

PIOTR CZUBLA, PIOTR STRZYŻ

ROCK MATERIALS IN THE MANUFACTURE OF CANNONBALLS IN POLAND – SELECTED EXAMPLES¹

In studies on the manufacture of historical arms and armour, researchers usually focus on identifying the technology of weapons forged from iron alloys, most commonly swords, followed by other blade and blunt weapons. Little attention is paid to projectile arms, but the issue of production of artillery ammunition is completely overlooked. So far, no studies of this kind were published in the Polish literature, no otherwise in the rest of Europe: the subject was considered marginally at most. Therefore, the research program on the development of early firearms in Poland included petrographic analysis of stones used in the production of cannonballs from four, quite precisely dated assemblies of Bolesławiec on the Prosna River, Chojnice, Człuchów and Puck (Fig. 1). The conducted expertises allowed an accurate characterization of used stones, including the determination of defects in the material, and made it possible to trace the ways of their distribution.

Historical-archaeological background of examined assemblages

Amongst the analyzed missiles, the oldest artefact is a 15 cm diameter ball from Bolesławiec on the Prosna River (Fig. 2:1). The deposition of this and other, larger calibre munitions from the Bolesławiec assemblage took place during the military activities of Władysław Jagiełło and his conflict with Władysław Opolczyk in the years of 1391–1396. The hostilities in the vicinity of Bolesławiec concentrated in 1393 and 1396, when the princely castle was besieged with artillery, as evidenced by historical accounts from Kraków². It is likely in this case that some war materials, including ammunition, had been prepared in advance and transported to the selected objects.

Research in Puck (Putzig) provided an interesting collection of missiles (Fig. 3). 22 cannonballs of 5.5–13.5 calibre and weight of 0.3–3.5 kg were acquired. All these findings come from the west side of the castle: specimens of greater

diameter (9.0–13.5 cm) were excavated in the area of the castle gate, smaller ones (5.5–8.5) near the castle house. The chronology of this set is defined by a layer dated to the 1350s and 1360s, which can be also correlated with information about the Castle Puck. The castle house had been built in the early years of the 15th century, but the military actions took place here only during the Thirteen Years' War: first, the castle passed into the hands of the Prussian Union, and in 1457 it became the residence in exile of Charles VIII of Sweden³. Puck returned to the possession of the Teutonic Knights in the night from 13 to 14 October, when the surprised (drunk) Swedish crew left the walls of the fortress. In 1464, Puck was under siege by the Polish army. Crusaders defended themselves from April to September, but denied assistance they finally surrendered the castle⁴. Thus, these events allow to determine the dating of found ammunition to 1464.

The dating of a set of cannonballs from Chojnice (Konitz) (Fig. 2: 2–3) is not so clear. The assemblage comprises nine balls (12.7–18.5 cm in diameter) found during excavations of the Old Market. In the 15th century, Chojnice was besieged three times by the Polish army. The first one took place in the summer of 1433. Teutonic sources mention four large cannons („III groze bochsén”) shooting bucket-sized missiles („grossze den eyn eymer”) taking part in the siege⁵. The second attempt to take control of the town took place in the initial period of the Thirteen Years' War (April–September 1454). Sources relating to these events mention that 2 field cannon guns and 2 terrace guns had been sent here from Toruń⁶. Final military activities took

³ J. Kruppé, M. Milewska, *Zamek pucki w badaniach archeologicznych 1991–1996*, „Kwartalnik Historii Kultury Materialnej”, Vol. 45/1, 1997, p. 43; L. Kajzer, S. Kołodziejewski, J. Salm, *Leksykon zamków w Polsce*, Warszawa 2001, p. 408; M. Haftka, *Zamki krzyżackie w Polsce. Szkice z dziejów*, Malbork–Płock 1999, p. 258.

⁴ M. Biskup, *Trzynastoletnia wojna z Zakonem Krzyżackim 1454–1466*, Warszawa 1967, pp. 623–624, 667–668; J. Kruppé, M. Milewska, *op. cit.*, p. 45; M. Haftka, *op. cit.*, pp. 259–260.

⁵ *Die ältere Hohmeisterchronik*, Scriptorum Rerum Prussicarum, Vol. II, ed. M. Toeppen, Leipzig 1866, p. 634; J. Szymczak, *Początki broni palnej w Polsce (1383–1533)*, Łódź 2004, pp. 244–245.

⁶ M. Biskup, *Wykaz broni i innego sprzętu wojennego wysłanego przez Toruń w okresie wojny trzynastoletniej*, „Zapiski

¹ This work has been financially supported by the Polish Ministry of Science and Higher Education, project No. NN 109260239, project manager P. Strzyż.

² *Najstarsze księgi i rachunki miasta Krakowa od r. 1300 do 1400*, eds. J. Piekosiński, J. Szujski, Kraków 1878, Vol. 2, pp. 244, 245.

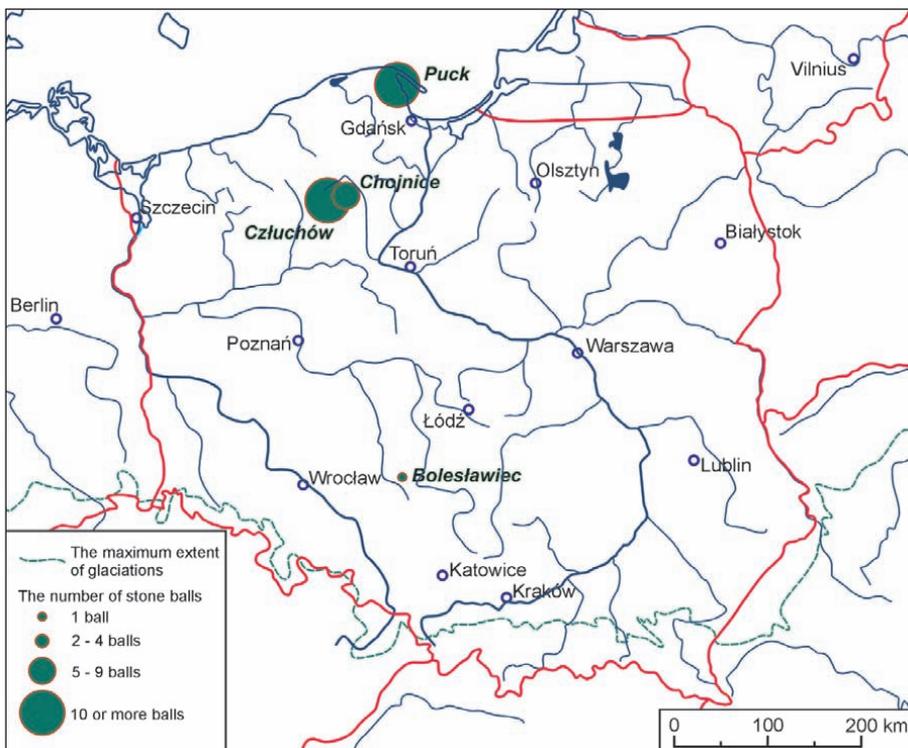


Fig. 1. The distribution of analyzed missiles on the territory of Poland, by P. Czubla.

place in the year 1466, when a great field cannon gun and veuglaires among other firearms were used during the bombardment of town walls⁷. Unfortunately, we do not know exactly which of the mentioned events should be connected with the Chojnice assemblage, but it is worth to mention a description of Jan Długosz, who commented the situation in 1433: „during the siege, in many places walls and the bulwark were bombarded without rest from a great number of cannons, and large troops were sent to all neighbouring localities (...), who provided the military with necessary food”⁸. It is, therefore, likely that in addition to food, stones for production of ammunition were also brought here.

The dating of cannonballs found in the castle of Człuchów (Schlochau) poses some problems too (Fig. 4: 1–4). The total of artefacts acquired here amounts to 55 specimens, most found in a dig situated between the outer wall and the castle tower (Fig. 4: 1). The projectiles were found here in a cluster of 40 examples in a single layer. These represent calibres from 10 to 27 cm and weight between 1.5 and 26.4 kg. In this case, we do not know whether this assemblage can be connected to the siege, or should be rather treated as castle ammunition. The latter option seems much more probable, and the missiles were simply stored in the space between the walls. Equipment

lists prepared on a regular basis within the Order prove that firearms appeared in the castle in 1392, and in a few years Człuchów had „2 grosse buchszen” and „cleyne steynbuchszen” at its disposal. In 1413, the number of guns shooting stone projectiles rose to a total of 10, and were provided with „7 schog buchsensteine”. In subsequent records equipment numbers did not change, but the supply of cannonballs rose to „60 buchsteine czu der grosten buchszen” and „9 schog und 10 styne cleyne und gros czu der anderen bochszen”⁹.

Rock materials in the studied cannonball assemblages

Cannonballs from Człuchów and Chojnice are characterized by very similar types of rock materials used in their manufacture. As many as 14 projectiles from Człuchów and 6 from Chojnice were made of different types of granitoids (granitic rocks) of Scandinavian origin (erratics) – Tab. 1, Figs. 2, 3. Granite gneisses were represented much less frequently: 2 missiles from both places. One ball from Chojnice was made of syenitoid (syenitic rock) (CHR/1097/00/9). This material is recorded in only one description of medieval cannonballs¹⁰. This was probably mainly to its relatively low presence among glacial erratics of Central Europe and slightly less favourable technical properties in comparison to granitoids. It is also possible that during initial field identification, syenitoids were often misdiagnosed as granites (granitoids). This should not be too surprising, since the difference between the two groups

Historyczne”, Vol. XXXI/1, 1966, p. 86; idem, *Trzynastoletnia wojna...*, p. 252.

⁷ M. Biskup, *Wykaz sprzętu...*, pp. 90–91; idem, *Trzynastoletnia wojna...*, pp. 693–694; J. Szymczak, *op. cit.*, p. 262.

⁸ *Jana Długosza Roczniki czyli kroniki sławnego Królestwa Polskiego*, ed. J. Mrukówna, Warszawa 2009, Vol. 11-12 (1431-1444), p. 124.

⁹ *Das Grosse Ämterbuch des Deutschen Ordens*, ed. E. Zismer, Danzig 1921, pp. 649–656.

¹⁰ P. Strzyż, *Średniowieczna broń palna w Polsce. Studium archeologiczne*, Łódź 2011, p. 155.

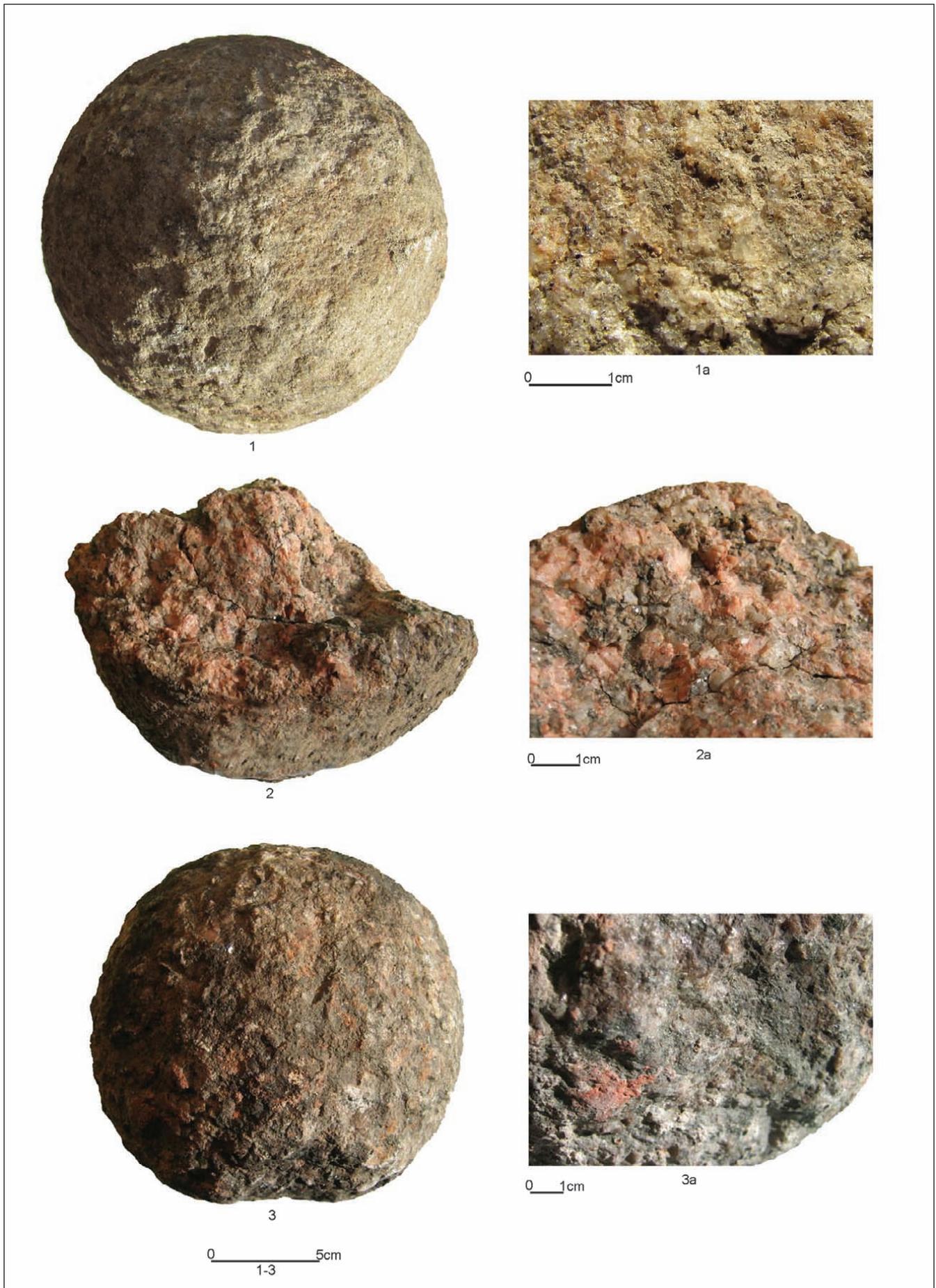


Fig. 2. 1, 1a – Bolesławiec on the Prosna River; 2, 2a – Chojnice, CHR/1097/00/4; 3, 3a – Chojnice, CHR/1097/00/6, 1-3 Photo P. Strzyż.

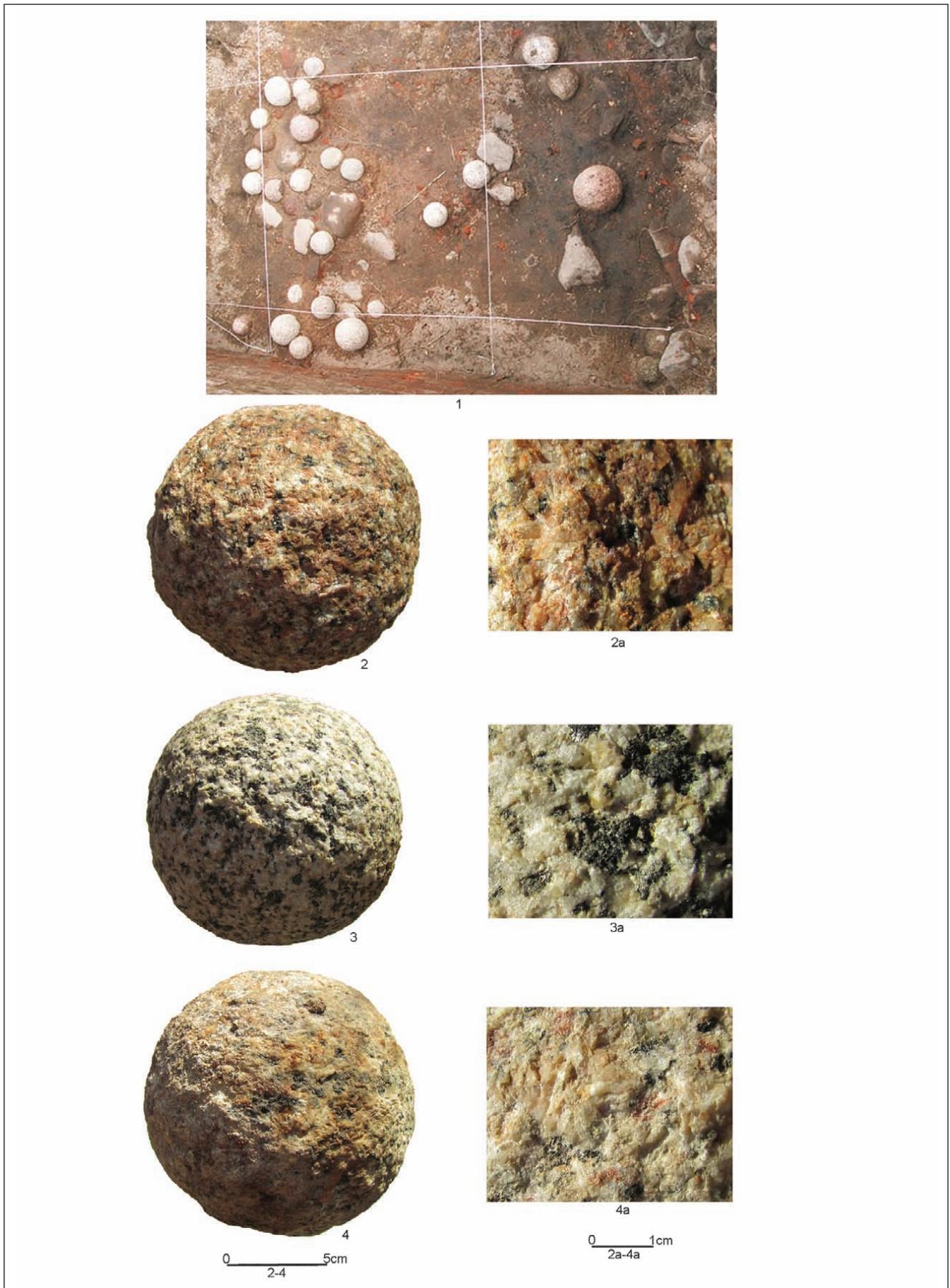


Fig. 3. 1 – Człuchów castle, trench 19, stone balls in situ, Photo M. Starski; 2, 2a – Człuchów, Cz. z. 19B.12/17; 3, 3a – Człuchów, Cz. z. 19B.12/6; 4, 4a – Człuchów, Cz. z. 19B.12/19; 2-4, Photo P. Strzyż.



Fig. 4. Palaeozoic limestones outcrop on the island of Gotland, Photo P. Czubla.

can be summed to, putting things simply, a greater presence of quartz in granitoids and potassium feldspar in syenitoids. The border value between these two groups is set at 20% of quartz in the group of felsic minerals (quartz, potassium feldspars, plagioclase feldspars, feldspathoids)¹¹. Qualitative composition of minerals in both groups is very similar, and the macroscopic evaluation of quartz content can be easily mistaken.

In Człuchów, apart from granitoid missiles and those made of granite gneisses, one cannonball was diagnosed as made of intrusive igneous rock (pegmatite/aplite) and another one of Palaeozoic Palaeoporella limestone. Among the granitoids Siljan (Cz.Z.19B.12/17 – Fig. 3: 2, 2a) and Järna (Cz.Z.19B.12/6 – Fig. 3: 3, 3a)¹² granites derived primarily from Dalarna (Sweden) were identified, as well as rocks from Åland Islands (Cz.Z.15B.78, Cz.Z.19B.12/9, Cz.Z.19B.12/18, Cz.Z.19B.12/25), Prick granite from the continental part of Finland (Cz.Z.19B.12/20), and granite from Bornholm (Cz.Z.19B.12/19 – Fig. 3: 4, 4a). A common feature of most of these rocks is primarily a fine and medium crystalline texture and low content of mica (biotite). These properties enable precise carving of stone to an expected size and spherical shape. Rocks of an inequigranular texture, such as

Rapakivi granites, aplites and pegmatites were characterized by a considerable heterogeneity, which contributed to breaking in directions contrary to intentions of the craftsman and to formation of irregular chips. Hence, the lesser presence of these rocks in the Człuchów ammunition assemblage.

Człuchów and Chojnice are located very close to each other, and both were covered by the last Scandinavian glaciation. Therefore, the kinds of rock materials available there were the same. Mass occurring glacial erratics remained in use, most of which had been pre-smoothened during transport, or even before they had been taken by the ice sheet, which dragged them to the territory of Poland. This initial, natural treatment facilitated the work of stonemasons who produced cannonballs. Due to the diversity and abundance of available material it was possible to choose raws of the best technical parameters. Here, however, a dissonance between the two sites appears. While the Człuchów assemblage is clearly characterized by the preference of fine and medium crystalline granitoids with favourable technical properties, the set from Chojnice is more of a random collection of rocks of varied suitability for the manufacture of ammunition (CHR/1097/00/1 do CHR/1097/00/8). Some projectiles from Chojnice were also rather poorly treated, indicating haste in their preparation. The use of rocks of worse properties, such as coarse grained granites and granite gneisses (CHR/1097/00/2, CHR/1097/00/4 – Fig. 2: 2, 2a; CHR/1097/00/6 – Fig. 2: 3, 3a, CHR/1097/00/7), as well as rocks with a conspicuous directional texture accentuated by a concentration of biotite crystals (CHR/1097/00/3, CHR/1097/00/4), suggest that the Chojnice balls were produced under conditions of limited raw materials access. This applies also to the use of syenitoid (CHR/1097/00/9),

¹¹ *Igneous rocks: a classification and glossary of terms*, ed. R. W. le Maitre, Cambridge 2004, pp. 21–27, 29; P. Czubla, E. Świerczewska-Gładysz, W. Mizerski, *Przewodnik do ćwiczeń z geologii*, Warszawa 2009, pp. 73–78.

¹² P. Smed, *Steine aus dem Norden: Geschiebe als Zeugen der Eiszeit in Norddeutschland*, Berlin–Stuttgart 2002, pp. 130–154; P. Czubla, D. Gałązka, M. Górka, *Eratyki przewodnie w glinach morenowych Polski*, „Przegląd Geologiczny”, Vol. 54/4, 2006, pp. 352–362.

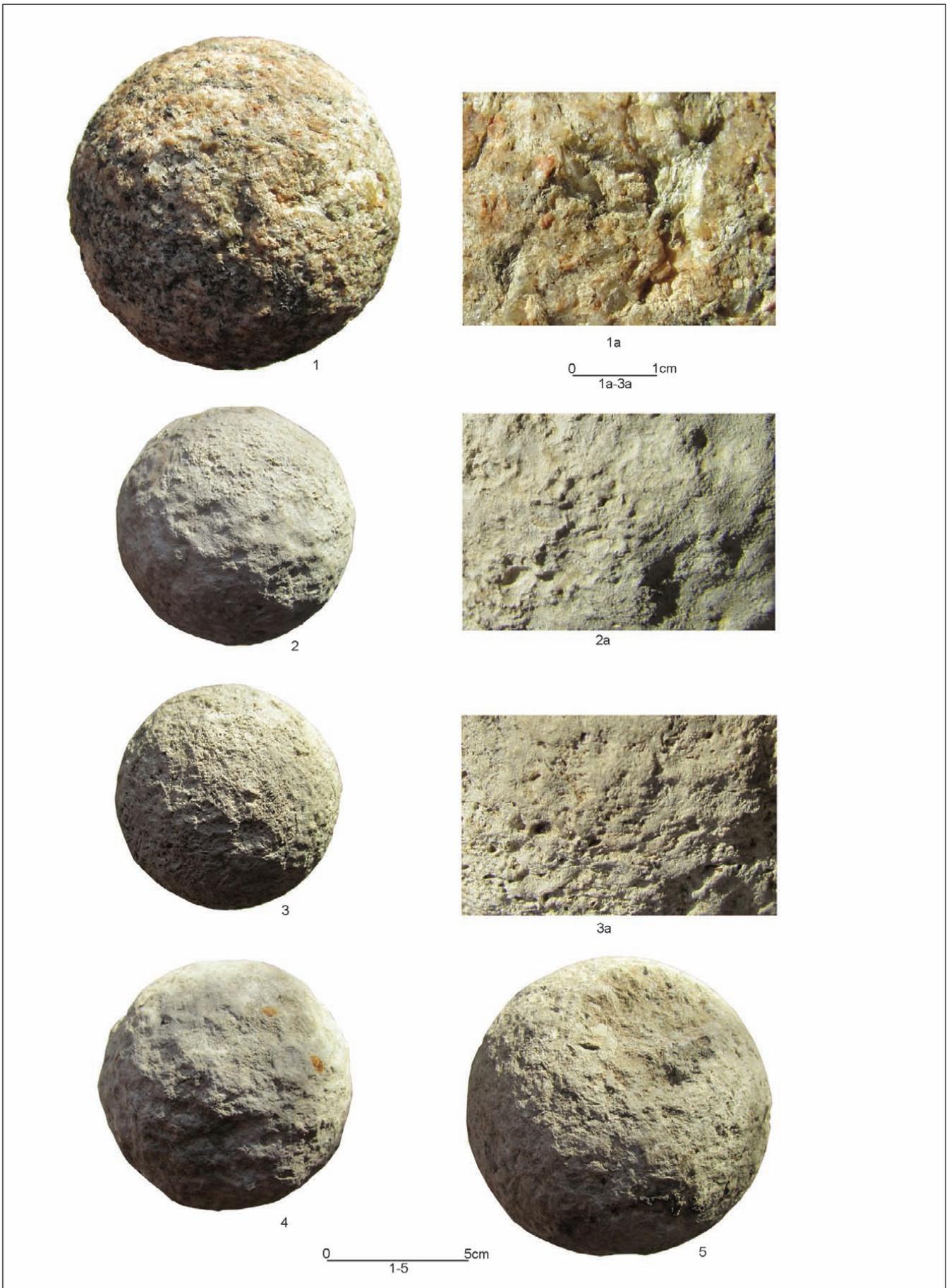


Fig. 5. 1, 1a – Puck, Pk.Z.35/53; 2, 2a – Puck, Pk.Z. 36/23; 3, 3a – Puck, Pk.Z.31/43; 4 – Puck, Pk.Z.49/15; 5 – Puck, Pk.Z. 37/26; 1-5 Photo P. Strzyż.

which as a result of perfect cleavage of potassium feldspar's large crystals did not really allow a precise shaping of a rock into a sphere. The next argument is provided by a ball made from a boulder a bit too small in relation to the expected size of the projectile (CHR/1097/00/5). It was carved only as much as to remove the portions of stone that went beyond the required calibre. Both aforementioned hasty work and use of inferior, unsorted material, suggest that the assemblage in question was manufactured during the siege of Chojnice. The besieged town's crew surely had a limited access to raw materials, but taking into consideration the huge amount of defected missiles in the set and their location, it is most probable that they were produced and used by the besiegers. Preparation of balls in place during the siege was not uncommon in the Middle Ages. Large cannonballs produced logistical problems, therefore, masons tended to participate in military expeditions in order to provide the artillery with ammunition manufactured on the spot¹³.

Quite different in petrographic terms is the projectile assemblage from Puck. Among the eleven examined artefacts, as much as ten were made of Palaeozoic limestone, and only one (PkZ.35.53) of granitoid (Fig. 5: 1). Six projectiles (PkZ.35.60, PkZ.35.79, PkZ.37.26, PkZ.40.70, PkZ.41.25 and PkZ.49.15) were carved from the same raw material – the Silurian crinoidal limestone¹⁴. Another two were made from a very similar type of rock, and only the two remaining from a different type of limestone (Fig. 5: 2–5, 2a–3a). Palaeozoic (Silurian and Ordovician) limestones form extensive outcrops extending from southwest to northeast along the basin of the Baltic Sea¹⁵. They are exposed on the surface primarily on the islands of Gotland (Fig. 4) and Öland, in the form of erratics they are present on almost all Polish territory. Limestone rarely has been used for making cannonballs in Poland. In this regard, the most preferred material were granitoids and other igneous rocks, and sandstones in southern Poland¹⁶. Igneous rock are much harder, more uniform and heavier than limestones: features which meet the needs of manufacturers of projectiles best. The only serious drawback of igneous rocks as a raw material for the production of cannonballs was the significant processing effort, often resulting from the higher hardness of most minerals present in the rocks of this group. In most of the Polish territories (with a possible exception of the south, which had not been covered by ice in the Pleistocene (Fig. 1) both limestone and igneous rocks are easily available in the form of erratic boulders. In this situation, preference for the latter is hardly surprising.

Unusual rock material dominant in the Puck assemblage can be explained in two ways: either the cannonballs were made in Puck and the raw material used for their manufacture was a large erratic boulder of Gotland limestone, or they were brought from a workshop situated on the island. The first hypothesis seems less likely, since the assemblage's petrographic differentiation is much higher than a one that would be possible in a single, even a fairly large erratic boulder. If the balls, which vary in material, were made of different limestone erratics, one would rather expect a much greater petrographic variety of limestone, which is typical for erratics' complexes of Poland¹⁷. This hypothesis also opens the question, why one would choose limestone, when crystalline rocks were plenty available. A relatively precise carving is surely an argument against haste in production, hence, there was no pressure to choose an inferior (but easier to work with) raw material. The second hypothesis seems much more logical. Whole of the island of Gotland is built of different varieties of limestone. Crystalline rocks there occur only as a few scattered erratics. The small petrographic variation within the limestone (as evidenced by the assemblage of Puck) is possible even in a quarry of a small scale. Exploitation of local limestone on Gotland has been carried from the 12th century¹⁸. In the form of different products, it was transported to mainland Scandinavia and Western as well as Central Europe. Another argument in favor of this conception was the documented presence of numerous and qualified stonemasons on Gotland. It seems only natural to manufacture cannonballs from the material appearing en masse on the spot that was also exploited for other purposes. If the second considered hypothesis is correct, the analyzed set of projectiles is an import from Gotland. This would confirm trade connections, as well as perhaps military connections of southern coast of the Baltic Sea with the Baltic islands, which is true to the political situation at the time. From 1398 to 1409 Gotland had been held by the Teutonic Knights, and was later sold to Sweden. King Charles VIII of Sweden had been leasing Puck during the time of 1457–1460, before it was captured by the Order¹⁹.

The cannonball from Bolesławiec (Fig. 2: 1, 1a) was made from a fine crystalline granitoid harvested from Polish erratic boulders. This missile is characterized by precise carving and an advantageous choice of raw material. Not only the used granitoid is fine grained, it also contains little biotite, which is fairly evenly distributed throughout the

¹³ J. Szymczak, *op. cit.*, p. 151.

¹⁴ Judging only after the surface characteristics, because these balls were not cut for analysis.

¹⁵ A. Martinsson, *Nielsens Grund och Hoburgs Bank I Östersjön*, „Geologiska Föreningen i Stockholm Förhandlingar”, Vol. 87/3, 1965, pp. 326–336; P. Smed, *op. cit.*, pp. 43–48.

¹⁶ P. Strzyż, *op. cit.*, p. 60.

¹⁷ P. Czubla, *Eratyki fennoskandzkie w utworach czwartorzędowych Polski Środkowej i ich znaczenie stratygraficzne*, „Acta Geographica Lodziensia”, Vol. 80, 2001, p. 49.

¹⁸ J. Roosval, *Die Steinmeister Gottland; eine Geschichte der führenden Taufsteinwerkstätte des schwedischen Mittelalters, ihrer Voraussetzungen und Begleit-Erscheinungen*, Stockholm 1918, pp. 1–242.

¹⁹ S. M. Kuczyński, *Wielka Wojna z Zakonem Krzyżackim w latach 1409–1411*, Warszawa 1980, pp. 95–96, 99; J. Kruppé, M. Milewska, *op. cit.*, p. 43.

	Granitoids	Syenitoids	Intrusive igneous rock	Granite gneisses	Limestones	Sum
Bolesławiec	1	-	-	-	-	1
Chojnice	6	1	-	1	-	8
Człuchów	14	-	1	2	1	18
Puck	1	-	-	-	10	11
Sum	22	1	1	3	11	38

Tab. 1. Number of analyzed cannonballs from each site and their division based on the raw material used.

whole volume of the rock. Such features encourage precise carving.

Rocks as a raw material for making cannonballs

Cannonballs were on most occasions a product used only once. In many cases, there was a need for an ad hoc production to replace the missing pieces of ammunition. Therefore, attempts were made to use locally available raw materials²⁰ as much as possible, or if need be imported from a shortest possible distance. During military campaigns and sieges, projectile shortages were replenished with production from raw materials occurring in the area of military operations, or the route of the march of troops²¹. This influenced the considerable variation of used rock materials. Large one-off orders, as the one submitted in 1319 by King Henry V of England in Maidstone quarries for making as much as 7000 hard Kentish Ragstone limestone missiles²², were exceptional. Naval artillery operated on different principles. Maritime units had to resupply cannonballs in port towns, which lead to the uniformity of material used. E.g., in the wreck of Mary Rose, out of the total of 387, only 10 projectiles were made from a material different than the mentioned Kentish Ragstone²³.

The opinion of the use of any available stone in the manufacture of cannonballs is hard to accept²⁴. Physical properties influenced to a decisive extent both the effort (cost) of rock processing to expected size and shape, as well as the lethality. Most useful for making missiles would be all hard and heavy rocks with as homogeneous internal structure as possible. This would include basalts, diabases and fine crystalline granitoids²⁵, diorites and gabbroids. The bigger

the crystals (grains, blasts), the harder it was to carve a shape as close to an ideal sphere as possible. Excellent cleavage of some rock-forming minerals (feldspar, amphibole) led to the formation of numerous chips. Problems with producing cannonballs of ideal shape and the manufacture technique of cannon barrels forced to leave a substantial free space on the bore rim – usually 3–5% of the missile's calibre, which entailed a decrease in exhaust pressure and the loss of a large part of the energy²⁶. As a result, range and accuracy suffered, and the loading time was significantly prolonged due to the need to use wooden wedges.

Balls made of soft and easily workable rocks were prone to cracking when hitting an obstacle, which on one hand could have been an effective way of striking multiple human targets, on the other it rendered the projectile ineffective against solid walls²⁷. Sometimes the cannonballs made of very soft rocks cracked in the bore bottom or at the muzzle at the moment of gunpowder firing, bringing no effect, if not a negative one. Such balls were sometimes wrapped with iron bands running in grooves carved on the projectile's surface²⁸. This increased both the workload and the price, also due to the use of costly metal. The feature disqualifying a rock as a raw material for the manufacture of missiles was the occurrence of splitting surfaces: intrusions, cracks, joints, preferred orientation of crystals. They all led to rock breaking, but seldom in directions in accordance with the mason's intention. The exceptions were cases where splitting allowed to break smaller pieces from the larger boulder for further carving. It is difficult to agree with the suggestion from the expertise of a cannonball from Vysoké Mýto near Pardubice, Czech Republic. There, an opinion appeared that making balls of basaltoids was facilitated by the fact that many of them are occurring in

²⁰ *The Oxford Encyclopedia of Medieval Warfare and Military Technology*, ed. C. J. Rogers, Oxford 2010, Vol.1, p. 84.

²¹ Por. K. Górski, *Historia artylerji polskiej*, Warszawa 1902, pp. 42–43, 45, 239–240; J. Szymczak, *op. cit.*, p. 151; J. Orna, V. Dudková, *Archeologické doklady obléhání Plzně husity*, „*Archaeologia historica*”, Vol. 37/1, 2012, pp. 169–170.

²² <http://www.gallagher-group.co.uk> (22.07.2013).

²³ *Weapons of Warre: The Armaments of the Mary Rose. The Archaeology of the Mary Rose*, ed. A. Hildred, Vol. 3, Portsmouth 2011, pp. 342–343.

²⁴ *The Oxford Encyclopedia...*, p. 84: “... using hammer and chisels, made from whatever stone was commonly available...”.

²⁵ Cf. F. Mende, *Die nordischen Geschiebe Norddeutschlands*, „*Naturwissenschaftliche Monatsschrift des Deutschen*

Lehrervereins für Naturkunde”, Vol.40/9, Stuttgart 1927, pp. 261–275: „... zu kriegerischen Zwecken verwendete der preußische Ordensritter die Geschiebe. Er ließ in den Jahren 1401–1411 aus feinkörnigen Granitgeschieben Steinkugeln verschiedener Größe herstellen...”.

²⁶ K. Gerlach, *Okreśtowanie dział kamienne*, „*Morze Statki i Okrety*”, No. 1, 2011, p. 68.

²⁷ J. Szymczak, *op. cit.*, p. 149; P. Strzyż, *op. cit.*, p. 59; J. Ki-nard, *Artillery: an illustrated history of its impact*, Santa Barbara 2007, p. 36.

²⁸ K. Gerlach, *op. cit.*, pp. 68, 69.

the form of pillow lavas. The rock material used to make this projectile was supposed to come from a neighbouring quarry in the vicinity of Jičín²⁹. Spherical weathering is present in volcanic rocks, especially basalts, but only if they solidified in an underwater environment (pillow lavas). Cainozoic basaltoids of the northern part of the Bohemian Massif were formed in subaerial conditions and, therefore, lava pillows are not present there. Often columnar thermal jointed basalts can be found that could have actually made the work of the stonemason easier.

The diversity of rock types used in the manufacture of missiles was relatively high, but some of their types were completely unsuitable for processing. There are no known cases of use of such rocks as slates or gneisses. The literature documents the use of granite, granite gneiss, basalt, limestone, sandstone, arkose, conglomerate, dolomite and marble³⁰. In the territory of Poland, granite and sandstone materials are noted most commonly, limestones are rarer, and basalt and syenite finds are very scarce. In many cases, material description are limited to inconcrete indications like “sedimentary rock”, “stone” or “erratic boulder”³¹. In fact, petrographic diversity of raw materials that were used is much higher. In field conditions, petrographic identification allows only a rough determination of the type of rock, which is somewhat problematic. Best example is the repeated indication of cannonball material as granite. It is an obvious simplification, because granite is only one of the four types of granitoids (next to alkali granite, granodiorite and tonalite), distinguished on the basis of the ratio between potassium feldspars and plagioclases³². A macroscopic, field determination of these ratios is not possible, therefore, it is most proper to indicate a wider petrographic group – in this case granitoid. A complete lack of identification of materials such as dioritoids, gabbroids, dolerites in literature is most probably due to the inability to recognize these types of rocks, rather than them being discarded by past cannonball manufacturers. The presence of basalt balls in Elbląg and Piotrków Trybunalski leads to this kind of conclusion³³. Carving basalt was not much easier than dolerite, dioritoid or gabbroid, and the properties of cannonballs manufac-

tured from these materials would be pretty much the same. Therefore, it can be assumed that such projectiles could be found in different collections, but are described there as, e.g., erratic stone or even granite. On the other hand, the scarce presence of basalt balls in Polish collections can suggest the difficult carving of gabbroids and dioritoids to be a secondary cause of their avoidance as a raw material for cannonball productions. The presence of more than 300 occurrences of basalts in Lower Silesia (volcanic cones, plugs and flood basalt)³⁴, and even the erection of a castle on a basaltoid volcanic neck (Grodziec in Kaczawa Foothills) allow to expect a much larger representation of these rock types in the form of cannonballs.

Contrary to the popular belief, the Middle European Plain covered with loose Quaternary deposits provided an opportunity to obtain a very wide variety of rock materials. They came in the form of erratic boulders carried by subsequent ice sheets of Fennoscandia and the Baltic seabed. When they had been incorporated into the mass of ice, and later, during their transport and sedimentation, the least resistant rocks were eliminated. As a result, mostly harder rocks survived in the Pleistocene deposits, more resistant to mechanical damage, and thus more suitable for the manufacture of cannonballs. Suitable rocks were, admittedly, not concentrated in specific sites, such as the Sudetes or the Carpathian Mountains, but spread over a large area, which forced the manufacturers to search for the preferred types of rocks.

It is puzzling that balls made of sandstone in Poland were found mainly south of the 52nd parallel³⁵. It can be inferred that this was because of the possibility to use local outcrops of sandstone, which occurs only in southern Poland, mainly in the Carpathian Mountains, but also in the Sudetes, Holy Cross Mountains, and in a few small outcrops outside this area. It is unclear, what caused the resignation of the use of Proterozoic Jotnian sandstones or Cambrian sandstones of Bornholm, Skåne, or of the bottom of the Baltic Sea, which were commonly found in glacial deposits of the northern and central Poland. It is possible that the use of these relatively hard quartz sandstones and quartzites in the manufacture of projectiles was difficult due to the easy splitting parallel to original bedding. Even in the metamorphosed quartzites, the rock cracking along flat interlayer surfaces occurred fairly easily, which almost completely precluded the production of balls from them. However, similar defects were also typical of local sandstones,

²⁹ J. Zavřel, *Vysoké Mýto – kamenné projektily*, Praha 2013, typescript in Institute of Archaeology and Ethnology of Polish Academy of Sciences in Łódź. We would like to thank the Author for sharing analyzes results. For sharing research materials from Vysoké Mýto we extend our thanks to Sylwester Chmielowiec from Archaia-Praha o.p.s.

³⁰ K. Gerlach, *op. cit.*, p. 68; J. Orna, V. Dudková, *op. cit.*, p. 166; *Weapons of Warre...*, pp. 339, 343; B. Chudzińska, *Pozostałości średniowiecznej, ręcznej broni palnej z zamku w Muszynie*, „Acta Militaria Mediaevalia”, Vol. 7, 2011, p. 205, fig. 3: 4; *The Oxford Encyclopedia...*, p. 84.

³¹ J. Szymczak, *op. cit.*, pp. 148–149; P. Strzyż, *op. cit.*, pp. 123–190, 209–211.

³² *Igneous rocks...*, pp. 21–27, 29; P. Czubla, E. Świerczewska-Gładysz, W. Mizerski, *op. cit.*, pp. 73–78.

³³ P. Strzyż, *op. cit.*, p. 150, 174.

³⁴ *Atlas Śląska Dolnego i Opolskiego*, ed. W. Pawlak, Wrocław 1997, pp. 13–14; *Mapa geologiczna regionu dolnośląskiego z przyległymi obszarami Czech i Niemiec (bez utworów czwartorzędowych) 1:100 000*, ed. L. Sawicki, Warszawa 1995; *Mapa geologiczna regionu dolnośląskiego z przyległymi obszarami Czech i Niemiec 1:100 000; Podstawy litostratygraficzne i kodyfikacja wydzielen*, ed. L. Sawicki, Warszawa 1997, pp. 16–18.

³⁵ P. Strzyż, *op. cit.*, p. 60.

for example Krośnian, and they were used to produce projectiles on a large scale³⁶. Undoubtedly, Carpathian, Holy Cross Mountains' and Sudetian sandstones were much more susceptible to carving than the sandstones and quartzites from Fennoscandia, cemented by silica.

Production of stone cannonballs in the Middle Ages was relatively expensive, but many times cheaper than the manufacture of metal ones. It is clear that the time required to carve one specimen depended both on the material and size of the ordered missiles. Certain information in this issue are provided by medieval Teutonic accounts. In 1410, in Elbląg, the Order purchased 22 three-scores of "buchsenstynne klein und grot" for 43 Marks and 19.5 Scot, so one specimen costed ca. 1.5 grosses. Four years later, 41 stone balls weighing a total of 12.5 Zentner cost about 2.5 grosses a piece³⁷. A much larger and more expensive cannonball was carved in 1408 in Malbork by stonemason Hannos. It cost as much as 4.5 Vierd, which is more than 1 Mark³⁸. The same craftsman, for making 2 three-scores of balls the size of the head, received payment in the amount of 5 Marks, i.e., 2 grosses a piece³⁹. For comparison, in Czech Cheb, in 1453, 30.5 three-scores stone projectiles (1830 pieces) cost 15 three-scores [grosses] and 45 grosses, which equals ca. half a gros per piece⁴⁰. The contemporary carpenter's or bricklayer's daily wage in Gdańsk was 2 or 3 grosses, if the employer did not provide food⁴¹. Stonemasons' incomes were probably at a level similar to other skilled craftsmen. This assumption is confirmed in a record from the 1st half of the 16th century, which informs that a weekly wage of a stonemason reached 12–15 grosses⁴². Based on the above data, it can be

assumed that the skilled mason was able to forge from one to three balls daily, depending on their size and the material used. Opinion that the craftsman needed one to two days to finish one projectile seems to be exaggerated in conjunction with the above data, the more that this remark referred to ship ammunition, which was mostly of small and medium calibre⁴³.

It is not clear, how the masons came into possession of the relevant material. It is probable that they themselves engaged in gathering the required rocks in quarries or on fields. However, there are records that residents of villages located in the vicinity of Łuck were required to provide stones for missiles for the castle⁴⁴. It is not possible to determine how common this practice was. The necessity of proper knowledge in order to choose preferable types of rocks suggests against a wide use of this form of raw material supply. Łuck, however, lies beyond the reach of the Pleistocene glaciations⁴⁵. Therefore, there was only direct rock substratum available and it was possible to precisely determine what kind of rock should be delivered to the castle, and in which location it should be gathered. Huge variations of erratic boulders of the regions farther north would make it much more difficult to obtain a suitable material by the unqualified local population.

Known cannonballs from the territory of Poland were usually made of different types of granitoids, sandstones and limestones. Other rock materials were used occasionally. Granitoids were the basic raw material utilized in the manufacture of stone balls from the analyzed sites, only the Puck assemblage was dominated by limestone. In the majority of these places, there is a visible, clear connection between raw materials used in the projectile manufacture and the geological structure of the immediate area, although this does not exclude the material pre-selection, in order to choose the most useful pieces. A detailed and fuller analysis of rock materials used in the production of cannonballs in Poland requires prior verification of the already catalogued records, where almost all findings were made of igneous rocks and are described as granite. Based on the analysis of the degree of selection of raw materials, carving methods, and possible cracks or other surface damage, conclusions can be drawn regarding the circumstances under which the cannonballs were made and used.

³⁶ *Ibidem*.

³⁷ W. Świętosławski, *Koszty broni palnej i jej użycia w państwie krzyżackim w Prusach na początku XV wieku*, „Studia i Materiały do Historii Wojskowości”, Vol. 35, 1993, p. 25; J. Szymczak, *op. cit.*, pp. 149–150. The then Zentner was about 54–55 kg, which gives an average ball weight of 16.5–16.75 kg. On the basis of original artefacts, we know that granite cannonballs of such a weight have a diameter of about 23 cm. Among the finds from the territory of Prussia, examples of a similar size were found in Chojnice (24 cm calibre, 17.1 kg weight), Town Hall in Elbląg (23 cm calibre, 17 kg weight), Lidzbark Warmiński (Heilsberg) (23 cm calibre, 15.5 kg weight) and Toruń (Thorn) (22.9 cm calibre, 15.9 and 16.9 kg weight); cf. P. Strzyż, *op. cit.*, cat. No. 83, 210, 432, 1006, 1007.

³⁸ It can be assumed that it was designed to a cannon of ca. 50 cm calibre – perhaps the great bombard cast in the local foundry in 1408. Among the cannonballs stored in Malbork, a dozen or so has a calibre around 42–49 cm and a weight of 101–155 kg; cf. W. Świętosławski, *op. cit.*, p. 25; P. Strzyż, *op. cit.*, cat. Nos. 583–590, tab. XXXIII: 4–5; G. Żabiński, *The Grose Bochse – a Teutonic Supergun from 1408*, „Fasciculi Archaeologiae Historicae”, Vol. 25, 2012, p. 36, fig. 3.

³⁹ W. Świętosławski, *op. cit.*, p. 25; J. Szymczak, *op. cit.*, p. 150.

⁴⁰ J. Durdík, *Palne zbraně a puškaři v Chebu v letech 1450–1470*, „Historie a Vojevství”, 1965/4, p. 525.

⁴¹ J. A. Szwagrzyk, *Pieniądz na ziemiach polskich X–XX w.*, Wrocław 1990, pp. 60–61.

⁴² K. Górski, *op. cit.*, pp. 45, 239; J. Szymczak, *op. cit.*, p. 151.

⁴³ K. Gerlach, *op. cit.*, p. 68.

⁴⁴ J. Szymczak, *op. cit.*, p. 151.

⁴⁵ V. A. Matoshko, *Limits of the Pleistocene Glaciations in the Ukraine: A Closer Look*, [in:] *Quaternary Glaciations – Extent and Chronology. A Closer Look*, eds. J. Ehlers, P. L. Gibbard, P. D. Hughes, Amsterdam 2011, pp. 406–407.

Streszczenie

Surowce skalne w produkcji kul armatnich w Polsce – wybrane przykłady

W badaniach nad produkcją dawnego uzbrojenia dotychczas pomijanym zagadnieniem była kwestia produkcji amunicji artyleryjskiej. W związku z tym wykonano analizy petrograficzne skał wykorzystanych przy produkcji kul kamiennych pochodzących z czterech, datowanych od schyłku XIV po 2. poł. XV w., zespołów: Bolesławca nad Prosną, Chojnic, Człuchowa oraz Pucka. Przeprowadzone badania pozwoliły na dokładne rozpoznanie wykorzystanych surowców.

Analiza petrograficzna wykazała, że amunicja z Człuchowa i Chojnic cechuje się bardzo podobnym doбором użytego materiału. Aż 14 kul z Człuchowa i 6 z Chojnic wykonano z różnych typów granitoidów pochodzenia skandynawskiego. Znacznie mniej licznie reprezentowane były granitognejsy – po 2 kule z obydwu stanowisk, a w zespole z Chojnic znalazł się także jeden okaz wykonany ze syenitoidu. W Człuchowie rozpoznano także pojedyncze egzemplarze wykute z magmowej skały żyłowej (pegmatytu/aplitu) i z paleozoicznego wapienia paleoporellowego. Wśród granitoidów zidentyfikowano granity Siljan i Järna, wywodzące się pierwotnie z Dalarny (Szwecja), skały alandzkie, granit Prick z kontynentalnej części Finlandii oraz granit z Bornholmu. Ich cechą wspólną jest drobnokrystaliczna i średniokrystaliczna tekstura. Powyższe właściwości umożliwiają precyzyjną obróbkę kamienia do pożądanego rozmiarów i kulistego kształtu. Również kula z Bolesławca wykonana została z drobnokrystalicznego granitoidu (głazu narzutowego) i wyróżnia się dokładną obróbką i korzystnym doбором materiału skalnego.

Człuchów i Chojnice położone są bardzo blisko siebie, w strefie objętej ostatnim zlodowaczeniem skandynawskim, w związku z czym rodzaje surowców skalnych możliwych do pozyskania w ich najbliższej okolicy były identyczne. Korzystano z masowo występujących na polach eratyków (głazów narzutowych), a wiele z nich było już wstępnie obtoczonych podczas transportu. Ta wstępna, naturalna obróbka ułatwiała dalszą pracę kamieniarzy, a z uwagi na różnorodność dostępnego materiału istniała możliwość

wybrania takiego, który cechował się możliwie najlepszymi parametrami technicznymi. Jednak, o ile w zespole kul z Człuchowa dostrzegamy preferowanie drobno- i średniokrystalicznych granitoidów, to w Chojnicach mamy do czynienia raczej z przypadkowym zbiorem skał o bardzo zróżnicowanej przydatności do wyrobu amunicji. Część kul z Chojnic jest na dodatek stosunkowo słabo obrobiona, co wskazuje na pośpiech w ich przygotowywaniu, i pozwala przypuszczać, że produkowano je w warunkach ograniczonego dostępu do surowca.

Odmienny pod względem petrograficznym jest zespół kul z Pucka. W przewadze wykonano je z paleozoicznych wapieni, a tylko jedną z granitoidu. Sześć kul sporządzono z identycznego surowca – z sylurskiego wapienia krynowidowego, kolejne dwie z bardzo podobnego typu skały i tylko dwie z nieco innego rodzaju wapienia. Wykorzystane surowce – paleozoiczne (sylurskie oraz ordowickie) wapienie tworzą rozległe wychodnie rozciągające się z południowego zachodu na północny wschód wzdłuż niecki Morza Bałtyckiego, a na powierzchni odsłaniają się przede wszystkim na Gotlandii i na Olandii, zaś w postaci skał narzutowych występują na prawie całym obszarze Polski. Nietypowy surowiec skalny dominujący w zespole kul z Pucka można tłumaczyć na dwa sposoby. Albo kule zostały wykonane w Pucku lub okolicach, a w charakterze surowca wykorzystano duży głąz narzutowy wapienia gotlandzkiego, albo co bardziej prawdopodobne kule pochodzą z warsztatu na Gotlandii, w którym wykorzystywano skały odsłaniające się na miejscu.

W związku z powyższymi spostrzeżeniami trudna do zaakceptowania wydaje się opinia o wykorzystywaniu do wyrobu kul armatnich dowolnego dostępnego kamienia. Właściwości fizyczne wpływały w decydującym stopniu zarówno na prędkość (koszt) obróbki fragmentu skały do oczekiwanych rozmiarów i kształtu, jak też na siłę i sposób rażenia wykonanego z niej pocisku. Najbardziej przydatne do wyrobu kul byłyby wszelkie twarde i ciężkie skały o możliwie homogenicznej budowie wewnętrznej.

