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TRANSCARPATHIAN CONTACTS OF THE LATE GLACIAL SOCIETIES OF THE POLISH LOWLANDS

Identification of exotic raw-materials discovered within the context of Late Glacial societies of the North European Plain is a crucial factor in discussion about far-reaching exchange systems of goods and ideas. The present paper considers the occurrence of obsidian finds on the Polish Lowlands, hundreds of kilometers away from its sources located south of the Carpathians. The focus is on chemical recognition and identification of a large and unique assemblage of obsidian artefacts from two Polish localities based on non-invasive Prompt Gamma Activation Analysis (PGAA). As a result, a clear connection of northern Polish obsidians with its outcrops located on the northern (Slovakian) fringe of the Tokaj Mountains was established that is the first detailed identification of obsidian finds from the territory of Poland ever. A review of Polish and Slovakian obsidian assemblages from the Late Glacial times and the importance of obsidian exchange and mobility for Late Palaeolithic societies of Central Europe are discussed supported by analytical results of PGAA.

KEY WORDS: obsidian, Late Glacial, Central Europe, Poland, Slovakia, Hungary, exchange, mobility, provenance, prompt gamma activation analysis

1. INTRODUCTION

The Northern Hemisphere, due to periodical glaciation periods in its history, witnessed a number of dramatic climatic changes that heavily influenced human presence in the Northern part of Central Europe. During Last Glacial Maximum (between ca. 26.5-20 ka; Clark et al. 2009) most of the North European Lowland was either covered by ice-sheet or was an arctic desert devoid of any signs of life. Only at the very end of Pleniglacial (Greenland Stadial 2) Central European Lowland was available for human settlement unless the evidence of such an early occupation of that area is still under discussion (Terberger, Street 2002; Kabaciński, Sobkowiak-Tabaka 2012). However, there is no controversy that at the beginning of Late Glacial (Greenland Interstadial 1; ca. 14750 ka BP – Björck et al. 1998; Lowe et al. 2008) groups of hunter-gatherers inhabited continuously vast areas of the European Northern Lowlands. Relatively fast climatic changes during the Late Glacial recorded in the Greenland ice-cores and other fossil archives led to transformation of arctic and shrub tundra environment present at the beginning of the Late Glacial (Greenland Interstadial-1e) to open forest envi-

Fig. 1. Contour map showing the area discussed in the paper

ronment (often dominated by birch or pine) in the Allerød (Greenland Interstadial-1c - 1a) being again replaced by arctic and shrub tundra with groups of pine trees and willow-birch thickets at the end of the Late Glacial (Younger Dryas – Greenland Stadial 1) (Björck et al. 1998; Coope et al. 1998; Ralska-Jasiewiczowa 2004). Along with climatic changes also a subsistence strategies of the first populations of Northern Europe were modified ranging from reindeer hunting in tundra conditions to elk and small fauna hunting in birch forests. Typical feature of that Palaeolithic hunters, especially at the beginning and at the end of the Late Glacial was a high degree of mobility forced by large-scale migrations of herds of reindeers that are consider as their main source of food (Sturdy 1975; Campbell 1977; Bokelmann 1979; Kozłowski 2004; for opposite view see Kabaciński, Sobkowiak-Tabaka 2009). As a side effect of migrations an opportunity of exchange of ideas and goods, including exotic raw materials between different groups of hunters could occur.

The aim of the paper is to discuss the occurrence of obsidian finds in the Polish Lowland, a central part of the North European Lowland, during the Late Glacial, i.e. the period between the first LG warming (Greenland Interstadial-1e, ca. 14 750 ka BP and Younger Dryas (Greenland Stadial-1, ca. 11 550 GRIP ka BP – Björck et al. 1998; Rasmussen et al. 2008). During the Late Glacial the Lowland and territories between the Plain and southern mountain chains witnessed the presence of a number of hunter-gatherer societies (Fig. 1). At the dawn of the Late Glacial, southern uplands were sparsely inhabited by final Magdalenian groups while at the same time vast areas of the western Polish Plain were settled by the Hamburgian people. Later on, in the mid-Late Glacial, Federmesser-like groups (Arch Backed Piece Technocomplex) inhabited the area, while during the Younger Dryas the Swiderian and to some degree Ahrensburgian hunters densely settled the Plain and southern uplands.

Characteristic for all of the above societies was the exploitation of local flint sources to produce tools necessary for basic economic activities. In the case of upland areas, it was mainly Jurassic Cracow flint or chocolate flint. While on the Plain

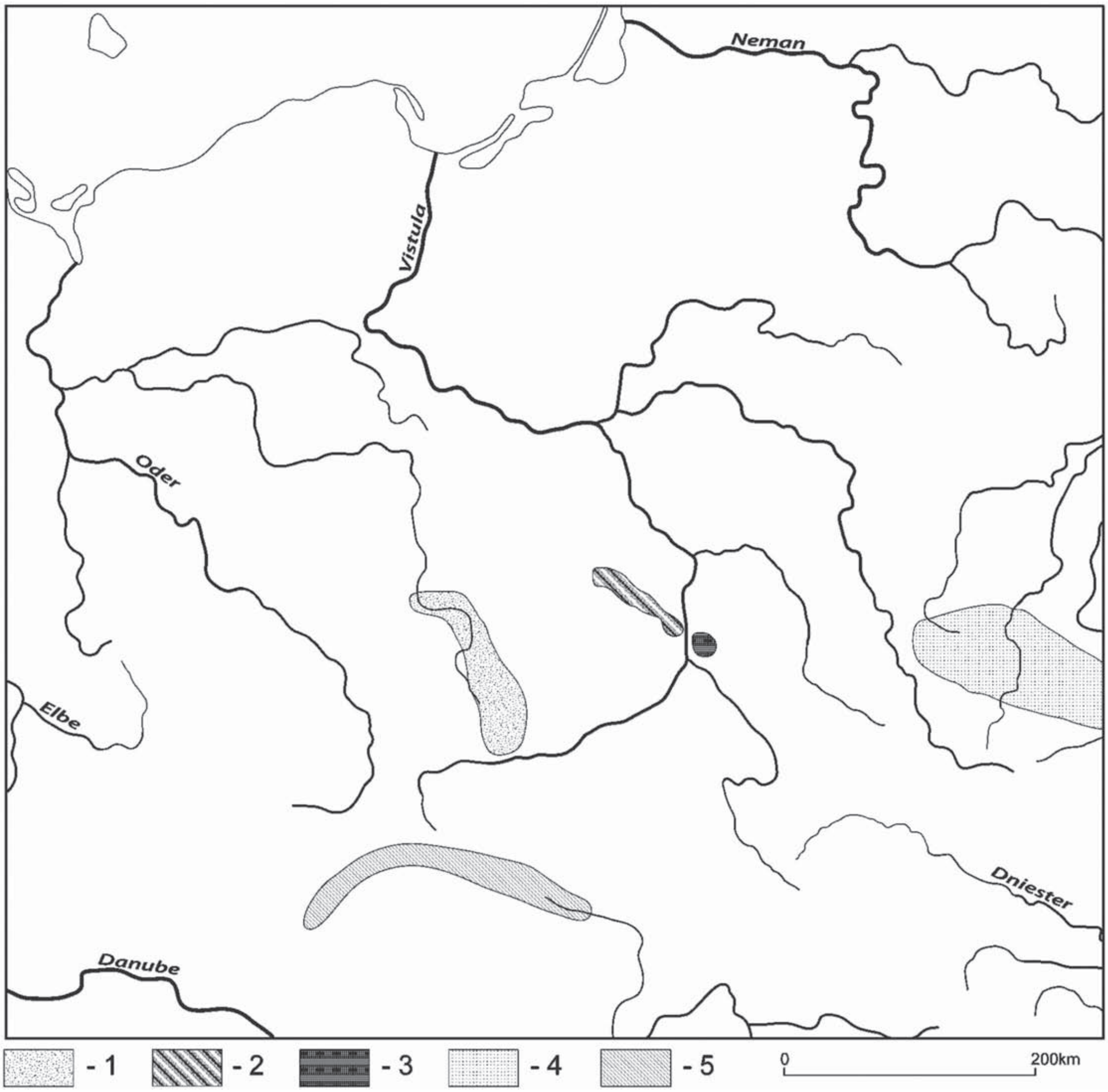


Fig. 2. Outcrops of flints and radiolarites in Poland: 1 – Jurassic flint; 2 – chocolate flint; 3 – Świeciechów flint; 4 – Volhynian flint; 5 – radiolarite (acc. to. Sulgostowska 2005, Fig. 10, Kozłowski 2013, Fig. 15). Computer processing by P. Szejnoga

the basic source was local erratic Baltic Cretaceous flint brought in by the last ice-sheet form Scandinavia. The distribution of flint from southern Poland is well recognized during the Late Glacial (Sulgostowska 2005). For instance, chocolate flint was widely distributed on the Plain and single finds were discovered even at distances of several hundred kilometres. No doubt it had an economic impact given the value of the raw material (Fig. 2). There are two specific materials, however, that seemed to play a different role within LG societies of the Lowland, namely radiolarite and obsidian.

Radiolarite was procured and worked on a large scale all around the Carpathian Basin. Its sources are known from Hungary in the south, to the Pieniny Mountains and Silesia on the north (Biró 2009; Foltyn et al. 2009; Rydlewski 1989). On the Plain, only single finds are recorded (Sulgostowska 2005). Until now, the most distant radiolarite import was found on the Polish Lowland in the Swiderian assemblage at Janów 25 (Koło county), ca. 350 km from the outcrops (Kabaciński et al. 2009), and at Szynych 13 (Grudziądz county), ca. 460 km from the Pieniny Klippen Belt (Jurzysta 2010)[1].

[1] The radiolarite core was found near the concentration IV, belonging to Swiderian people but inside also some younger materials (Mesolithic ones) were found. It is very difficult to solve the problem to whom this core has belonged (Jurzysta 2010).

Obsidian, due to its characteristic appearance and well documented outcrops in Central Europe, is an even better marker of long-distance contacts. It is an igneous rock, effusive (mostly acidic), consisting almost exclusively of volcanic glass. It is an amorphous substance, mostly transparent or translucent with strong glassy luster. Its colour varies from black, dark grey and sometimes brown-yellow to dark green, olive, orange, red, blue, purple and gold (Żaba 2003). Obsidian is a product of acidic rhyolitic volcanism. Its geological age is relatively old in the Carpathian Basin, estimated between 15.2 to 12 million years for the northern (Slovakian) sources, and younger (around 9 million years) for the southern (Hungarian) sources. From a Northern Lowland perspective the nearest European territories with obsidian outcrops are central and south-eastern Slovakia, north-eastern Hungary and western Ukraine (Rosania et al. 2008).

In the late 1970s, modern analytical methods were developed to characterise the outcrops of Carpathian obsidians. They were divided into two major groups – *Carpathian 1* (C1) connected with outcrops in the vicinity of Viničky and Cejkov (Slovakia) and *Carpathian 2* (C2) from the Tokaj Mts. in Hungary (Williams, Nandris 1977; Williams-Thorpe et al. 1984, 1987; Biró 2014). Taking into consideration the latest results study on the Carpathian obsidians, three main groups can be distinguished. Apart from C1 and C2, we have to consider C3 (Transcarpathian) obsidian from the vicinity of Rokosovo, today's Ukraine (Williams-Thorpe et al. 1984, Rosania et al. 2008). Rosania et al., claimed two more obsidian types (C4 and C5): however, these can be associated with perlite sources that did not yield knappable obsidian.

As far as obsidian artefacts from Poland are concerned, only one two pieces from Rusko (Lower Silesia, south-western part of Poland) and Rydno (central Poland) have been previously examined. In the first case, unfortunately destructive, physical and chemical methods have been used, namely: polarising microscopy, scanning electron microscopy, electron microprobe and X-ray diffraction phase analysis. The obtained qualitative identification of Al, Si, Fe, Sn, Ag, Mn and Cl allowed only rough comparison of the examined piece with Slovakian and Hungarian obsidians. On the basis of the occurrence of iron and grey colour of the artefact and opacity, the author suggests its connection with obsidian 2E from Tokaj Mts. in Hungary (Pawlikowski 1994). In case of eight Mesolithic artefacts from Rydno non-destructive energy dispersive x-ray fluorescence (EDXRF) has been conducted. Results of these studies indicate that all artefacts were manufactured from *Carpathian 1* obsidian (Hughes, Werra 2014). Other obsidian collections have been intuitively linked to outcrops based on macroscopic analyses (Sulgostowska 2005; Szeliga 2002).

2. OVERVIEW OF OBSIDIAN UTILISATION BY THE LATE PALAEOLITHIC SOCIETIES IN POLAND AND SLOVAKIA

Studies of obsidian finds in Poland began in the 1920s when, for the first time, obsidian was recognized in a surface collection from Małopolska (southern Poland) (Kozłowski 1923). The oldest obsidian artefact in Poland – a Lower Palaeolithic side-scraper – came from Rusko, site 31 (Lower Silesia, south-western Poland; Burdukiewicz, 1994; Pawlikowski 1994). Obsidian artefacts attributed to the Middle Palaeolithic are known from three sites: Rybnik, site A, Obłazowa Cave and Ciemna Cave (Valde-Nowak et al. 2003; Ginter 1986) (Fig. 3). Most are single tools or debitage pieces, and only the inventories from Obłazowa Cave are typologically varied.

In the Upper Palaeolithic utilization of obsidian increased, especially in Slovakia and Hungary (Biró 1984). Inventories of obsidian connected with Gravettian settlement were also reported in Romania, Ukraine, Moravia, Austria (Williams-Thrope et al. 1984). From Poland single finds belonged to the Szeletian inventories (Obłazowa Cave, layer XI; Valde-Nowak 2003) Aurignacian (Kraków-Zwierzyniec; Sawicki 1949) and Gravettian (Kraków-Spadzista-Street; Sobczyk 1995), and have lately been discovered at site 10 in Targowisko (Little Poland) (Fig. 3). The latter one is of particular interest because it is the largest obsidian assemblage in Poland, consisting of three tools, 29 flakes, 14 blades and ca. 250 chunks (Wilczyński 2010). Intensive use of obsidian in this period is confirmed by finds from eastern Slovakia, at sites located in the vicinity of Cejkov (I, II i IIII), Hrčel, Kašov, Val'aty and Bušovce. The obsidian finds range from 60 to over 80% of the total number

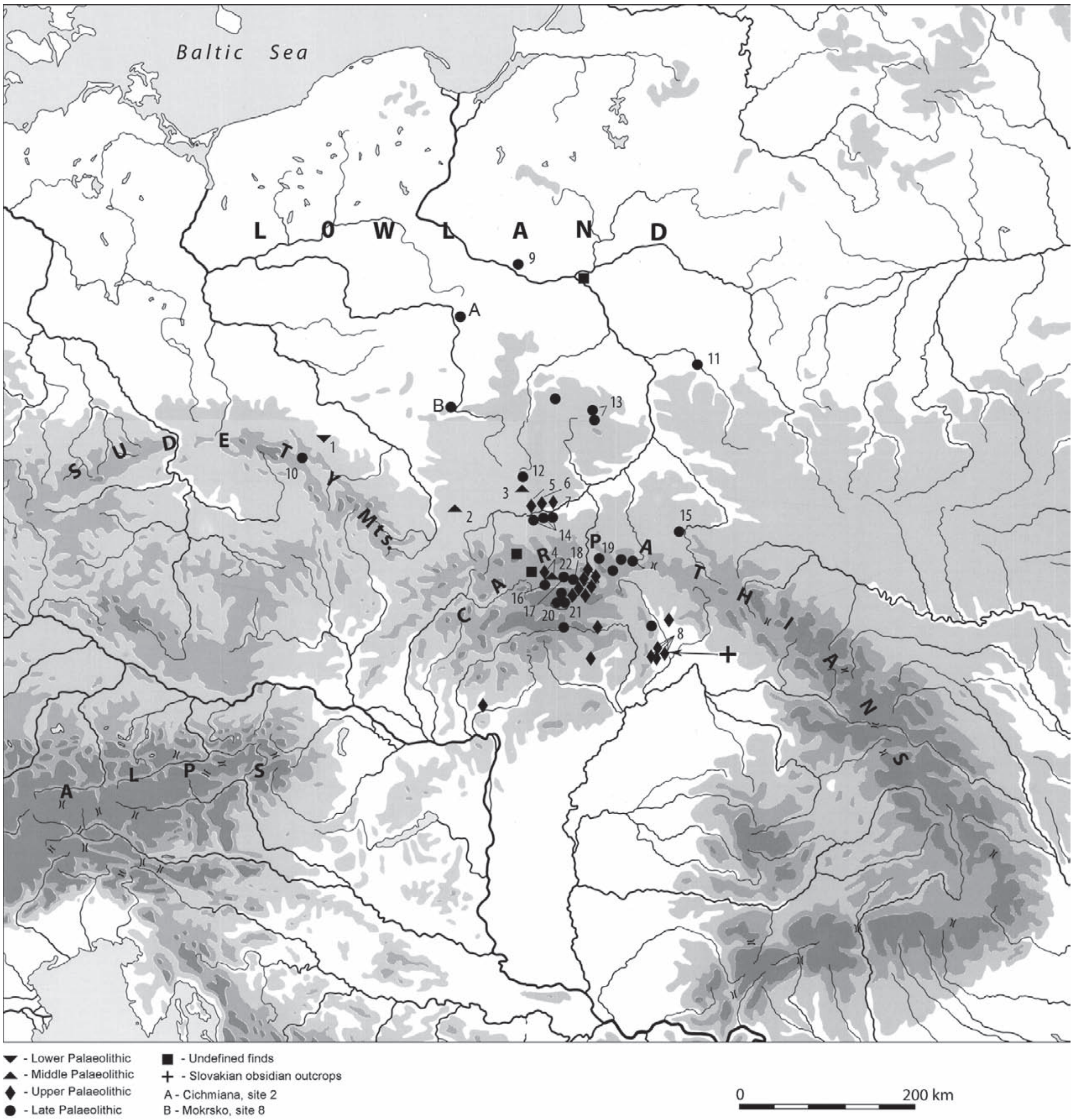


Fig. 3. Location of main sites discussed in the paper: 1 – Rusko, site 31; 2 – Rybnik, site A; 3 – Ojców, Ciemna Cave; 4 – Nowa Biała, site 2; 5 – Kraków-Zwierzyniec, site I; 6 – Kraków, Spadzista Street B; 7 – Targowisko, site 10 and 11; 8 – sites from the vicinity of Cejkov; 9 – Płock; 10 – Mieroszów, site 9; 11 – Czerniejów; 12 – Glanów, site 3; 13 – Rydno; 14 – sites from the vicinity of Kraków; 15 – Wołodź, site 7; 16 – Nowa Biała, site 1; 17 – Sromowce Niżne, site 1; 18 – Skwirtne, site 1; 19 – Tylicz, site A; 20 – Smižany; 21 – Spišska Stara Ves, site 1; 22 – Vel'ky Slavkov

of artefacts in the inventories (Kaminská, Ďuda 1985; Kaminská, Kozłowski 2002; Kaminská 2007). Additionaly artefacts made on brown radiolarite are known from Nietoperzowa Cave (Chmielewski 1975, 121).

There are no traces of obsidian within the Polish final Magdalenian and Hamburgian cultures. Carpathian obsidian appears in the assemblages dated from the mid-Palaeolithic. Numerous obsidian finds are connected with Arched Backed Piece Technocomplex concentrations in the Rydno complex (Schild, Królik, 1981; Tomaszewski et al. 2008). Other sites where obsidian is present are located in the Podhale region (southern Poland), namely Nowa Biała 1, Sromowce-Niżne 1 (Valde-Nowak

1987), Skwirtne 1 (Valde-Nowak 1996) and Tylicz A (Tunia 1978). The inventories are relatively numerous only in Rydno, Skwirtne and Tylicz (Fig. 3). The technological structure of these assemblages is quite homogenous consisting mostly of flakes, occasional blades, cores and tools (2 end-scrapers, backed pieces (3), a core-like burin, dihedral burin, and an undefined tool).

Obsidian was also used by societies connected with Tanged Point Technocomplex. Recently discovered Cichmiana located in the central Polish Lowland is the only Swiderian site where several obsidian artefacts were discovered (Winiarska-Kabacińska, Kabaciński 2009). In southern Poland so far only single finds have been recorded (i.e. "somewhere near Płock", Kraków-Bagno, Glanów, Czerniejów[2], Kraków-Bieżanów 15, Wołodź, Mokrsko and Mieroszów; Krukowski 1920; Sulgostowska 2005; Osipowicz, Szeliga 2004). Single obsidian artefacts may also be attributed to the Swiderian settlement complex in Rydno (as in the case of radiolarite, Schild et al. 2011) (Fig. 3).

In eastern Slovakia three obsidian tanged points, similar to the Lyngby-type points, were found in Sol' and Kamenica nad Cirochou III. The most significant Late Palaeolithic sites in Slovakia were recorded in the Spiš region (mostly in the area of Poprad). Obsidian was the second most common raw material next to radiolarite here (Kaminská 2007). The first Swiderian (Tanged Point Technocomplex) site in Slovakia was discovered in Vel'ky Slavkov (Spiš region). The assemblage consisted of over 500 artefacts, including willow-leaf points (4 whole and 1 one fragment) made mainly of Slovakian radiolarite and obsidian (Bárta 1980). Additional Sviderian sites, like Pod Skalkou, Nad skalami II and Spisška Teplica rarely have obsidian artefacts (Kaminská 2007). The occurrence of radiolarite confirms penetration into Polish territory, as the nearest radiolarite outcrops are located in the Pieniny Mountains.

At Spišska Stara Ves 1, one Ahrensburgian tanged point was discovered. Among the raw materials, radiolarite, chocolate flint, Volhynian, Baltic and occasionally Świeciechów flint and, rarely, Eastern Slovakian obsidian was identified (Soják 2002).

At the site of Smižany, attributed to the Late Palaeolithic, obsidian was the most common raw material (over 50%). There also are several surface collections with obsidian artefacts i.e. Spišská Bela, Kežmarok, Krížova Ves, Podhorany, Podlíniec and Stará L'ubovňa. Also, one obsidian artefact is known from Vel'ká Ves nad Iplom (southern Slovakia) attributed to the Late Palaeolithic (Bárt, 1965; Soják 2002), and one at Sliská Jablonica dated to the Pre-Boreal (Kaminská 2007).

3. LATE PALAEOLITHIC OBSIDIAN FINDS FROM THE POLISH PLAIN ANALYSED BY PGAA METHOD

The main goal of this paper is to present results pertaining to the identification of sources of obsidian artefacts from the Northern European Plain – over 600 km far from the nearest obsidian outcrops. There are only two sites on the Plain where Late Palaeolithic obsidian artefacts have been found: Cichmiana and Mokrsko (Fig. 3). For the provenance study of obsidians from Cichmiana and Mokrsko (Fig. 4, 5), prompt gamma activation analysis (PGAA) at the Budapest Research Reactor was applied.

However, 33 pieces found to be too small to obtain a compositional result with satisfying precision within reasonable acquisition time by PGAA at BRR in Budapest.

Cichmiana, site 2

The site is located in the central part of the Polish Lowland (Fig. 3). The excavations carried out in 2000 and 2003 yielded over 10.000 Late Palaeolithic artefacts of Swiderian culture in the form of 20 concentrations in the area of 1,5 hectars (Fig. 5). That is the largest site of that culture ever discovered in the Lowland considering a number of concentrations found (Kabaciński et al. 2009).

The inventories were made predominantly of erratic Cretaceous Baltic flint and chocolate flint with single finds of Jurassic Cracow flint and hornstone. Of special value was discovery of a unique find of small obsidian workshop in the eastern part of concentration no. 4. It comprises 49 obsidian

[2] Apart from other obsidian artefacts the colour of tanged point from Czerniejów is greenish (Sulgostowska 2005).

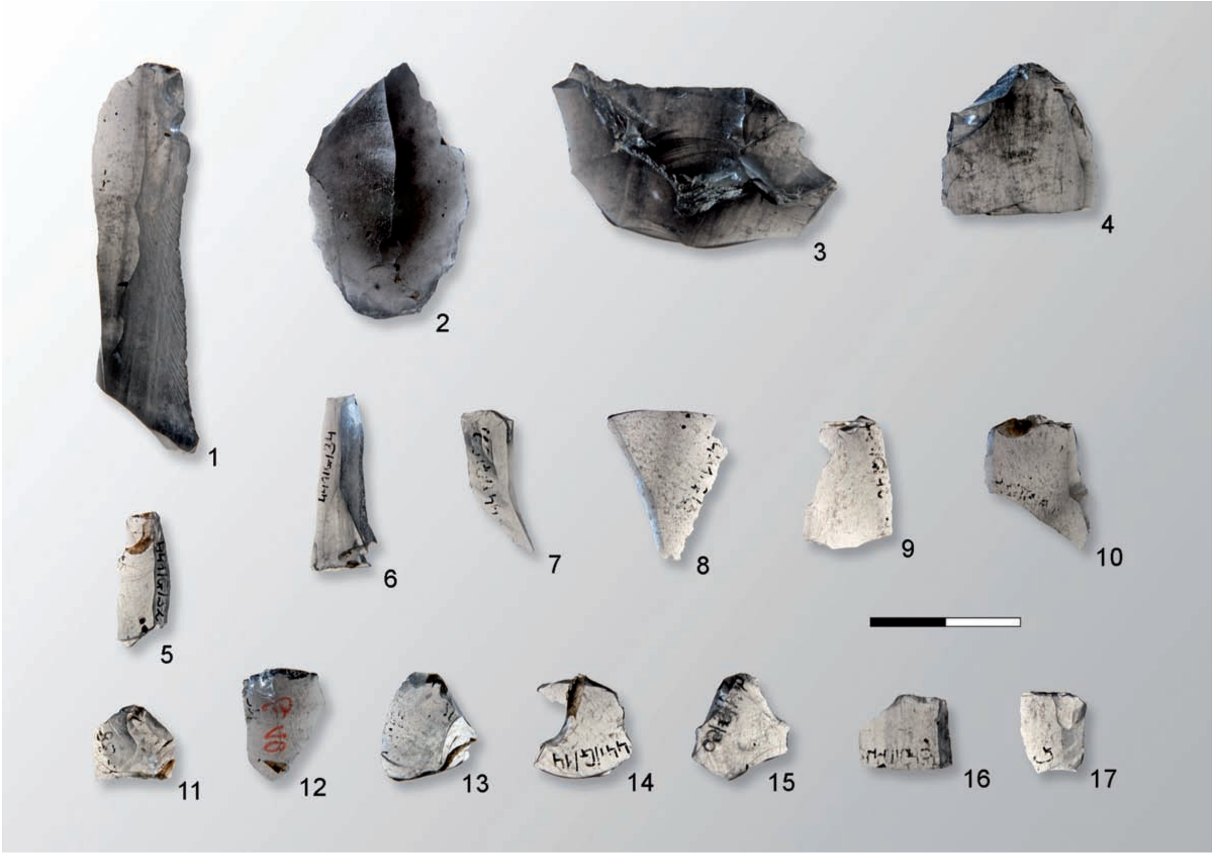


Fig. 4. Obsidian artefacts analysed: 1, 3-17 – Cichmiana, site 2; 2 – Mokrsko, site 8 (photo by P. Szejnoga)

artefacts including 6 tools (1 burin, 2 truncations, 2 retouched blades and 1 retouched chip) and few dozens of small chips (Fig. 4.1, 3-17).

Obsidian artefacts from Cichmiana are mostly small in size, and the analysis of raw material, technology and typology has not provided the final answer to whether the Late Palaeolithic community processed one or more obsidian core. Certainly the core must have already been prepared before it was brought to the site as indicated by the lack of cortical material. The technological analysis suggests a direct percussion technique of core exploitation. Micro-wear analysis of the assemblage showed that only seven of 49 artefacts were used for scraping or cutting wood or other unidentified soft material (truncations, retouched blade, blades, flakes) (Winiarska-Kabacińska, Kabaciński 2009). From this collection 16 pieces were analyzed by PGAA (Table 1).

Mokrsko, site 8

The second site from where obsidian artefact has been chosen for investigation is located at the dune in Mokrsko in the southern part of the Lowland (Fig. 3). In 1929 during field survey carried out by J. Dekleta and J. Rajewski (Jażdżewski 1929) a small dihedral burin measuring 34 × 20 × 11 mm was recovered (Fig. 4.2).

4. PROMPT GAMMA ACTIVATION ANALYSIS

4.1. The method

PGAA was chosen to determine the elemental composition of the obsidian samples in a non- destructive way. PGAA is a nuclear analytical method that utilizes a horizontal beam of cold neutrons guided from a research reactor (Révay, Belgya 2004). During PGA analysis, a simultaneous irradiation and detection of prompt and delayed gamma photons are performed. The upgraded PGAA facility of the Budapest Research Reactor was described by Szentmiklósi et al. in 2010. The quantitative analysis is based on the precise identification of characteristic prompt-gamma peaks in the spectra, as well as on the careful determination of the peak areas, according to Révay 2009. The most important feature of PGAA that makes it favourable in archaeometry is that it provides an average bulk composition of the irradiated volume, without sampling or any other destruction of the object. Furthermore, induced radioactivity decays fast after the irradiation. Thus, samples can be further analysed with other methods or returned to the collection.

In principle, PGAA is able to detect all chemical elements, but with very different sensitivities, basically depending on neutron capture cross-sections. In case of geological (silicate) samples, most major components (oxides of Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K and H) and a few significant trace elements (mostly B, Cl, Gd and in some cases also Sc, V, Cr, Co, Ni, Cd, Nd, Sm andEu) can be quantified.

The reliability of our PGAA method has been checked trough measurements of geological Standard Reference Materials (Gméling et al. 2005, 2007, 2014), from which rhyolite is the closest to obsidians in composition (Kasztovszky et al. 2008). Furthermore, the PGAA data on various types of obsidians have been compared with compositions obtained by INAA/ENAA, pXRF, ICP-OES, ICP-MS as well as SEM-WDS/EDS and reported by Odone et al in 1999, by Williams-Thorpe in 1995, by Le Bourdonnec et al. in 2005 and by Tykot in 1997. Unfortunately, Mg content of obsidians found to be below the PGAA's detection limit. Concentrations of major components are given in oxide form. Oxides are calculated according to oxidation numbers. In addition to the major components, PGAA is one of the few methods to determine hydrogen, as well as trace elements of boron and chlorine with high sensitivity. For most types of obsidians, concentrations of major components determined by PGAA agreed well with the results by other authors (see the Supplementary material). Unfortunately, trace elements, except Sm and Gd are not comparable, because B and Cl are usually not measured by other method than PGAA. On the other hand, a series of trace elements, such as Zr, Rb, Sr, Ba, etc. which can be very useful in obsidian provenance research, are easily measurable by other methods but below the detection limits of PGAA.

Although, geochemical behaviours of B and Cl in volcanic glass are still subjects of various studies (Barns et al. 2014; Schmitt, Simon 2004), systematic survey of them in provenance research is not known, probably due to the few numbers of applicable analytical methods. Based on our analytical results of 222 obsidian samples, we have found that B and Cl concentration data can be successfully used in obsidian characterisation. Nd, Sm and Gd are also well measurable by PGAA, but their applicability in obsidian provenance research are not proved. Other trace elements, such as Li, Y, Zn, Zr, Rb, Sr and Ba – known to be useful in obsidian provenance research (Kilikoglou et al. 1995; Oddone et al. 1999; Milcic 2014) – were found to be below the detection limits of PGAA.

For irradiation of the objects, a collimated beam of $7.6 \cdot 10^7$ $cm^{-2} \cdot s^{-1}$ intensity cold neutrons with 14×14 mm^2 and 20×20 mm^2 area cross-sections has been used. The applied neutron beam has covered the whole material of the black transparent obsidian samples, in case of most objects. In addition, the 0.5 to 5 mm thick objects were totally transparent for cold neutrons. Since obsidian is considered to be homogeneous in mm to cm scale, the obtained average composition is regarded to be characteristic of the whole sample. In most cases, acquisition times were chosen to be between 2000 and 9000 s, to collect a sufficient number of counts to determine the concentration of most major and some trace components. In some instances, prolonged acquisition times of 40000 to 450000 s have been applied, to see if we could improve the number of identified trace elements, or the uncertainty of results. Unfortunately, some pieces of the collection found to be too small to achieve statistically significant data in a reasonable time.

4.2. Results

From PGAA investigation it was possible to quantify the major components of SiO_2, TiO_2, Al_2O_3, Fe_2O_3(t), MnO, CaO, Na_2O, K_2O and H_2O, and traces of B, Cl, Nd, Sm and Gd (Table 1). Concentrations of the determined major components are given in mass%, while trace elements are expressed in μg/g.

In order to establish the characteristic types of the investigated archaeological pieces, their compositions have been compared to previous PGAA data of various archaeological and geological obsidians of Carpathian and Mediterranean origin. Comparative archaeological pieces have been investigated

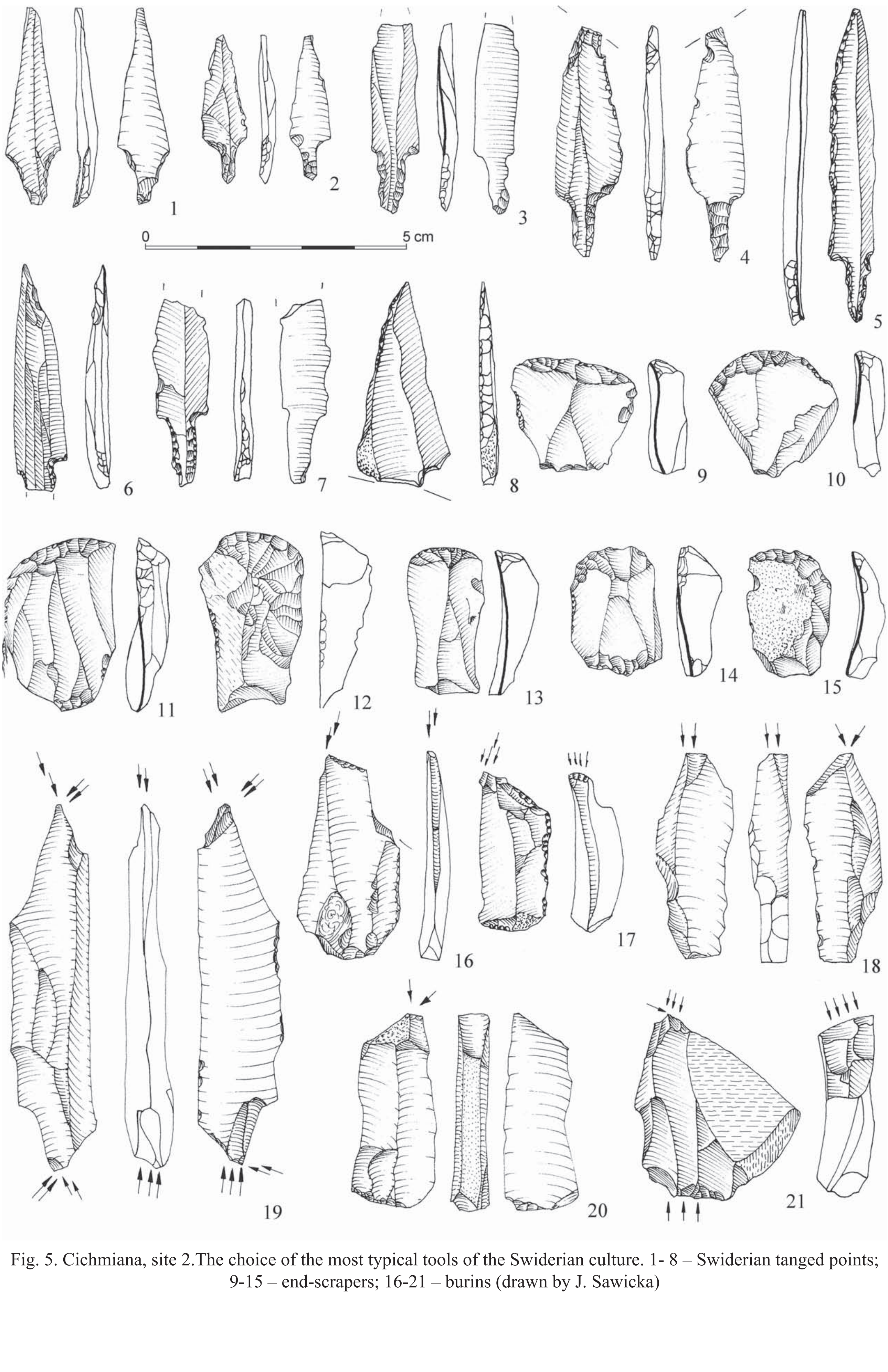
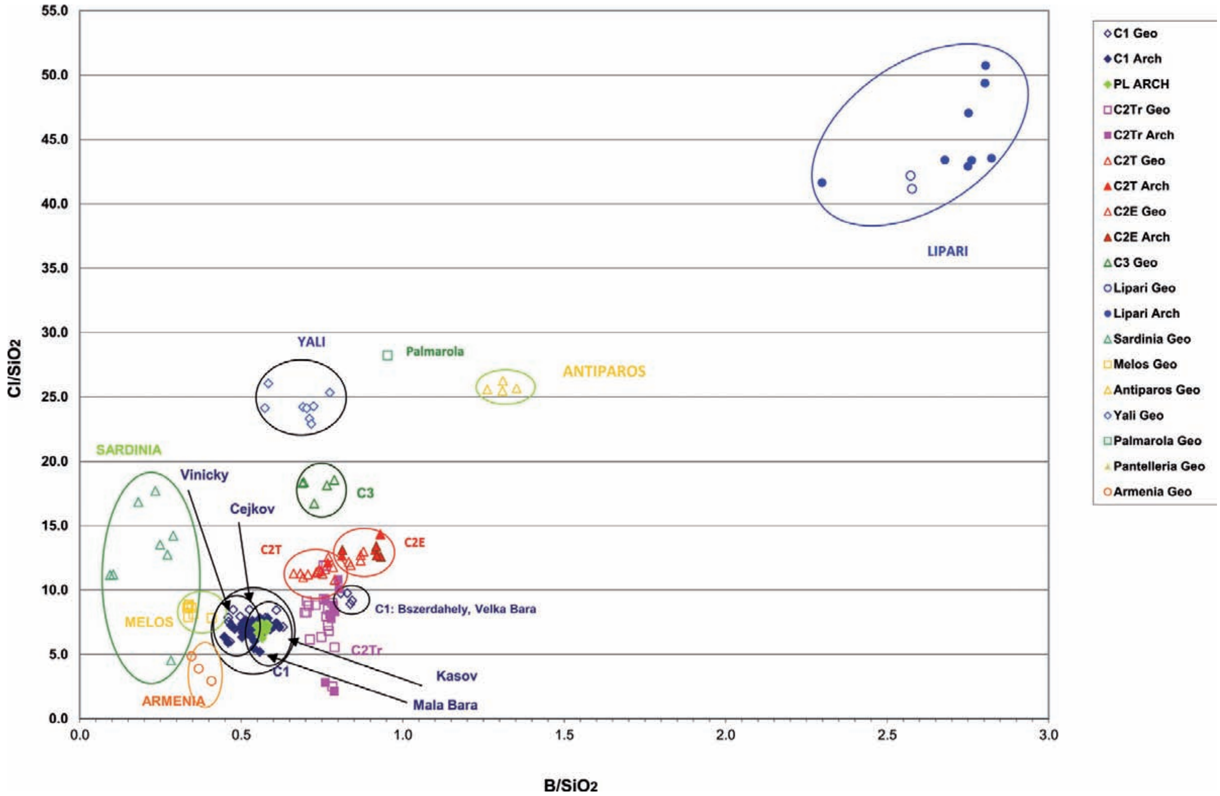


Fig. 5. Cichmiana, site 2.The choice of the most typical tools of the Swiderian culture. 1- 8 – Swiderian tanged points; 9-15 – end-scrapers; 16-21 – burins (drawn by J. Sawicka)



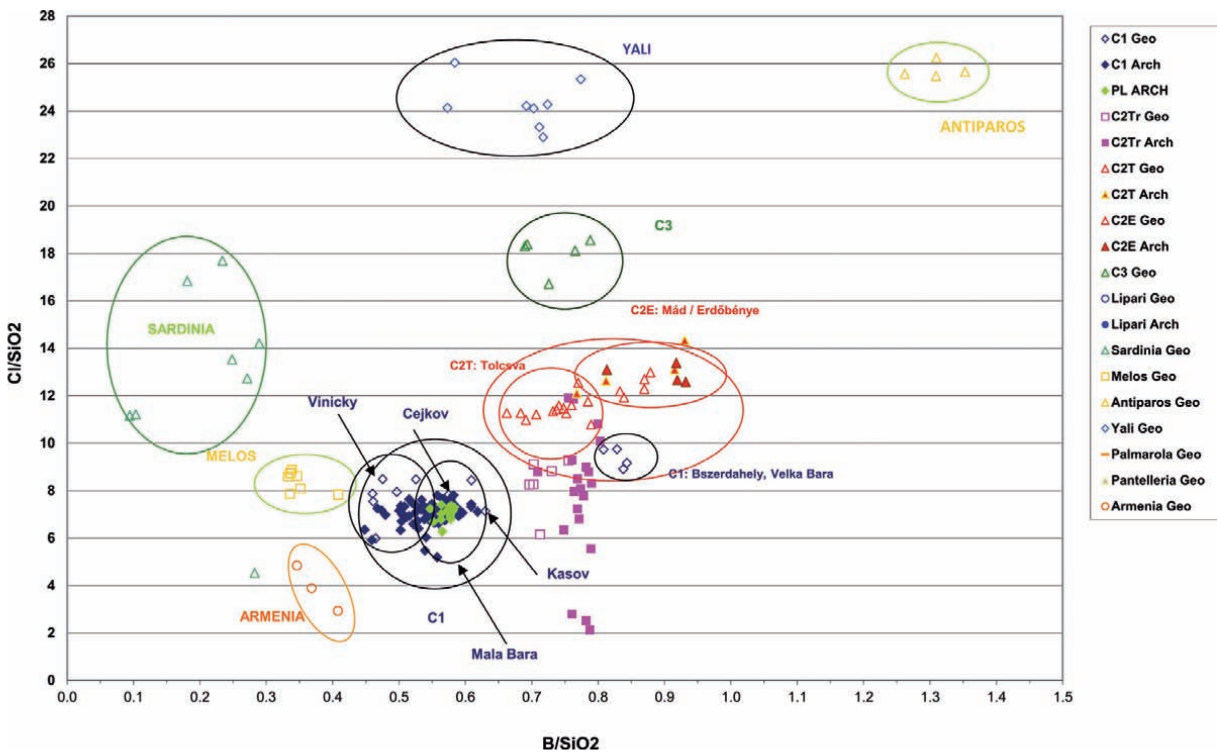


Fig. 6a and 6b. A possible classification of raw material for Polish archaeological objects, based on their B and Cl content. Fig 4b is an insert of Fig 4a within various cooperations between Hungary and Poland, Romania, Croatia, Ukraine and Serbia. Geological samples were received from the Lithoteca collection of the Hungarian National Museum. All reference samples were considered according to their types (C1, C2, etc.,) as it was established earlier by macroscopic studies and PGAA. For references, data of C1 type (90 pieces), C2 type (52 pieces, including subtypes of C2T, C2Tr and C2E), C3 type (5 pieces), Lipari type (11 pieces), Sardinia type (8 pieces, including A, B and C subtypes), Melos type (8 pieces, from Adamas and Demenegaki), 4 pieces from Antiparos, 8 pieces from Yali, 1 piece from Palmarola, 1 piece from Pantelleria and 3 pieces from Armenia, Sevan Lake have been used. Detailed results of archaeological obsidians from Hungary (Biró et al. 2005; Kasztovszky et al. 2008,) and from Croatia (Kasztovszky et al. 2009) have been published earlier; results on archaeological obsidians from Romania is going to be published soon. Both the average concentrations of major components (Table 2), and also significant components of TiO_2, MnO, alkaline and Fe_2O_3(t), as well as B and Cl have been studied. Most of all, TiO_2, B and Cl were found to differentiate between groups of various geographical origins. As far as we know, no systematic provenance study based on B and Cl contents of obsidians have been done yet, though Elekes et al. have tried to differentiate between obsidians, according to their Li and B contents (Elekes et al, 2000). According to Fig 4a-b, B and Cl contents separate samples of Sardinia, Antiparos, Yali, Melos, Lipari, as well as C1, C2 and C3 types from each other. Furthermore, based on TiO_2-content (Fig. 5), C2T (Tolcsva) and C2E (Erdőbénye) subgroups, subgroups of Melos (Adamas and Demenegaki) and also Sardinian A, B and C groups can be distinguished. Also, both on Fig. 4a-b and on Fig. 5, one very distinct subgroup of C1 appears, represented by the source of Mala Bara, Slovakia. In Figures 4a-b and 5 we suggested drawing the border of particular groups of data points.

Based on the data obtained by PGAA (Table 2, Fig. 6a-b and Fig. 7) it can be seen that the archaeological objects found in Poland are most similar to the Carpathian 1 (C1, i.e. Slovakian, northern part of the Tokaj Mts.) type and clearly separable from Carpathian 2 and from other Mediterranean types.

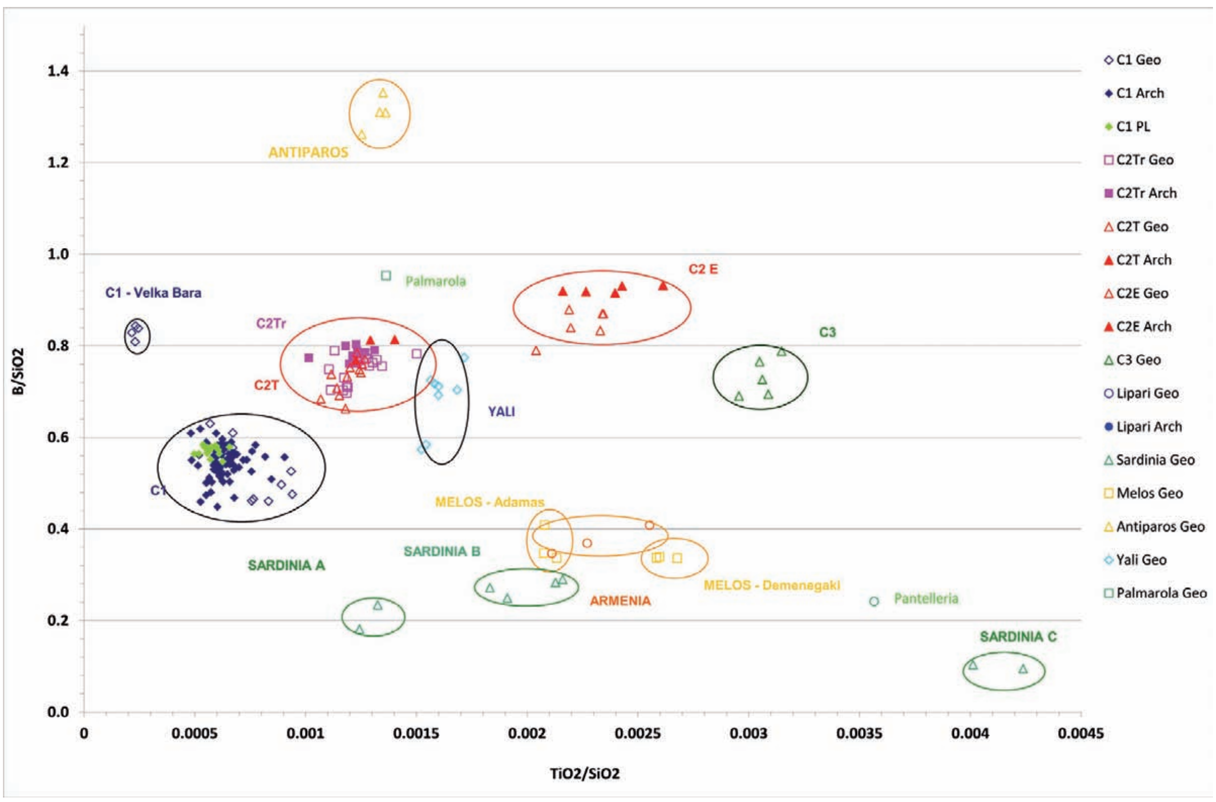


Fig. 7. A possible classification of raw material for Polish archaeological objects, based on their boron- and titanium-oxide content

Furthermore, with careful studying the compositions of C1 group, one can distinguish between the Vinicky, and the other origin C1 obsidians, however, separation of Kasov, Cejkov and Mala Bara origin ones from each other is not possible using the PGAA data.

5. DISCUSSION

There are two general ways of interpreting long-distance transport of exotic raw materials and items, that is to say exchange and contacts between human groups (Eriksen 2002; Whallon 2006). More advanced theories distinguish four kinds of mobility – residential, logistical, network and informational (Whallon 2006).

Exchange was the most common form of interaction for goods, ideas, patterns, knowledge and people circulation among prehistoric societies, i.e., the so called "*total social phenomena*" (Mauss 1925). It was not only a "pure" business transaction but also played an important role in ceremonial life (i.e. Sahlins 1972). In the classical approach to the subject three types of exchange are distinguished: reciprocity, redistribution and trade activity (Mauss 1925). It is obvious that exotic raw materials have different prestige values in areas located far from their outcrops and in places located close to the sources (Tykot 2011). Given ethnological analogies, the presence of exotic raw materials could be an expression of social rather than exclusively economic exchange between human groups (Whallon 2006; van Gijn 2010).

Long-distance exchange of obsidian could have had different backgrounds. For example, the evidence of obsidian use by Holocene societies from Melanesia seems to be the indicator of the existence of a formal exchange network during the colonisation process. In this case, obsidian helped maintain connections with homeland (Summerhayes 2009). On the other hand, in New Zealand, which in contrast to Melanesia was settled via a process of rapid coastal exploration, the massive use of obsidian played a significant role in connecting and cementing social networks (Walter et al. 2010). Unlike Melanesian and New Zealand sites, which yielded large quantities of obsidian, inventories uncovered in the Polish Lowland contain negligible amounts of obsidian implements, which probably may have been classified as "eccentric" raw material (Tykot 2011).

Analysis of maps showing the distribution of Late Glacial luxury artefacts made of exotic raw materials in Poland document a wide communication network, especially along the north-south axis. The raw materials were most likely distributed along large river valleys – such as the Vistula, Oder and Warta – important communication routes linking the Swiderian communities together.

For the Upper Palaeolithic Gravettian groups living relatively close to obsidian outcrops, the material could have had first of all technological significance, as evidenced by a considerable quantity of obsidian artefacts in the inventories (i.e. Targowisko, site 10 in southern Poland). The situation changed in the Swiderian, with obsidian holding technological significance only for the most southern groups from the Carpathian Mountains, notably in Slovakia. To the north, on the Polish Plain, finds are rare and have no technological (economical?) importance.

A small share of artefacts made of exotic raw materials in the Late Glacial inventories from the Polish Lowland shows that while the presence of obsidians and radiolarites had no economic significance, it nonetheless must have had symbolic meaning. The dispersion of artefacts made of the raw materials in question is an effect of direct/successive long-reaching/distance exchange or prestige chain exchange (Sahlins 1972; Renfrew, Bahn 2001; Tykot 2011; Moutsiou 2014). Analysis of obsidian exchange among Aboriginal societies in Australia showed that apart from functional role, obsidians may have been imbued with symbolic meaning due to limited number of outcrops, glassy appearance, translucency and different colours – "If something is transported over long distances, then it must have been valued at some point" (Torrence 2005).

On the other hand, the presence of exotic raw materials could represent different expressions of mobility of the Late Glacial societies. In Late Palaeolithic Europe, most numerous items made on "exotic" raw materials obtained from the distance of over 600km from the archaeological site were registered among Magdalenian implements (Weniger 1987; Eriksen 2002). The analysis of implements made on exotic (>50 km) materials in southwestern

Germany may represent long-distance migrations or barter transactions during seasonal movements or even direct procurement, while fossil molluscs (as well as jet and ammonites) indicate rather luxury items, for own use (Eriksen 2002). However, in many cases these exotic raw materials could be obtained from other groups and be the manifestation of social contacts and caused by ritual or ceremonial reasons apart from seasonal migrations (Whallon 2006).

Recently, the foreshaft made from cetacean bone (probably whale) was identified at a Magadalenian site in Andernach-Martinsberg. The re-examination of this bone implement shows that this marine material was obtained from a source located over 1000 km away from the site. The authors suggest that the presence of the whale item is the result of an individual travel rather than seasonal migrations (Langely, Street 2013). Such special, exotic or even "eccentric" (Tykot 2011) finds could have played an important role in long-distance social motivated mobility, i.e. information exchange, alliance-mating, ritual and ceremony reasons (Whallon 2006; Speth et al. 2013).

Given long-distance movement of obsidian artefacts from Slovakia to the Polish Plain (ca. 600 km), the exchange could have taken place, most probably, by indirect means. In this case materials lose their utilitarian functions and start to play symbolic role (Moutsiou 2014). It was connected with the distribution of news, ideas and social knowledge. Extralocal (exotic) materials/artefacts play a very important role in maintaining relationships between individuals and groups (Mauss 1925; Whallon 2006). Similar to unusual pendants (original form and/or valuable raw material) encountered, i.e. in Magdalenian inventories from the Swabian Jura (Eriksen 2002), single obsidian artefacts (Mokrsko) or several items most probably made of one core (Cichmiana) could be an indicator of social status or prestige.

It should be emphasised that obsidian and chocolate flint coexist at many sites, i.e. Cichmiana (Poland), Vel'ky Slavkov (Slovakia). At Rydno (the hematite quarry and chocolate flint processing centre), obsidian was found both in concentrations belonging to the Arch Backed Technocomplex (Schild, Królik 1981) and Swiderian ones (Schild 1975; Schild et al. 2011), which suggests that chocolate flint could have been an equivalent for obsidian (Sulgostowska 2005). We should also highlight that at many sites which produced chocolate flint or obsidian, radiolarite occurred as well, i.e. Janów (Kabaciński et al. 2011), Rydno (Schild, Królik 1981; Schild et al. 2011), Vel'ky Slavkov (Bárta 1980). A special case in this respect is a red-ochre mine at Rydno. The presence of jasper from the Vag river, obsidian from Slovakia and Hungary, Jurassic and Świeciechów flint confirms the existence of a regular exchange network, where chocolate flint and hematite colorant was obtained, pointing to strong social ties (Schild 1975). The wide distribution of chocolate flint indicates a well-developed network of group interaction, marking the potential range of intermarriage arrangements and exchange of goods (Schild 2001). This system was surely cemented by symbolic communion and beliefs shared by members of the group (Płonka 2012).

Worth noting is the fact that, except for the assemblages from Cichmiana, Rydno and Tylicz, other Late Palaeolithic obsidian artefacts belong to a "special" form, mostly tools, like tanged points (Tyniec-Bagno, Czerniejów, Wołodź, Glanów), backed blades (Nowa Biała, Rydno), end-scrapers (Skwirtne) or burins (Mokrsko, Mieroszów). It also supports the hypothesis of a special meaning of such kinds of objects.

SUMMARY

Late Glacial hunter-gatherers inhabiting the Central European Lowland were highly dependent on local resources of flint raw material. In the case of Poland it was local erratic Baltic Cretaceous flint brought by the last ice-sheet from Scandinavia. More to the south, different kinds of quarried flint, such as chocolate or Jurassic Cracow, were used; all of that locally extracted material was distributed over hundreds of kilometres. However, in very rare cases two very specific raw materials, i.e. radiolarite and obsidian were also in use. For the moment obsidian seems to be the best marker of long-distance exchange and mobility pattern, because its nearest sources are south of the Carpathians, in south-eastern Slovakia and north-eastern Hungary. On the basis of a modern analytical method (PGAA) three

main groups of Carpathian obsidian can be distinguished (C1 in SE Slovakia, C2 in NE Hungary and C3 in Transcarpathian Ukraine, all of them with further sub-groups).

From southern Poland and from Slovakia obsidian is recorded in different quantities at a number of sites and in most cases was considered as any other raw material. That is certainly not the case for the Polish Lowland where obsidian finds are extremely rare during all of the Late Glacial and up to now it is known from two sites only. Among them the most exceptional is a small workshop discovered at Cichmiana (Kabaciński et al. 2009) in the central Polish Plain, which was related to a Swiderian settlement. Another, single find of the Late Glacial age comes from Mokrsko.

Prompt gamma activation analysis was successfully applied for precise identification of the provenance of obsidian artefacts. The great advantage of the method is its non-destructive character which is especially important in the case of very rare archaeological artefacts. The PGAA results of 17 Late Palaeolithic finds from Polish Lowland sites links the artefacts with a Carpathian C1 group located in the northern parts of the Tokaj Mts. in Slovakia (Fig. 3).

Certainly, obsidian played an important role among Late Glacial societies living north of the Carpathians. However, its meaning was not the same for Swiderian groups located in southern Poland, relatively close to the outcrops and inhabiting the Lowland. The first groups used obsidian as any other knappable rock. For Lowland societies obsidian was something exceptional and unique and did not have a technological or economical meaning. Just the opposite, it expressed on one hand maintained relations between more southern and northern bands – being eventually at the same time part of much wider network of ideas, social knowledge and prestige exchange.

Acknowledgements

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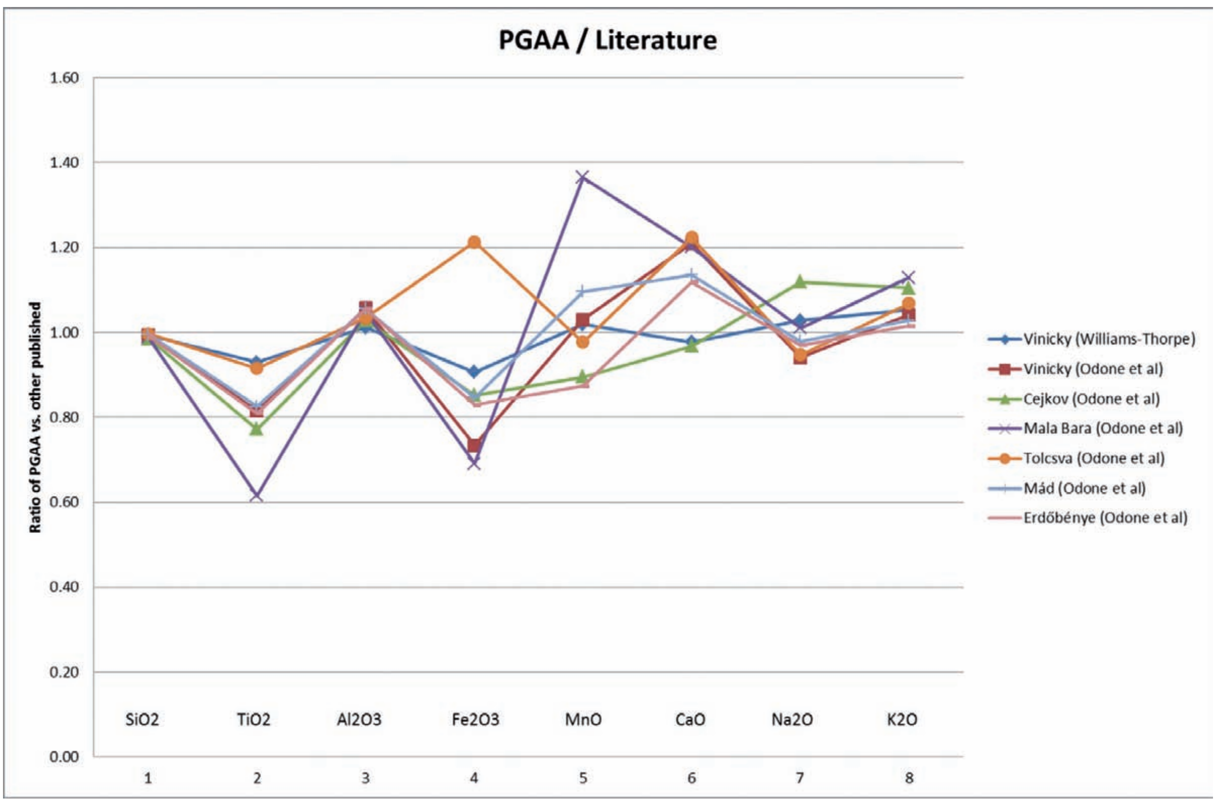

Fig. 8. Comparison of compositional data obtained by PGAA at the Budapest Research Reactor with those published by other researchers. PGAA data are devided by literature data

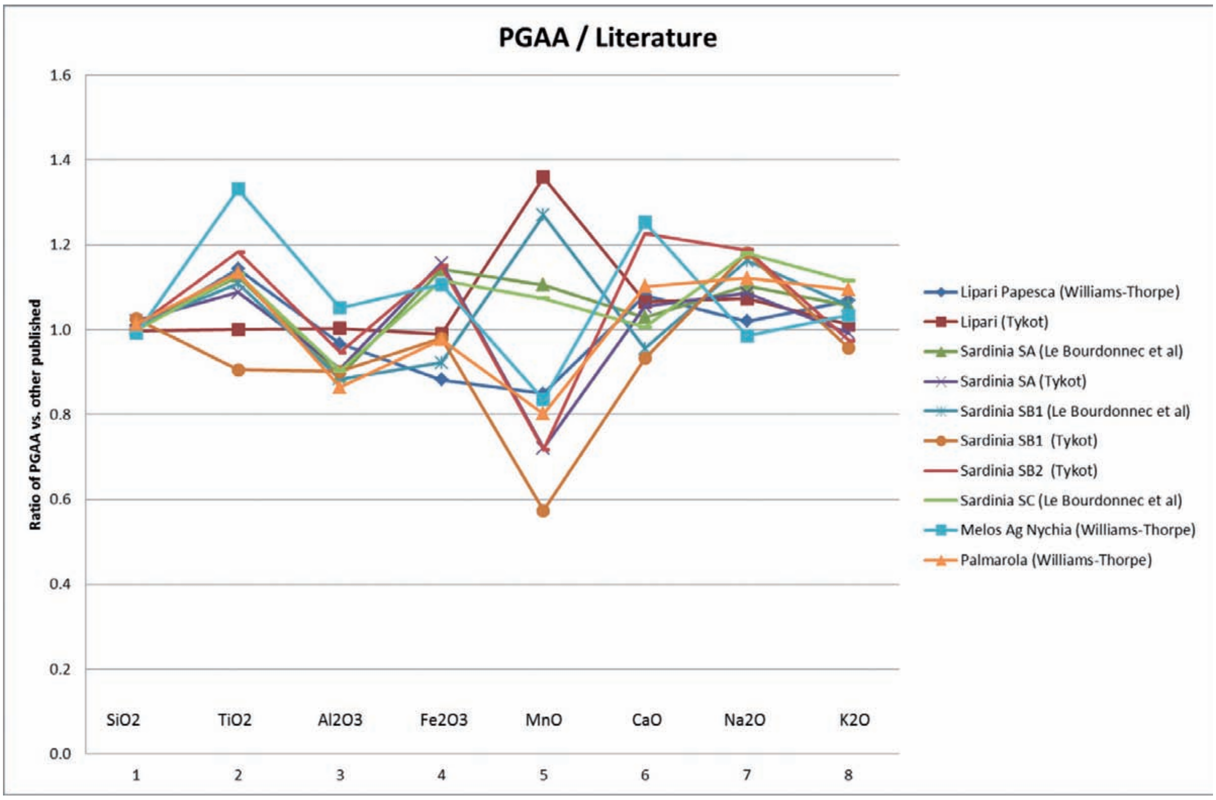

Fig. 9. Comparison of compositional data obtained by PGAA at the Budapest Research Reactor with those published by other researchers. PGAA data are devided by literature data

We would like to thank Professor Marzena Szmyt – Director of the Poznań Archaeological Museum for permission to investigate the obsidian artefact from Mokrsko (collection no. MAP/MW 1929:531).

Supplementary material

In order to further check the reliability of the PGAA method in provenance research of obsidians, we have compared the concentration data measured at our laboratory with those published by other authors.

For comparison, we have used data for major components published by Oddone et al (Oddone et al. 1999), Williams-Thorpe (Williams-Thorpe 1995), Le Bourdonnec et al (Le Bourdonnec et al. 2005) and by Tykot (Tykot 1997).

The authors above have used instrumental- and epithermal neutron activation analysis (INAA/ENAA); XRF and ICP-OES; ICP-MS as well as electron microprobe (SEM-WDS/EDS), respectively, to determine the compositions of the obsidians.

As one can see from Table 3, and Figures 8 and 9, in most cases, PGAA results agree quite well with the results by other authors. However, when comparing Ti, Fe and Mn results of PGAA with those reported by Milic (2014), significant differences have been found. Milic has measured significantly lower concentrations with portable XRF for these elements. As Milic mentions in his paper, "inter-laboratory tests have shown the ability of pXRF instruments to effectively discriminate different sources, although the elemental concentrations reported were not always comparable to the results produced using other instruments without further calibration" – obviously, because of the sensitivity of portable XRF to size- and shape-effects.

Unfortunately, trace elements, except Sm and Gd are not comparable, because B and Cl are usually not measured by other method than PGAA. On the other hand, a series of trace elements, such as Li, Y, Zn, Zr, Rb, Sr and Ba, which can be very useful in obsidian provenance research (Kilikoglou et al. 1995; Oddone et al. 1999, Milcic 2014), are easily measurable by other methods but below the detection limits of PGAA.

Table 1. Concentrations of major and some trace components for the investigated artefacts as determined by PGAA. The values of major oxides are in mass%, while he trace elements in μg/g. The last digit of the given values represents the precision of the method.

Site	Inventory no.	SiO2	TiO2	Al2O3	Fe2O3	MnO	CaO	Na2O	K2O	H2O	Cl	B	Sm	Gd	Nd
Mokrsko	MAP/MW 1929:531	77	0,048	12,5	1,03	0,057	0,82	3,59	4,76	0,13	0,0557	4,22E-03	3,71E-04	4,01E-04	2,59E-03
Cichmiana	G52	76,4	0,042	12,9	0,82	0,057	0,77	3,95	4,79	0,16	0,0479	4,32E-03	2,98E-04	3,75E-04	2,74E-03
Cichmiana	G31	76,7	0,04	12,8	1,03	0,06	0,78	3,66	4,78	0,14	0,0538	4,32E-03	2,87E-04	3,79E-04	3,23E-03
Cichmiana	G61	76,5	0,043	12,8	0,97	0,059	0,86	3,71	4,82	0,18	0,056	4,41E-03	2,97E-04	3,83E-04	2,50E-03
Cichmiana	G10	76,5	0,044	12,9	0,88	0,059	0,77	3,81	4,79	0,14	0,0511	4,22E-03	2,96E-04	3,73E-04	2,44E-03
Cichmiana	G19	76,7	0,044	12,8	0,88	0,055	0,74	3,66	4,84	0,18	0,0531	4,43E-03	2,98E-04	3,82E-04	2,23E-03
Cichmiana	G34	76	0,045	13,1	0,99	0,056	0,73	3,83	4,9	0,17	0,0545	4,42E-03	3,11E-04	4,02E-04	2,67E-03
Cichmiana	G3	76,4	0,05	12,9	0,93	0,057	0,84	3,74	4,86	0,17	0,0561	4,42E-03	3,04E-04	3,95E-04	2,94E-03
Cichmiana	G14	76,6	0,044	12,9	0,93	0,056	0,76	3,65	4,84	0,17	0,0542	4,43E-03	3,02E-04	3,84E-04	3,01E-03
Cichmiana	G30	76,6	0,046	12,7	0,96	0,054	0,81	3,76	4,81	0,15	0,0549	4,39E-03	2,98E-04	3,81E-04	2,74E-03
Cichmiana	G42	76,6	0,042	12,9	0,89	0,057	0,77	3,65	4,79	0,17	0,0521	4,43E-03	2,96E-04	3,73E-04	3,20E-03
Cichmiana	G9	76,6	0,047	12,8	1	0,059	0,76	3,71	4,78	0,19	0,0566	4,32E-03	3,02E-04	3,96E-04	3,49E-03
Cichmiana	G57	76,2	0,042	12,9	0,98	0,054	0,81	3,93	4,9	0,17	0,0535	4,40E-03	2,94E-04	3,76E-04	3,41E-03
Cichmiana	G38	76,5	0,044	12,8	0,94	0,058	0,88	3,64	4,94	0,17	0,0547	4,39E-03	2,89E-04	3,73E-04	3,40E-03
Cichmiana	G60	76,9	0,038	12,7	0,91	0,057	0,74	3,66	4,75	0,17	0,0521	4,33E-03	2,97E-04	4,05E-04	3,05E-03
Cichmiana	G32	76,2	0,041	13	0,96	0,059	0,82	3,73	4,86	0,19	0,0556	4,45E-03	3,06E-04	4,08E-04	2,37E-03
Cichmiana	G12	76,4	0,046	13	0,97	0,061	0,78	3,64	4,85	0,18	0,0549	4,43E-03	3,00E-04	3,88E-04	3,72E-03

Table 2. Comparison of average bulk compositions for archaeological objects from Poland and for “C1”, “C2”, “C3”, their sub-types, as well as Lipari, Melos, Antiparos, Yali, Armenia, Palmarola and Pantelleria origin geological references. The values are given in mass%, except for Cl, B, Sm and Gd, which are in µg/g

Type/Location	Pieces	SiO2	TiO2	Al2O3	Fe2O3	MnO	CaO	Na2O	K2O	H2O	Cl	B	Sm	Gd	B/SiO2	Cl/SiO2	TiO2/SiO2
Archaeological Poland	Average (25)	76.4	0.043	12,9	0.94	0.058	0.79	3.73	4.83	0.19	541	44.0	3.0	3.9	0.58	7.08	0.00056
C1/Vinicky	Average (6)	76.2	0.065	13.1	1.00	0.051	0.92	3.59	4.61	0.32	588	36.7	3.1	3.9	0.48	7.71	0.00085
C1/Cejkov	(1)	76.2	0.046	13.1	1.02	0.054	0.79	3.57	4.88	0.17	597	43.9	3.2	4.1	0.58	7.83	0.00061
C1/Mala Bara	Average (2)	75.8	0.051	13.1	0.75	0.068	0.93	3.84	5.06	0.27	608	45.0	3.5	4.9	0.59	8.02	0.00067
C1/Velka Bara	Average (4)	73.9	0.017	14.0	0.84	0.051	1.26	3.76	4.61	1.40	694	61.3	3.0	3.5	0.83	9.39	0.00023
C1/Kasov	(1)	75.9	0.043	13.0	1.10	0.053	1.21	3.95	4.59	0.14	541	47.7	3.0	3.6	0.63	7.13	0.00057
C2/Tr Tolcsva, Mahagonian	Average (26)	75.0	0.092	13.2	1.47	0.049	0.98	3.92	4.98	0.17	585	56.9	4.0	4.9	0.76	7.80	0.00123
C2T/Tolscva	Average (12)	74.5	0.104	13.6	1.49	0.049	0.99	3.87	4.98	0.24	898	57.5	4.0	4.8	0.77	12.06	0.00140
C2E/Mád-Erdöbénye	Average (14)	73.8	0.140	13.9	1.69	0.044	1.07	3.91	5.03	0.34	893	61.0	4.2	5.0	0.83	12.11	0.00190
C3/Rokosovo	Average (5)	71.9	0.220	14.4	2.86	0.076	2.22	3.93	3.98	0.26	1295	52.7	3.0	3.3	0.73	18.01	0.00306
Lipari	Average (11)	74.3	0.080	12.8	1.61	0.068	0.77	4.33	5.19	0.45	3312	201.9	5.3	5.9	2.72	44.58	0.00108
Sardinia A	Average (2)	76.3	0.098	12.2	1.45	0.058	0.62	3.75	5.21	0.26	1316	15.8	4.6	5.3	0.21	17.25	0.00128
Sardinia B	Average (4)	75.8	0.154	12.3	1.32	0.057	0.70	3.99	5.32	0.25	749	20.8	3.2	3.4	0.27	9.88	0.00203
Sardinia C	Average (2)	73.8	0.304	12.8	1.92	0.031	0.88	3.88	6.08	0.17	826	7.3	7.3	7.2	0.10	11.19	0.00413
Melos Adamas	Average (4)	76.5	0.161	12.9	1.07	0.068	1.25	3.98	3.54	0.47	644	26.3	1.8	1.9	0.34	8.41	0.00211
Melos Demenegaki	Average (4)	75.4	0.200	13.8	1.45	0.067	1.58	3.94	3.35	0.18	642	25.3	1.7	1.9	0.34	8.52	0.00265
Antiparos	Average (4)	75.6	0.100	12.6	0.83	0.088	0.39	4.45	4.81	0.90	1946	98.9	0.8	0.8	1.31	25.73	0.00132
Yali	Average (8)	76.8	0.123	12.2	1.00	0.040	0.68	3.93	4.55	0.44	1866	52.6	2.0	1.9	0.68	24.29	0.00160
Armenia	Average (3)	74.4	0.172	13.4	1.14	0.081	0.95	4.76	4.47	0.52	289	27.9	2.0	2.4	0.37	3.88	0.00231
Palmarola	(1)	74.9	0.102	11.6	1.79	0.088	0.52	5.23	5.09	0.42	2113	71.4	7.8	7.9	0.95	28.21	0.00136
Pantelleria	(1)	71.8	0.256	4.4	9.19	0.308	0.48	8.43	4.35	0.17	5290	17.3	26.0	30.0	0.24	73.65	0.00357

Table 3. Comparison of compositional data obtained by PGAA at the Budapest Research Reactor with those published by other researchers

Type	Pieces	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	Na_2O	K_2O	H_2O	Cl (ppm)	B (ppm)	Sm (ppm)	Gd (ppm)
C1/Vinicky (PGGA)	Average (6)	76.2	0.065	13.1	1.00	0.051	0.92	3.59	4.61	0.32	588	36.7	3.12	3.86
Vinicky (Williams-Thorpe)		76.81	0.07	12.99	1.1	0.05	0.94	3.49	4.37	0.67				
Vinicky (Odone *et al.)*		76.6	0.0798	12.43	1.36	0.0494	0.760	3.81	4.42				5.12	7.81
C1/cejkov (PGGA)		76.2	0.046	13.1	1.02	0.054	0.79	3.57	4.88	0.17	597	43.9	3.16	4.11
Cejkov (Odone *et al.)*		77.4	0.0600	12.73	1.20	0.0599	0.813	3.19	4.42				4.94	7.60
C1/Mala Bara		75.8	0.051	13.1	0.75	0.068	0.93	3.84	5.06	0.27	608	45.0	3.53	4.88
Mala Bara (Odone *et al.)*		76.7	0.0828	12.49	1.09	0.0498	0.774	3.80	4.48				7.20	8.90
C1/without Velka Bara (PGGA)	Average (90)	76.3	0.049	12.9	1.00	0.056	0.83	3.68	4.74	0.24	542	41.5	3.21	3.89
C1 (Milic)	Min		0.0283		0.6811	0.0364								
C1 (Milic)	Max		0.0387		0.7909	0.0439								
C2/Tr Tolcsva, Mahagonian (PGGA)	Average (26)	75.0	0.092	13.2	1.47	0.049	0.98	3.92	4.98	0.17	585	56.9	4.02	4.88
C2T/Tolscva (PGGA)	Average (12)	74.5	0.104	13.6	1.49	0.049	0.99	3.87	4.98	0.24	898	57.5	3.98	4.83
Tolscva (Odone *et al.)*		75.2	0.1005	12.75	1.57	0.0505	0.804	4.14	4.66				5.90	9.15
C2E/Mád-Erdöbénye (PGGA)	Average (14)	73.8	0.140	13.9	1.69	0.044	1.07	3.91	5.03	0.34	893	61.0	4.20	5.04
Mád (Odone *et al.)*		74.1	0.1700	13.13	2.00	0.0400	0.945	3.99	4.89				6.10	8.50
Erdöbénye (Odone *et al.)*		74.4	0.1733	13.13	2.04	0.0502	0.959	4.03	4.95				6.20	8.10
C2 (Milic)			0.0326		0.705	0.0258								
C2 (Milic)			0.2356		1.255	0.0421								
Lipari (PGGA)	Average (11)	74.3	0.080	12.8	1.61	0.068	0.77	4.33	5.19	0.45	3312	201.9	5.32	5.87
Lipari Papesca (Williams-Thorpe)		74.1	0.07	13.23	1.83	0.08	0.71	4.24	4.86	0.76				
Lipari (Tykot)		74.5	0.08	12.8	1.63	0.050	0.72	4.03	5.13					
Sardinia A (PGGA)	Average (2)	76.3	0.098	12.2	1.45	0.058	0.62	3.75	5.21	0.26	1316	15.8	4.55	5.30
Sardinia SA (Le Bourdonnec *et al.)*		75.8	0.0870	13.7	1.27	0.052	0.604	3.40	4.93					
Sardinia SA (Tykot)		74.7	0.09	13.4	1.25	0.080	0.59	3.45	5.25					
Sardinia B (PGGA)	Average (4)	75.8	0.154	12.3	1.32	0.057	0.70	3.99	5.32	0.25	749	20.8	3.18	3.38
Sardinia SB1 (Le Bourdonnec *et al.*)		75.1	0.1387	13.9	1.43	0.045	0.731	3.43	5.03					

Type	Pieces	SiO2	TiO2	Al2O3	Fe2O3	MnO	CaO	Na2O	K2O	H2O	Cl (ppm)	B (ppm)	Sm (ppm)	Gd (ppm)
Sardinia SB1 (Tykot)		73.8	0.17	13.6	1.35	0.100	0.75	3.38	5.56					
Sardinia SB2 (Le Bourdonnec *et al.*)		76.0	0.1272	13.3	1.24	0.031	0.613	3.23	5.27					
Sardinia SB2 (Tykot)		75.1	0.13	13.0	1.15	0.080	0.57	3.36	5.46					
Sardinia C (PGGA)	Average (2)	73.8	0.304	12.8	1.92	0.031	0.88	3.88	6.08	0.17	826	7.3	7.32	7.15
Sardinia SC (Le Bourdonnec *et al.*)		73.8	0.2692	14.2	1.72	0.029	0.871	3.29	5.46					
Sardinia SC (Tykot)		72.7	0.27	13.9	1.52	0.140	0.87	3.31	5.90					
Sardinia Monte Arci (Williams-Thorpe)		74.3	0.09	13.83	1.55	0.07	0.58	3.7	4.97	0.67				
Melos Adamas (PGGA)	Average (4)	76.5	0.161	12.9	1.07	0.068	1.25	3.98	3.54	0.47	644	26.3	1.79	1.94
Melos Demenegaki (PGGA)	Average (4)	75.4	0.200	13.8	1.45	0.067	1.58	3.94	3.35	0.18	642	25.3	1.73	1.86
Melos Demenegaki (Milic)	Min		0.1113		0.682	0.0354								
Melos Demenegaki (Milic)	Max		0.1294		0.728	0.0432								
Melos Ag Nychia (Williams-Thorpe)		75.94	0.15	13.11	1.31	0.08	1.26	4	3.24	0.61				
Antiparos (PGGA)	Average (4)	75.6	0.100	12.6	0.83	0.088	0.39	4.45	4.81	0.90	1946	98.9	0.81	0.77
Antiparos (Milic)			0.0439		0.421	0.0509								
Yali (PGGA)	Average (8)	76.8	0.123	12.2	1.00	0.040	0.68	3.93	4.55	0.44	1866	52.6	1.96	1.95
Yali (Milic)	Min		0.0510		0.422	0.0212								
Yali (Milic)	Max		0.0776		0.511	0.0257								
Palmarola (PGGA)	(1)	74.9	0.102	11.6	1.79	0.088	0.52	5.23	5.09	0.42	2113	71.4	7.81	7.88
Palmarola (Williams-Thorpe)		73.87	0.09	13.5	1.83	0.11	0.47	4.66	4.65	0.71				
Pantelleria (PGGA)	(1)	71.8	0.256	4.4	9.19	0.308	0.48	8.43	4.35	0.17	5290	17.3	25.98	29.99
Pantelleria (Williams-Thorpe)		71.65	0.23	7.6	9.38	0.28	0.3	6.86	4.29					

REFERENCES

Barnes J.D., Prather T.J., Cisneros M., Befus K., Gardner J.E., Larson T.E. 2014. Stable chlorine isotope behavior during volcanic degassing of H_2O and CO_2 at Mono Craters, CA, *Bulletin Volcanology* 76, 805-818.

Bárta J. 1965. *Slovensko v staršej a strednej dobe kamennej*. Bratislava.

Bárta J. 1980. Wielki Sławków – pierwsza osada kultury świderskiej na Słowacji. *Acta Archaeologica Carpathica* XX, 5-17.

Binford L.R. 1979. Organization and formation processes: looking at technologies. *Journal of Anthropological Research* 35, 255-273.

Biró K.T. 1984. Distribution of obsidian from the Carpathian Sources on Central European Palaeolithic and Mesolithic sites. *Acta Archaeologica Carpathica* XXIII, 5-42.

Biró K.T. 2009. Lithic Raw Materials in Hungary: a diachronic presentation on recent advances in Hungarian Petroarchaeology. (In:) J. Gancarski (ed.), *Surowce naturalne w Karpatach ich wykorzystanie w pradziejach i wczesnym średniowieczu. Materiały z konferencji, Krosno 25-26 listopada 2008 r*. Krosno, 23-39.

Biró K.T. 2014. Carpathian Obsidians: State of Art. (In:) Yamada – Ono(eds.), *Lithic raw material exploitation and circulation in Préhistory*. ERAUL 138, 47-69.

Biró K.T., Markó A., Kasztovszky Zs. 2005. ‘Red' obsidian in the Hungarian Palaeolithic. Characterisation studies by PGAA. *Praehistoria* 6, 91-101.

Björck S., Walker M.J.C., Cwynar L.C., Johnsen S., Knudsen K-L., Lowe J.J., Wohlfarth B., & INTIMATE Members. 1998. An event stratigraphy for the Last Termianation I\in the North Atlantic region based on the Greenland ice-core record; a proposal by the INTIMATE group. *Journal of Archaeological Science* 13 (4), 283-292.

Bokelmann K. 1979. Rentierjäger am Gletscherrand in Schleswig-Holstein? *Offa* 36, 12-22.

Le Bourdonnec F.-X., Delerue S., Dubernet S., Moretto Ph., Calligaro Th., Dran J.-C., Poupeau G. 2005. PIXE characterization of Western Mediterranean and Anatolian obsidians and Neolithic provenance studies. *Nuclear Instruments and Methods in Physics Research B* 240, 595-599.

Burdukiewicz J. 1994. Nowe stanowiska dolnopaleolityczne z okolic Strzegomia, woj. wałbrzyskie. *Śląskie Sprawozdania Archeologiczne* 35, 39-54.

Campbell J.B. 1977. *The Upper Palaeolithic of Britain. A Study of Man and Nature in the Late Ice Age*. Oxford.

Chmielewski W. 1975. Paleolit środkowy i górny. (In:) W. Chmielewski, W. Hensel (eds.), *Prahistoria ziem polskich. Paleolit i mezolit*, Wrocław-Warszawa-Kraków-Gdańsk, 9-158.

Clark P.U., Dyke A.S., Shakun J.D., Carlson A.E., Clark J., Wohlfarth B., Mitrovica J.X., Hostetler S.W., Marshall McCabe. 2009. The Last Glacial Maximum. *Science* 325, 710-714.

Coope G.R., Lemdhal G., Lowe J.J., Walking A. 1998. Temperature gradients in northern Europe during the last glacial-Holocene transition (14-9 14C Kyr BP) interpreted from coleopteran assemblages. *Journal of Quaternary Science* 13 (5), 419-433.

Elekes Z., Uzonyi I., Gratuze B., Rózsa P., Kiss A.Z., Szőő Gy. 2000. *Contribution of PIGE technique to the study of obsidian glasses*. *Nuclear Instruments and Methods in Physics Research B* 161-163, 836-841.

Eriksen B.V. 2002. Fossil Mollusks and Exotic Raw Materials in Late Glacial and Early Postglacial Find Contexts: A Complement to Lithic Studies. (In:) L.E. Fisher, Eriksen B.V. (eds.), *Lithic Raw Material Economy in Late Glacial and Postgalcial Western Europe*. *British Archaeological Reports 1093*. Oxford, 27-52.

Foltyn E., Foltyn E.M., Jochemczyk L., Waga J.M. 2008. Radiolaryty gliwickie. Pochodzenie, występowanie, wykorzystywanie, dystrybucja. (In:) J. Gancarski (ed.), *Surowce naturalne w Karpatach ich wykorzystanie w pradziejach i wczesnym średniowieczu. Materiały z konferencji, Krosno 25-26 listopada 2008 r.* Krosno, 141-166.

Ginter B. 1986. Obsidianimporte im Spätpaläolithikum und Mesolithikum in Südpolen. (In:) *Urzeitliche und Frühhistorisches Besiedlung der Ostslowakei in Bezug zu den Nachbarngebieten*. Nitra, 71-76.

Gméling K., Harangi Sz., Kasztovszky Zs. 2005. Boron and chlorine concentration of volcanic rocks: an application of prompt gamma activation analysis. *Journal of Radioanalytical and Nuclear Chemistry* 265(2), 201-212.

Gméling K., Kasztovszky Zs., Harangi Sz., Szentmiklósi L., Révay Zs. 2007. Geological use of prompt gamma activation analysis: importance of the boron concentration in volcanic rocks. *Journal of Radioanalytical and Nuclear Chemistry* 271(2), 397-403.

Gméling K., Simonits A., Sziklai László I., Párkányi D. 2014. Comparative PGAA and NAA results of geological samples and standards. *Journal of Radioana-*

lytical and Nuclear Chemistry 300, 507-516, DOI 10.1007/s10967-014-3032-2.

Hughes R.E., Werra D.H. 2014. The source of Late Mesolithic obsidian recovered from Rydno XIII/1959, Central Poland. *Archeologia Polski* LIX (1-2), 31-46.

Jażdżewski K. 1929. Osadnictwo prehistoryczne nad górną Prosną. *Z Otchłani Wieków* 4(5-6), 85-94.

Jurzysta E. 2010. Radiolarite core from Szynych 13, Northern Poland. *Acta Archaeologica Carpathica* XLV, 315-319.

Kabaciński J., Sobkowiak-Tabaka I. 2009. Big game versus small game hunting – subsistence strategies of the Hamburgian culture. (In:) M. Street, N. Barton, T. Terberger (eds.), *Humans, environment and chronology of the Late Glacial of the North European Plain*. Mainz, 67-75.

Kabaciński J., Sobkowiak-Tabaka I. 2012. Zasiedlenie Niżu Europejskiego u schyłku pleniglacjału w świetle danych środowiskowych. *Przegląd Archeologiczny* 60, 7-24.

Kabaciński J., Sobkowiak-Tabaka I., Winiarska-Kabacińska M. 2009. Janów, stanowisko 21 (AUT 425). (In:) J. Kabaciński, I. Sobkowiak-Tabaka (eds.), *Późny paleolit i mezolit basenu środkowej Warty. Late Palaeolithic and Mesolithic Settlement in The Middle Warta River Basin*. Poznań, 58-72.

Kaminská L'. 2007. The Final Palaeolithic in Slovakia. (In:) M. Kobusiewicz, J. Kabaciński (eds.), *Studies in the Final Palaeolithic Settlement of the Great European Plain*. Poznań, 111-127.

Kaminská L'., Ďuda R. 1985. K otáze významu obsidiánovej suroviny w paleolite Slovenska. *Archeologické Rozhledy* 37, 121-129.

Kaminská L'., Kozłowski J.K. 2002. Gravettian Settlement on the south and north side of the Western Carpathians. (In:) J. Gancarski (ed.), *Starsza i środkowa epoka kamienia w Karpatach polskich*. Krosno, 35-58.

Kasztovszky Z., Biró K.T., Markó A., Dobosi V. 2008. Cold neutron prompt gamma activation analysis – a non-destructive method for characterization of high silica content chipped stone tools and raw materials. *Archaeometry* 50(1), 12-29.

Kasztovszky Zs., Szilágyi V., T. Biró K., Težak-Gregl T., Burić M., Šošić R., Szakmány Gy. 2009. Horvát és bosnyák régészeti lelőhelyekről származó obszidián eszközök eredetvizsgálata PGAA-val / Provenance study of Croatian and Bosnian archaeological obsidian artefacts by PGAA. *Archeometriai Műhely / Archaeometry Workshop Budapest* 6 / 3, 5-14 [in Hungarian with English abstract].

Kilikoglou V., Bassiakos Y., Grimanis A.P., Souvatzis K., Pilali-Papasteriou A. Papanthimou-Papaefthimiou A. 1996. Carpathian Obsidian in Macedonia, Greece. *Journal of Archaeological Science* 23, 343-349.

Kostrzewski J. 1930. Obsidian implements found in Poland. *Man* 30, 95-98.

Kowalski S., Kozłowski J.K. 1959. O użytkowaniu jaspisu w epipaleolicie Polski południowej, *Materiały Archeologiczne* 1, 7-12.

Kozłowski J.K. 2004. *Świat przed rewolucją neolityczną*. Kraków.

Kozłowski J.K. 2013. Raw materials procurement in the Late Gravettian of the Carpathian Basin. (In:) Zs. Mester (ed.), *The Lithic raw material sources and interregional human contacts in the northern Carpathian regions*. Kraków-Budapest, 63-85.

Kozłowski L. 1923. *Epoka kamienia na wydmach wschodniej części Wyżyny Małopolskiej*. Warszawa-Lwów.

Krukowski S. 1920. Pierwociny krzemieniarskie górnictwa, transportu i handlu w holocenie Polski. Wnioski z właściwości surowców i wyrobów. *Wiadomości Archeologiczne* 5, 185-206.

Langley M.C., Street M. 2013. Long range inland-coastal networks during the Late Magdalenian: Evidence for individual acquisition of marine resources at Andernach-Martinsberg, German Central Rhineland. *Journal of Human Evolution* 64, 457-465.

Lowe J.J., Rasmussen O., Björck S., Hoek W.Z., Steffensen J.P., Walker M.J.C., Yu Z.C. the INTIMATE group. 2008. Synchronisation of palaeoenvironmental events in the North Atlantic region during Last Termination: a revised protocol recommended by the INTIMATE group. *Quaternary Science Review* 27, 6-17.

Mauss M. 1925. Essai sur le don. Forme et raison de l'échange dans les societies archaïques. *L'Année Sociologique* 1 (N.S. – 1923-1924), 30-186 [2001 *Szkic o darze. Forma i podstawa wymiany w społeczeństwach archaicznych*, translated by K. Pomian (In:) M. Mauss, *Socjologia i antropologia*, Warszawa, 165-306.

Milic M. 2014. PXRF characterisation of obsidian from central Anatolia, the Aegean and central Europe. *Journal of Archaeological Science* 41, 285-296.

Moutsiou T. 2014. *The Obsidian Evidence for the Scale of Social Life during the Palaeolithic*. BAR Internationale Series 2613. Oxford.

Oddone M., Márton P., Bigazzi G., Biró K.T. 1999. Chemical characterisations of Carpathian obsidian sources by instrumental and epithermal neutron activation analysis. *Journal of Radioanalytical and Nuclear Chemistry* 240 (1), 147-153.

Osipowicz G., Szeliga M. 2004. Analiza funkcjonalna obsydianowego liściaka schyłkowopaleolitycznego z Wołodzi, powiat Brzozów, województwo podkarpackie. *Acta Archaeologica Carpathica* XXXIX, 153-160.

Pawlikowski M. 1994. Artefakt z obsydianu z osadów środkowoplejstoceńskich w Rusku, gm. Strzegom. *Śląskie Sprawozdania Archeologiczne* XXXV, 79-84.

Płonka T. 2012. *Kultura symboliczna społeczeństw łowiecko-zbierackich środkowej Europy u schyłku paleolitu*. Wrocław.

Ralska-Jasiewiczowa M. (ed.) 2004. *Late Glacial and Holocene History of Vegetation in Poland based on Isopollen Maps*. Kraków.

Rasmussen S.O., Seierstad I.K., Andersen K.K., Bigler M., Dahl-Jensen D., Johnsen S.J. 2008. Synchronization of the NGRIP, GRIP, and GISP2 ice cores across MIS 2 and palaeoclimatic implications. *Quaternary Science Reviews* 27, 18-28.

Renfrew C., Bahn P. 2001. *Archeologia. Teorie, metody, praktyka*. Warszawa.

Révay Z., Belgya T. 2004. Principles of PGAA method. (In:) G.L. Molnár (ed.), *Handbook of Prompt Gamma Activation Analysis with Neutron Beams*. Dordrecht-Boston-New York, 1-30.

Révay Z. 2009. Determining Elemental Composition Using Prompt Gamma Activation Analysis. *Analytical Chemistry* 81, 6851-6859.

Rosania C.N., Boulanger M.T., Biró K. T., Ryzhov S., Trnka G., Glascock M.D. 2008. Revisiting Carpathian obsidian. *Antiquity* 82 (318), online: www.antiquity.ac.uk.

Rydlewski K. 1989. Pienińskie złoża radiolarytu i ich eksploatacja w epoce kamienia i wczesnej epoce brązu na Podhalu. *Acta Archaeologica Carpathica* XXVIII, 25-80.

Sahlins M.D. 1972. *Stone Age Economics*. Chicago.

Sawicki L. 1949. Wyniki badań obozowiska myśliwców z epoki lodowcowej na Zwierzyńcu w Krakowie. *Archeologické Rozhledy* 1, 74-76.

Schild R. 1975. Późny paleolit. (In:) W. Chmielewski, W. Hensel (eds.), *Prahistoria ziem polskich. Paleolit i mezolit*. Wrocław-Warszawa-Kraków-Gdańsk, 159-335.

Schild R. 2001. Three reasons why it is likely that the early Mesolithic population in Poland was not aboriginal. (In:) B. Ginter, B. Drobniewicz, B. Kazior, M. Nowak, M. Połtowicz (eds.), *Problemy epoki kamienia na obszarze starego świata. Księga Jubileuszowa dedykowana Profesorowi Januszowi K. Kozłowskiemu*. Kraków, 229-233.

Schild R., Królik H. 1981. Rydno a Final Palaeolithic Ochre Mining Complex. *Przegląd Archeologiczny* 29, 53-100.

Schild R., Królik H., Tomaszewski A.J., Ciepielewska E. 2011. *Rydno. A Stone Age Red Ochre Quarry and Socioeconomic Center. A Century of Research*. Warszawa.

Schmitt A.K., Simon J.I. 2004. Boron isotopic variations in hydrous rhyolitic melts:a case study from Long Valley, California. *Contributions to Mineralogy and Petrology* 146, 590-605.

Sobczyk K. 1995. *Osadnictwo wschodniograweckie w dolinie Wisły pod Krakowem*. Kraków.

Soják M. 2002. Osídlenie horného Spiša na sklonu staršej doby kamennej. (In:) J. Gancarski (ed.), *Starsza i środkowa epoka kamienia w Karpatach polskich*. Krosno, 255-278.

Sulgostowska Z. 2005. *Kontakty społeczności późnopaleolitycznych i mezolitycznych między Odrą, Dźwiną a Dnieprem. Studium dystrybucji wytworów ze skał krzemionkowych*. Warszawa.

Speth J.D., Newlander K., White A.A., Lemke A.K., Anderson L.E. 2013. Early Paleoindian big-game hunting in North America: Provisioning or Politics? *Quaternary International* 285, 111-139.

Sturdy D.A. 1975. Some reindeer economies in prehistoric Europe. (In:) E.S. Higgs (ed.), *Paleoeconomy*. Cambridge, 55-95.

Summerhayes G.R. 2009. Obsidian network patterns in Melanesia – sources, characterisation and distribution. *Bulettin of the Indio-Pacific Prehistory Association* 29, 109-123.

Szeliga M. 2002. Stan badań nad napływem obsydianu na ziemie polskie w starszej i środkowej epoce kamienia (na tle znalezisk środkowoeuropejskich. (In:) J. Gancarski (ed.), *Starsza i środkowa epoka kamienia w Karpatach polskich*. Krosno, 339-357.

Szentmiklósi L., Belgya T., Révay Z., Kis Z. 2010. Upgrade of the prompt gamma activation analysis and the neutron-induced prompt gamma spectroscopy facilities at the Budapest Research Reactor. *Journal of Radioanalytical and Nuclear Chemistry* 286, 501-505.

Terberger T., Street M. 2002. Hiatus or continuity? New results for the question of pleniglacial settlement in Central Europe. *Antiquity* 76, 691-698.

Tomaszewski A.J., Królik H., Ciepielewska E., Laprus-Madej B., Mańka D. 2008. Rydno's obisidians: almost all of them. (In:) Z. Sulgostowska, A.J. Tomaszewski (eds.), *Man – Millennia – Environment. Studies in honour of Romuald Schild*. Warszawa, 171-183.

Torrence R. 2005. Valued stone: how so? (In:) I. MacFarlane (ed.), *Many Exchanges: Archaeology, History, Community and the Work of Isabel McBryde. Aboriginal History Monograph 11. Aboriginal History Inc*., Canberra, 357-372.

Tunia K. 1978. Sprawozdanie z badań stanowiska z epoki kamienia w Tyliczu, woj. Nowy Sącz. *Acta Archaeologica Carpathica* XVIII, 227-233.

Tykot R.H. 1997. Characterization of the Monte Arci (Sardinia) Obsidian Source. *Journal of Archaeological Science* 24, 467-479.

Tykot R.H. 2011. Obsidian Finds on the Fringes of the Central Mediterranean: exotic or eccentric exchange. (In:). A. Vianello (ed.), *Exotica in the Prehistoric Mediterranean*. Oxford, 33-44.

Valde-Nowak P. 1987. Entdeckung der Paläolithischen Fundstellen im Tal des Białka Tatrzańska-Flusses. *Acta Archaeologica Carpathica* XXVI, 5-35.

Valde-Nowak P. 1991. Studies in Pleistocene Settlement in The Polish Carpathians. *Antiquity* 65, 593-606.

Valde-Nowak P., Nadachowski A., Madeyska T. (eds.) 2003. *Obłazowa Cave: Human Activity, Stratigraphy and Palaeoenvironment*. Kraków.

Walter R., Jacomb Ch., Brown-Muth S. 2010. Colonisation, mobility and exchange in New Zealand prehistory. *Antiquity* 84(324), 497-513.

Weniger G-C. 1987. Magdalenian Settlement and Subsistance in South-west Germany. *Proceedings of the Prehistoric Society* 53, 293-307.

Whallon R. 2006. Social networks and information: Non-"utilitarian" mobility among hunter-gatherers. *Journal of Anthropological Archaeology* 25, 259-270.

Wilczyński J. 2010. Obsidian products from Targowisko site 10 (powiat district of Wieliczka). (In:) J. Gancarski (ed.), *Transkarpackie kontakty kulturowe w epoce kamienia, brązu i wczesnej epoce żelaza*. Krosno, 115-137.

Williams O., Nandris J. 1977. The Hungarian and Slovak sources of archaeological obsidian: an interim report on further fieldwork, with a note on tektites. *Journal of Archaeological Science* 4, 207-219.

Williams-Thorpe O. 1995. Obsidian in the mediterranean and the near east: A provenancing success story. *Archaeometry* 37, 2, 217-248.

Williams-Thorpe O., Warren S.E., Nandris J. 1984. The distribution and provenance of archaeological obsidian in Central and Eastern Europe. *Journal of Archaeological Science* 11, 183-212.

Williams-Thorpe O., Warren S.E., Nandris J. 1987. Characterization of obsidian sources and artefacts from central and eastern Europe, using instrumental neutron activation analysis. (In:) K. T. Biró (ed.), *Proceedings of the international conference on lithic Raw material used in prehistory, flint mining and lithic raw material characterization in the Carpathian basin*, Vol. 2. Budapest, 271-279.

Winiarska-Kabacińska M., Kabaciński J. 2009. The first obsidian workshop at the Polish Lowland – a technological and microwear study. (In:). F. Sternke, L. Eigeland, L.-J. Costa (eds.), *Non-flint Raw Material Use in Prehistory. Old prejudices and new directions*, *BAR International Series 1939*. Oxford, 187-190.

Żaba J. 2003. *Ilustrowany słownik minerałów i skał*. Katowice.

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