres de Cracovie*, B: 1–47.

Pawłowski, J., 2003. Ocena koleopterofauny z wykopalisk staruńskich. (In Polish). *Prace Komisji Paleogeografii Czwartorzędu Polskiej Akademii Umiejętności*, 1: 163–169.

Porzucek, S. & Madej, J., 2008a. Gravimetric researches in Starunia. *Abstracts of the International Science-Technical Conference "IFNTUOG-40" on "Resources-saving Technologies in Oil and Gas Power Engineering"*, National Technical University of Oil and Gas in Ivano-Frankivsk, 16-20 April 2008, Ivano-Frankivsk: 16.

Porzucek, S. & Madej, J., 2008b. Badania grawimetryczne w Staruni w latach 2004–2007. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 171–172.

Porzucek, S. & Madej, J., 2009a. Recognition of geological structures at Starunia palaeontological site and vicinity (Carpathian region, Ukraine) based on gravity surveys. *Annales Societatis Geologorum Poloniae*, 79: 357–363.

Porzucek, S. & Madej, J., 2009b. Detection of near-surface geological heterogeneity at Starunia palaeontological site and vicinity (Carpathian region, Ukraine) based on microgravity survey. *Annales Societatis Geologorum Poloniae*, 79: 365–374.

Raciborski, M., 1914a. Roślinność szybu mamutowego w Staruni. (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 27–29.

Raciborski, M., 1914b. Liście i owoce mamutowego szybu w Staruni. (In Polish). In: Bayger, J. A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 30–33.

Rogala, W., 1907. Przyczynek do znajomości dyluwialnych utworów Galicji. (In Polish). *Kosmos*, 32: 350–363.

Schille, F., 1914. Owady (Insekta). Rząd: Łuskoskrzydłe (Lepidoptera). (In Polish). In: Bayger, J.A., Hoyer, H., Kiernik, E., Kulczyński, W., Łomnicki, M., Łomnicki, J., Mierzejewski, W., Niezabitowski, W., Raciborski, M., Szafer, W. & Schille, F. (eds), *Wykopaliska Staruńskie*. Muzeum im. Dzieduszyckich, Lwów, 15: 89–92.

Sechman, H., Kotarba, M. J., & Dzieniewicz, M., 2009. Surface geochemical survey at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 375–390.

Siegfried, E., 1912. *Die Naphthalagerstätten der Umgebung von Solotwina Ein Beitrag zur Tektonik des Karpathenrandes in Ostgalizien*. Verlag für Fachliteratur G.M.b.H., Wien, 72 pp.

Sokołowski, T., 2008. Rzeźba doliny Łukawca Wielkiego – stan i program nowych badań. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 177–181.

Sokołowski, T., 2009. Development of relief of the Velyky Lukavets River valley near Starunia palaeontological site (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae,* 79: 243–254.

Sokołowski, T. & Stachowicz-Rybka, R., 2008. Wykształcenie i geneza osadów czwartorzędowych w Staruni. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 183–186.

Sokołowski, T. & Stachowicz-Rybka, R., 2009. Chronostratigraphy and changes of environment of Late Pleistocene and Holocene at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae,* 79: 315–331.

Sokołowski, T., Stachowicz-Rybka, R. & Woronko, B., 2009. Upper Pleistocene and Holocene deposits at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae,* 79: 255–278.

Stach, J., 1930. The second rhinoceros from the diluvial strata of Starunia. In: Nowak, J., Panow, E., Tokarski, J., Szafer, W. & Stach, J. (eds), The second woolly rhinoceros (*Coelodonta antiquitatis* Blum.) from Starunia, Poland. *Bulletin Internationale de l'Académie Polonaise des Sciences et des Lettres de Cracovie, Ser. B,* Cracovie: 21–47.

Stachowicz-Rybka, R., 2008a. History of paleobotanic researches in Starunia. *Abstracts of the International Science-Technical Conference "IFNTUOG-40" on "Resources-saving Technologies in Oil and Gas Power Engineering"*, National Technical University of Oil and Gas in Ivano-Frankivsk, 16-20 April 2008, Ivano-Frankivsk: 15.

Stachowicz-Rybka, R., 2008b. Historia i program nowych badań paleobotanicznych w Staruni. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv –

Ivano-Frankivsk – Kraków. TBPŚ ”Geosfera”, Kraków: 187–189.

Stachowicz-Rybka, R., Kotarba, M. J., Stelmakh, O. R., Porzucek, S. & Burzewski, W., 2008. Miejsce i środowisko utworów plejstoceńskich znalezienia nosorożców włochatych w Staruni. (In Polish). In: Kotarba, M. J., Chornobay, Yu. M., Adamenko, O. M., Stachowicz-Rybka, R., Vovk, O. B., Stelmakh, O. R. & Prihodko, M. M. (eds), *Przyrodniczo-historyczna spuścizna Staruni.* Materiały II Międzynarodowej Konferencji Naukowej, Starunia – Lviv – Ivano-Frankivsk – Kraków. TBPŚ "Geosfera", Kraków: 191–193.

Stachowicz-Rybka, R., Granoszewski, W. & Hrynowiecka-Czmielewska, A., 2009a. Quaternary environmental changes at Starunia palaeontological site and vicinity (Carpathian region, Ukraine) based on palaeobotanical studies. *Annales Societatis Geologorum Poloniae*, 79: 279–288.

Stachowicz-Rybka, R., Gałka, M., Alexandrowicz, W. P. & Alexandrowicz, S. W., 2009b. Plant macrofossils and malacocoenoses of Quaternary mineral-organic sediments at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 297–313.

Stelmakh, O. R., 2005. Geomorphological and neotectonic features of the Starunia geodynamic test area. In: Kotarba, M. J., (ed.), *Polish and Ukrainian geological studies (2004–2005) at Starunia – the area of discoveries of woolly rhinoceroses*. Polish Geological Institute and Society of Research on Environmental Changes "Geosphere", Warszawa–Kraków: 87–93.

Szafer, W., 1930. The Diluvial Flora in Starunia. In: Nowak, J., Panow, E., Tokarski, J., Szafer, W. & Stach, J. (eds), The second woolly rhinoceros (*Coelodonta antiquitatis* Blum.) from Starunia, Poland. *Bulletin International de l'Académie Polonaise des Sciences et des Lettres de Cracovie,* Ser. B*,* Cracovie: 12–21.

Szafran, B., 1934. Mchy dyluwialne w Staruni. (In Polish). *Starunia,* 1: 1–17.

Szajnocha, W., 1881. *Górnictwo naftowe w Galicyi wobec ustawodawstwa górniczego*. (In Polish). Redakcya Muzeum, Kraków, 107 pp.

Szajnocha, W., 1892. Wosk ziemny w Galicyi. (In Polish). *Przewodnik Naukowo-Literacki*, 82: 177–187; 90: 266–283.

Ślączka, A., Kruglov, S., Golonka, J., Oszczypko, N., & Popadyuk, I., 2006. Geology and hydrocarbon resources of the Outer Carpathians, Poland, Slovakia and Ukraine: General geology. In: Golonka, J. & Picha, F. J. (eds), *The Carpathians and their foreland: Geology and hydrocarbon resources*. *American Association of Petroleum Geologists Memoir*, 84: 221–258.

Tokarski, J., 1930. Nowe wykopaliska u stóp Karpat w Staruni. (In Polish). *Wszechświat*, 1: 32–33.

Tołwiński, K., 1927. Z geologji południowej strefy przedgórza polskich Karpat wschodnich. (In Polish). *Sprawozdania Państwowego. Instytutu Geologicznego*, IV, 1–2: 246–272.

Vialov, O. S., Gavura, S. P., Danysh, V. V., Lemishko, O. D., Leshchukh, R.Y., Ponomariova, L. P., Romaniv, A. M., Smirnov, S. E., Smolinska, N. I. & Tsarnenko, P. N., 1988. *Stratotipy melovykh i paleogenovykh otlozheniy Ukrainskikh Karpat*. (In Russian). Naukova Dumka, Kyiv, 204 pp.

Windakiewicz, E., 1875a. Erdöl und Erdwachs in Galizien. *Berg- und Hüttenmännischen Jahrbuch*, 23: 1–68.

Windakiewicz, E., 1875b. *Olej i wosk ziemny*. (In Polish). Nakład Gazety Lwowskiej, Lwów, 155 pp.

Zeuner, F., 1934. Die Orthopteren aus der diluvialen Nashornschicht von Starunia (polnische Karpathen). *Starunia*, 3: 1–19.

Zuber, R., 1885. Studia geologiczne we wschodnich Karpatach. (In Polish). *Kosmos*, 10: 345–397.

Zuber, R., 1888. *Atlas Geologiczny Galicyi – tekst do zeszytu drugiego.* (In Polish). Komisya Fizyjograficzna Akademii Umiejętności, Kraków, 120 pp.

Zubrzycki, P., 1938. Starunia jako teren naftowy w świetle dotychczasowych wierceń. (In Polish). *Przemysł naftowy*, 21: 587–591; 22: 608–613