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GEMSTONES FROM THE DUCAL PART OF THE FORTIFIED SETTLEMENT OF POZNAŃ (10TH/11TH CENTURY) IN THE LIGHT OF GEMOLOGICAL STUDIES AND MICRO-RAMAN SPECTROSCOPY

Abstract: During archaeological excavations in Poznań there were discovered a ducal palace, a chapel dated to the 10th century, and goldsmith's workshop adjacent to them. In the layer of ashes at the bottom of the manufacture, there were fragments of gold found together with numerous glass beads and gems. Fourteen gems, made of rock crystal, agate, carnelian, milky chalcedony, garnet, were chosen for gemstone analysis and micro-Raman spectroscopy. The study material is dominated by beads (12 samples, of which six is faceted and six globular), while two pyrope samples have the cabochon cut. It should be emphasized that the rock crystal gems in the collection are usually heptagonal. Majority of the Poznań collection is of high quality, which is a sign of an advanced grinding and faceting technology.
Pyrope from the Poznań collection contains inclusions of apatite, rutile, quartz, and magnetite, identified with micro-Raman spectroscopy. A similar combination of inclusions was recognized in pyrope from deposits in Vestřev near Turnov (Bohemia), and hence it indicates that the artifacts from Poznań were made of the pyrope from those deposits. Considering inclusions in rock crystal artifacts from the Poznań collection it was assumed that the mineral was also of the Bohemian origin.

Keywords: rock crystal, garnet, early medieval artifacts, micro-Raman spectroscopy

INTRODUCTION

The archaeological excavations at Ostrów Tumski in Poznań initiated in 1999 have revealed the remains of a ruler's stone residence (the palace and chapel complex), partly underneath the Gothic Our Lady Church (K ó č k a-K r e n z 2010). Research has been conducted by a team of archaeologists from the Institute of Prehistory of the Adam Mickiewicz University in Poznań, headed by Hanna Kóčka--Krenz. The results of excavations, especially a dendrochronological analysis of

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the threshold beam of the door opening (the tree was cut down after 941), led to a conclusion that the palace was built shortly after the middle of the 10th century (Kóčka-Krenz 2004; 2005; 2006; Skoczylas 2005; Skoczylas, Michniewicz 2005).

Tab. 1. List of gemstones and decorative stones excavated in the ducal part of the Poznań fortified settlement (10th/11th century)

	Inventory number	Trench	Artefact	Type of cutting	Variety of Raw material identified with the help of Raman metod	Site
1	OT9/10/409w/04	XXV	Bead	faceted	Rock crystal	Closest vicinity of the ducal palatium (outside the medieval gold workshop)
2	OT9/10/917w/04	XXXII	Bead	Globular	Rock crystal	
3	OT9/10/926w/04	XXXII	Bead	Globular	Rock crystal	
4	OT9/10/333w/03	XXIV	Bead	Faceted	Agate	
5	OT9/10/490w/04	XXVI	Bead	Globular	Carnelian	
6	OT9/10/533w/04	XXVIII	Bead	Globular	Carnelian	
7	OT9/10/929w/04	XXXII	Bead	Globular	Carnelian	
8	OT9/10/176W/02		Bead	Faceted (heptagonal)	Rock crystal	
9	OT9/10/396W/04		Bead	Faceted (heptagonal)	Rock crystal	
10	OT9/10/547W/04	XXIX	Bead	Globular	Carnelian	
11	127/02; 424W/02	VII – shaft 13	Bead	Faceted (heptagonal)	Milk chalcedony	Within the gold workshop
12	146/02; 470W/02		Bead	Faceted	Carnelian	
13	439w/02		Cabochon	Cabochon	Garnet	
14	433w/02		Cabochon-cone	Cabochon	Garnet	

The residence was situated in the southern part of the ducal segment of the early medieval fortified settlement, close to the defensive ramparts. The western wall of the *palatium* was directly adjoined by a goldsmithery workshop was situated in a wooden building about 3×5 m in size (Kóčka-Krenz 2005, 2006). Its outline was exposed almost in total, but from its southern verge. Only the lower part of the building has been preserved, covered by destructed rock mate-

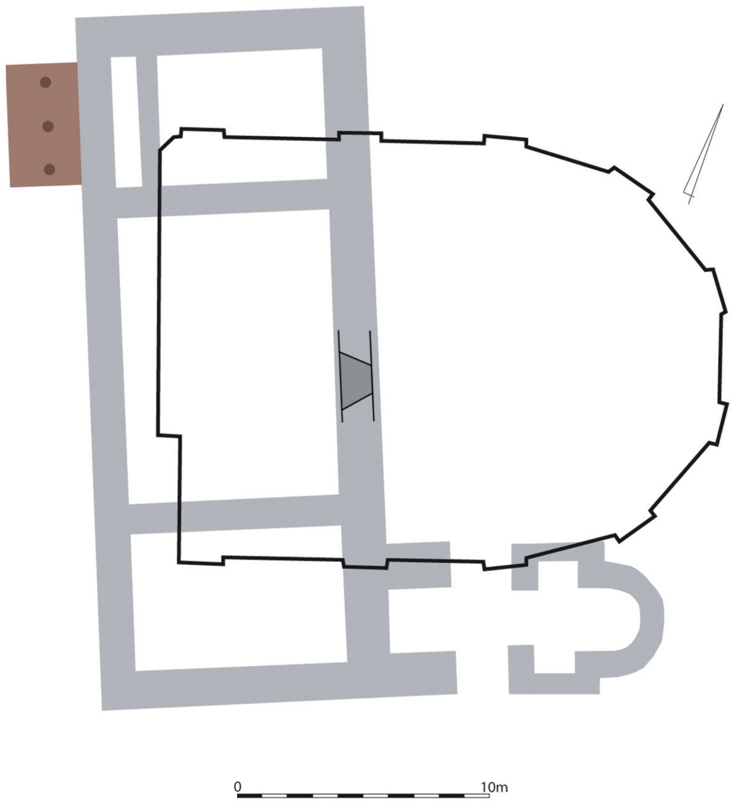


Fig. 1. Poznań − Ostrów Tumski. Location of the goldsmithery at palatium (drawing o. Antowska-Gorączniak) (K ó č ka-K r e n z 2006)

rial from dismantling the western wall of the *palatium*. Within the workshop, the impressions of posts were recorded in a circle of stones (most probably the posts supported the roof), together with a fragment of a layer of gypsum with impressions of roof boards and burnt boards in the south-western part, constituting the remains of the place where a goldsmith worked. The workshop originated in the second half of the 10^{th} century, soon after the erection of the ducal stone residence and it can be reconstructed as a quadrilateral wooden building with a roof supported by three posts, including one in the centre. The workshop had one workplace, situated in the south-western corner. Although the presence of a furnace or a hearth was not recorded within the building, crucibles and drops of melted gold suggest that it was equipped with a source of high temperatures. The workplace was abandoned due to a fire that must have happened before dismantling the *palatium* (Fig. 1). The excavation at the workshop yielded, among others, twelve beads, two cabochons, and five broken fragments of gemstones and decorative stones (Kóčka-Krenz 2006; Tab. 1). Other pieces include microscopic particles of blue, non-transparent stones, which were identified by Kóčka-Krenz (2005) as lapis-lazuli. This suggestion is strengthened by identification of a pigment obtained from lazurite on fragments of plaster excavated near the southern wall of the Our Lady Church. Further excavations gave 10 gemstones, albeit outside the limits of the early medieval goldsmithery. Hence, they cannot be related for sure to its activity, although they were all recorded in the nearest vicinity of the ducal *palatium* (Fig. 1).

The gemstones from the Poznań site have been identified macroscopically as garnets, rock crystal, agate, carnelian and chalcedony. The carnelian stones were worked by jeweler(s) into the form of cabochons, used to manufacture beads for necklaces. The cabochons made of garnet indicate that they were used for decorative ornaments in the cell technique (garnet *cloisonné*) and/or for setting in rings (Kóčka-Krenz 1993; 2006).

SOME REMARKS ABOUT GEMSTONES

It is difficult to indicate precisely a moment in the human history, when the first worked gemstones appeared. Working gemstones, resulting in their definite shape and getting out their natural features – shine and the play of light, has probably been known from the times of inventing techniques applied to manufacturing tools from rock materials. The cabochon cutting, producing oval surfaces and semicircular or ovoid shapes should be regarded as the oldest one.

Out of approximately 3400 minerals, in other words the natural chemical compounds originated in nature, particularly gemstones and decorative stones drew people's attention even in prehistoric times as the colored stones had impact on human senses and stimulated the imagination. There are over 120 types of gemstones and they are characterized by the beauty of color, transparency and vivid sheen as well as hardness and rarity of occurrence, the features which give them considerable practical value.

In the Middle Ages, gemstones – because of their value as a measure of wealth and magic power − were the objects of global trade. Some of them, like lapis lazuli, came from Afghanistan, which was at that time its only source. Others, such as diamonds, carnelians, amethysts were mined in India (Rapp 2009). In Europe, mainly rock crystals and garnets were mined since prehistoric times. In antiquity, the first "scientists" mostly devoted only cursory attention to gemstones; merchants, medics and jewelers were much more interested in this area. The then treatises on these stones often belong to the mineralogical and magical literature, which was an expression of the faith in their magical power.

The belief in the supernatural properties of gemstones is a part of the canon of the esoteric knowledge and demonstrates the timeless stability, regardless of advances in scientific knowledge. This phenomenon, confirmed by an extremely long tradition, dates back to the most primitive myths, ranging from stone amulets, talismans and "healing stones" known already in the Paleolithic, to the contemporary "stones and trees of happiness". The origins of the magic and symbolism of the stones should be above all connected with the civilizations of the ancient East, such as the Persians, Egyptians and Babylonians, and especially Chaldeans who developed astrological knowledge of the stones. However, it is worth emphasizing that also the Bible had a huge impact on all subsequent traditions. We find there, among others, the famous description of the 12 gemstones decorating the breastplate of an archpriest of Israel, i.e., of garnet, topaz, emerald, ruby, sapphire, jasper, opal, agate, amethyst, chrysolite, beryl and onyx; they were assigned many different symbolic meanings (Rapp 2009).

Basic knowledge of gemstones in the 4th and 3rd centuries BC can be found in the writings of both Aristotle and his pupil Theophrastus, who was the author of the famous treatise "On Stones" (for Polish translation see Theophrastus, 1963). Next, over the centuries the main sources of scientific knowledge about the stones were contained in the works of Pliny (1st century CE). The science on the stones was enriched in the early Middle Ages, mainly by Arab scholars: Avicenna (980-1037) and Al-Biruni (973-1048). The origins and development of modern mineralogical knowledge were set by the works of Georgius Agricola (Georg Bauer 1494-1555), especially his dissertation devoted to minerals "De nature fossilium libri X" (Agricola 1546). Later centuries, brought some encyclopedic works on occurrences as well as methods of extraction and processing of gemstones with reflections on their unusual features (e.g. de Boot 1609).

The value of the gemstone depends largely on its color and shade. Therefore, people always strived to optimize them so that the perceived color was the most attractive or the most intense. This was achieved by an appropriate selection of the form and type of cuts.

Today, in processing of gemstones, Schumann (2002) distinguished the following: glyptography, cutting and polishing of agates, cutting and polishing of colored stones, spherical cutting, cylinder cutting (in rotating barrels), drilling in gemstones and decorative stones as well as cutting and polishing of diamonds. The art of carving and engraving of stones, called from the Greek glyptography, includes engraving gems. The oldest stone sculptures are stone cylinders, coated in symbols and figures, which were used as seals or amulets. They come from ancient kingdoms of the Sumerians, Babylonians and Assyrians. Carving in stone was very popular in ancient Greece and achieved a high level also in Rome.

To the most popular types of stone cutting belong the following cuts: flat, convex (or cabochon), globular (round), and faceted. They are used mainly for agates and other non transparent precious and decorative stones. The faceted cut gives the stone many planes called facets (hence its name), and is mainly used for precious transparent stones.

The origins of grinding of gemstones are set in India and Iran. Here is what Lightbown (1992) writes: "There is evidence that the cutting of stones was practiced in eleventh – and twelfth – century Iran. The great scholar and scientist al Biruni (973-c. 1050) writes in his Book of Collections of Knowledge of Precious Stones, composed between 1041 and 1049, that the people of Khurasan and Iran know how to cut the diamond itself. Knowledge perhaps derived from India where the art of diamond cutting was already being practiced before the sixth century AD. Manuel Keene has recently shown that two faceted amethysts, one cut as an octagon and the other as a hexagon, set in rings which were found during excavations at Nishapur, but without a dated context, can be attributed to the tenth or eleventh century".

In Europe, the processing of gemstones probably began 36,000 years ago in Moravia and Silesia, where the Upper Paleolithic culture came into existence. In these areas, the ornaments of that time were made not only of foreign stones (jade), but mainly of the local ones (like hematite, amber, serpentinite, tektite, nephrite, chalcedony, agate, garnet and rock crystal (Mrazek 1996).

In the early Middle Ages, the processing of gemstones in Europe was widely practiced. There were, however, a few centers grinding garnet (grossular) and rock crystal, among others in Westphalia, where the crystal, jacinth and glass stones were polished (Lightbown 1992). A smaller grinding center was also in Wrocław (Kaźmierczyk, Sachanbiński 1978). In 1341 in Paris even cutting of emeralds and rubies was an everyday matter (Lightbown 1992).

ROCK CRYSTAL AND GARNETS AS GEMSTONES

Rock crystal

Since the dawn of time, humans were accompanied by rock crystal and garnet. Rock crystal is a pure, transparent variety of quartz (SiO_2). It usually develops into well-formed crystals. The name "rock crystal" is derived from the ancient Greek word "krystallos" which means "clear ice". The ancient Greeks believed that the crystals formed high in mountains and froze to such a degree that they would not melt. Many gemologists maintain that it is difficult to find another stone, apart from diamond, which could be compared with rock crystal in terms of purity, transparency and shine. No wonder that in all times and among all nations rock crystal was often compared to diamonds and even was given the name of "diamond" with an extra geographical or other epithet, e.g., *marmaroscher diamenten*, *alecon diamenten*, *diamenten von Chôtelleraul*, *Bristol diamonds*, *Buxton diamonds*.

Thanks to its advantages – mainly purity and hardness – rock crystal since ancient times has been highly valued as an excellent material for artistic processing. Making use of all the properties of rock crystal resulted in extraordinarily beautiful effects in jewelry. In the past, the wares made of rock crystal were valued much higher than nowadays. The lapidaries, thanks to their knowledge of the optical properties of crystal (refractive index method), achieved excellent visual effects, sometimes also using natural inclusions in this mineral.

Rock crystal probably most often got the people's attention: it was found during excavations with the remains of the Peking Man (*Sinanthropus pekinensis*). The oldest known rock crystal products − a variety of dishes, jewelry as well as magnifying glasses and lenses − come from China (Sylwestrzak 2000). One of the oldest lapidary centers, about 1500 CE in India, dealt mainly with quarto gems (Rapp 2009).

A lot of information about appearance and processing of rock crystal is contained in *Historia naturalis* of Pliny. He listed crystallus from India, Asia Minor, Alabanda, Orthosia, Cyprus, the Alps and an island in the Red Sea (N. H. 36. 1-2, 198; 37. 23-29, 56, 77, 116, 123, 127, 129, 132, 136, 197, 204) (Rapp 2009).

In ancient Egypt rock crystal was used in many objects, such as seals, amulets, inlay vessels and figures (Rapp 2009). Various luxury stones were also used in the culture of Minoan Crete, because they were found during excavations at Knossos. These stones may have been exported throughout the Mediterranean World. There are also examples of the rock crystal use in Japan and North America. For example, natural rock crystals were used for ritual purposes by prehistoric people in California, beginning about 6500 years BC (Rapp 2009).

In Europe, rock crystal was also used since the appearance of the man. It was found in bottom sediments of the cave Altamira in Spain, famous for its paintings of the Magdalenian culture. In Moravia (Czech Republic), during Paleolithic there was a complete industry of mining and processing of rock crystal, based on the local quartz deposits, mostly pegmatitic (Mrázek 1996). In Poland, prehistoric rock crystal artifacts were found in Lower Silesia (Sachanbiński et al. 2008). In the 10th and 11th centuries in Wrocław, the rock crystal from Jegłowa was a basic raw material of which beads were grinded (Kaźmierczyk and Sachanbiński 1978).

The untrammeled growth of rock crystal grinding was observed in Europe between the 12th and 15th centuries. There were produced numerous ornamental objects, such as beautifully carved vases, pitchers, goblets, gems, stamps, cups, crystal balls and beads. Rock crystal was also grinded in a form of diamonds for use in jewelry. A separate group of objects made of crystal were those for liturgical purposes. The objects and their parts were firstly cut out of a single crystal, and then decorated.

In the 13th century, there had already existed some large craft centers of rock crystal grinding. The main sites of production were Venice, Catalonia, Germany (Kiel, Nuremberg, Freiburg) and Prague. In the Renaissance times the production developed first in Milan, and later in France (Paris), Germany (the centers already well-known in the Middle Ages plus Augsburg), Prague and Vienna (Hahnloser and Brugger-Koch 1989).

This industry was based on local deposits, which are particularly rich in the Alps (der Kanton Wallis, Dauphine, Département de I'Iseře), in voids of marbles in Carrara (Italy), in Normandy (France), the Harz Mountains, in the eastern Pyrenees, the Carpathians, the Czech Republic and Poland (Lower Silesia), England (Cornwall) as well as on the rock crystal imported from Brazil, Madagascar and the Ural Mountains.

Garnets

Garnets are one of the oldest mineral groups known and used by humans. All of them have the same crystal structure, more than ten are gemstones. Based on their chemical composition, color, density and light refraction coefficient, six major garnet varieties used by jewelers have been distinguished: pyrope, almandine, spessartite, grossular, andradite and uvarovite (W e b s t e r 1975), with pyrope and almandine being the most popular.

The name "garnet" probably comes from the Latin name of fruits of the pomegranate tree (Punica granatum), because of the similarity of the color and shape of the most common garnet varieties to the pomegranate seeds, or maybe from the word *garnum* (grain, seed). In antiquity and medieval times, rubies, red garnets and spinels were given a common name "carbuncles" from the Latin term *carbunculus* (meaning burning charcoal). This term was also used by Pliny to denote red almandine and other red stones.

Pyrope garnet $Mg_3Al_2[SiO_4]$ is usually blood-red but this hue may be tinged with yellow or purple. Its name is derived from Greek word for "fiery". For a long time pyrope has been called "carbuncle", for example by Pliny, who lists sources of this stone as India, North Africa, Caria, Ethiopia Miletus, Orchomenos, Chios, Corinth, Troezen, Marseilles and Lisbon (R a p p 2009). Current deposits of pyrope are localted in many countries, including the United States (Arizona, Colorado), Russia, Australia, Tanzania, Burma, Brazil and Argentina. However, the most important and famous deposits of pyrope are those in the Czech Republic – in the České Středohoři Mts (Třebenice, Podsedice, Dlažkovice and Měrunice localities).

The garnet group minerals, especially pyrope, are so widely used as gems because of their beautiful color and shine. Those with the highest quality of transparent color can be faceted as the process reveals the highest light reflection. The stones with little or no clarity can be made into cabochons. Garnets have been used in brooches, rings, and necklaces made of flat-cut beads (in the Bohemia probably since the 5^{th} century). They often occurred in the articles of jewelry of the Merovingian Dynasty (5^{th}-8^{th} centuries) (M r á z e k 1996).

According to Seifert and V r a ń a (2005), the Bohemian garnet has been known since the Middle Ages. In 1900 two bronze rosette jewels with garnet were found in the Třebenice village churchyard. They date as early as the 10^{th} or 11^{th} century. The archival records from the 15^{th} century mentioned the use of garnet in a bishop ring and a cross. At the same time, garnet was used in the production of a Gothic jewel called the Elisabeth Belt, which is kept in the town museum of Hradec Králové, as well as in the relics of Saint Vitus and Loreta treasures, such as Crucifixion, Pacification, Hungarian and Gothic chalices (S e i f e r t and V r a ń a 2005).

Garnet mining in Bohemia was first described by the "father of mineralogy" Georgius Agricola in his work *De Natura Fossilium* (1546). The emperor Rudolph II (1552-1612) was the admirer of the Bohemian garnets. During his reign, Prague was one of the most important centers for working with gemstones in Europe. Moreover, it was Rudolph's personal physician, Anselmus Boetius de B o o t (1609), who first used the term *Bohemian garnet*. In the 18^{th} century, Bohemian garnets were also processed in Germany – in Waldkirchenau near Freiburg and in Nuremberg. In the Baroque era, the industry of processing the Bohemian garnet shifted to the town of Turnov. At that time, about ten thousand people worked in the garnet industry. Garnets were often combined in jewelry objects with other local stones, like peridot or opal.

The greatest prosperity of the "garnet industry" was recorded in the Victorian times. In the 19^{th} century, a new riveting technology enabled the utilization also of smaller Bohemian garnets. They were set in rings, earrings, necklaces, brooches, pendants, diadems, hoods, and combined art pieces, often offered as valuable gifts to important persons, for instance Czar Nicholas (1833), Crown Prince Rudolph Habsburg (1871), Sarah Bernhardt (1888), British Queen Elisabeth II (1990) and Pope John Paul II (1993) (S e i f e r t and V r a ń a 2005).

Almandine ($Fe_3^2 + Al_2[SiO_4]_3$) is a deep red, brownish-red or brownish-black stone. Its color is similar to that of pyrope, however, the hue is more violet or more brown and usually paler than pyrope's. The name is derived from a town of Alabanda (currently in south-west Turkey), where the stone was found and mined. It is worth noting that almandine was the first used as a gemstone of all the garnets. The most important deposits of this garnet are in Afghanistan, Sri Lanka, India, Australia, Madagascar, Brazil, the USA, the Czech Republic, Burma, Russia and Romania. In the past, especially violet almandine was perceived as a highly valuable stone. Pliny lists a source for this mineral as Alabanda in Asia Minor (Pliny N.H. 36.62: 37.921, quot. from R a p p 2009). Almandine from the Egyptian Eastern Desert and the Sinai was used as early as the Pre-dynastic times. It appeared in ancient Greece and Rome after Alexander the Great's conquest of the East. Medieval Arab traders procured almandine form Afghanistan. In Mesoamerica, garnet was used as a gemstone and for mosaic inlays (R a p p 2009).

2. MATERIAL

The Poznań collection of decorative stones consists of 14 pieces (Tab. 1), with the predominance of artifacts made of rock crystal and carnelian (five items each), followed by garnets (two items) and single objects of agate and milky chalcedony. Ten objects were excavated in the nearest vicinity of the *palatium*, whereas four were found within the goldsmithery (Sachanbiński et al., 2008b).

Among the artifacts beads predominate (12 pieces), including six globular (Fig. 2 and 3) and six faceted (Fig. 4, 5, 6, 7). The two remaining include a garnet with the cabochon cut (Fig. 8) and a cone-shaped garnet (Fig. 9). It should be emphasized that the artifacts from rock crystal (Fig. 4 and 5) have the heptagonal outline. Besides, their girdles are thick. These features imply that they all originated in one workshop.

The carnelian bead is equally well-made (Fig. 7). It is elongated in the form of an octagonal pillar truncated bilaterally with the surfaces perpendicular to its elongation. The agate bead is characterized by the poorest quality of production (Fig. 6). It is more oval-shaped than the beads from rock crystal and the width of its side facets is shorter.

3. METHODS

The precious stones from the Poznań collection have been subject to gemological studies, carried out under a polarizing microscope Nikon Eclipse E 600 POL.

Next, the stones and the comparative standards, comprising pieces of a Czech rock crystal and garnets, were analyzed with a non-destructive method of Raman spectroscopy. Raman spectra were obtained in the Laboratory of Cultural Heritage Studies of the Chemistry Department at the University of Wrocław, using a spectrometer Horiba Yvon Jobin T64000 equipped with a confocal microscope (with 50× objective). The laser line at 514 nm of an Ar/Kr laser was employed for Raman excitation. The laser power at the exit was below 150 mW. The Raman spectra were dispersed using a diffraction grating (1800 lines/mm) and detected by a CCD camera. To separate the Rayleigh signal, the notch filter was used. The spectra were recorded in the range 100-4000 cm^{-1} with the spectral resolution *ca* 2 cm^{-1}. The integration time and a number of accumulations (minimum 2) were chosen separately for each sample.

For years the technique of Raman spectroscopy has been successfully employed for identification of microinclusions in gemstones. Its main advantage lies in its non-destructive character and in the fact that it does not require any special preparations of a sample. Hence, no harm is done to any object analyzed, which obviously prefers the method to the studies of gems. Minerals frequently contain fluid and solid inclusions, incorporated during the growth of the crystals at the particu-

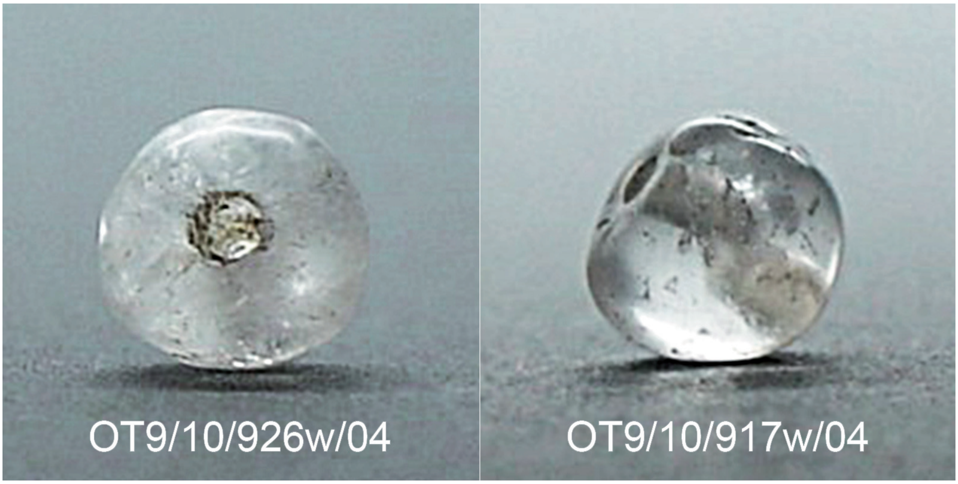


Fig. 2. Globular beads made of rock crystal – the Poznań collection

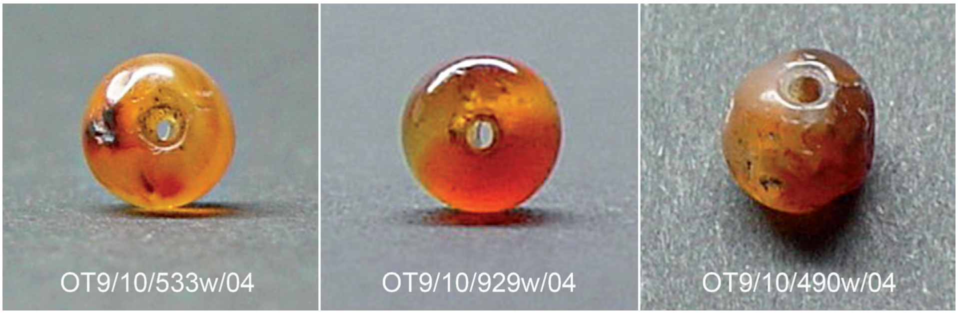


Fig. 3. Globular beads made of carnelian – the Poznań collection

lar pressure (P), temperature (T) and composition (X) conditions (R o e d d e r 1984; G ü b e l i n and K o i v u l a 1986; H y r š l and N i e d e r m a y r 2003).

The study of inclusions by micro-Raman spectroscopy is a common method to determine these P-T-X conditions (Z i e m a n n 2006), thus the data can also be used as fingerprints for mineral specimens of certain localities. A comparison of the inclusion parameters measured with corresponding data banks may give indications on the origin of the sample. This method becomes increasingly important for identifying the origin of uncut and cut gemstones (B e r s a n i and L o t t i c i 2010).

The data quoted in the literature (S a c h a n b i ń s k i et al. 2008a) showed that analyses using the method of Raman spectroscopy may be useful for the determination of the place of origin of artifacts from rock crystals.

Fig. 4. Faceted bead with the heptagonal outline made of rock crystal – the Poznań collection

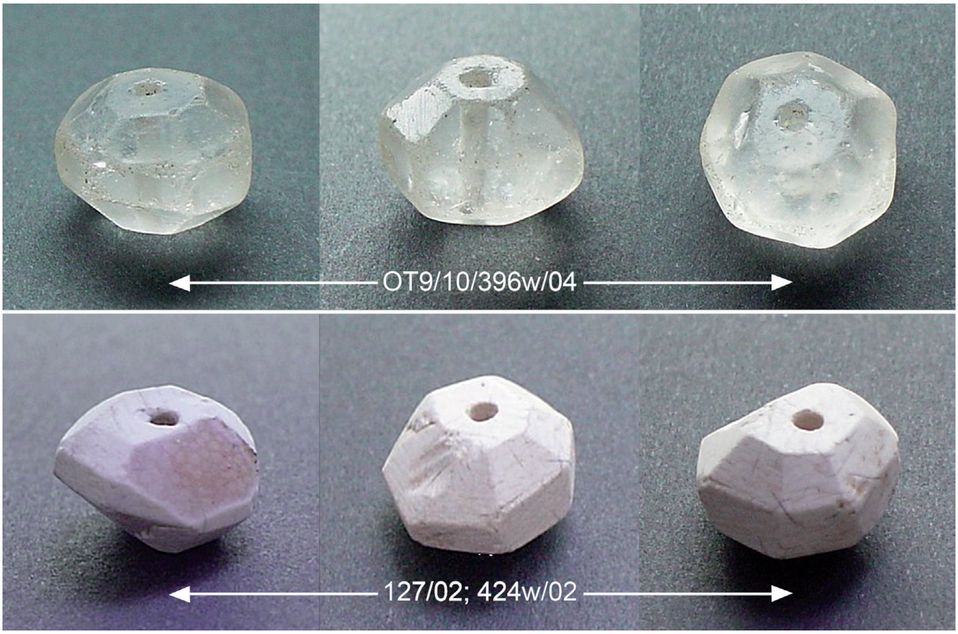


Fig. 5. Faceted bead made of rock crystal (top) and chalcedony (bottom) – the Poznań collection

Fig. 6. Faceted bead made of agate – the Poznań collection

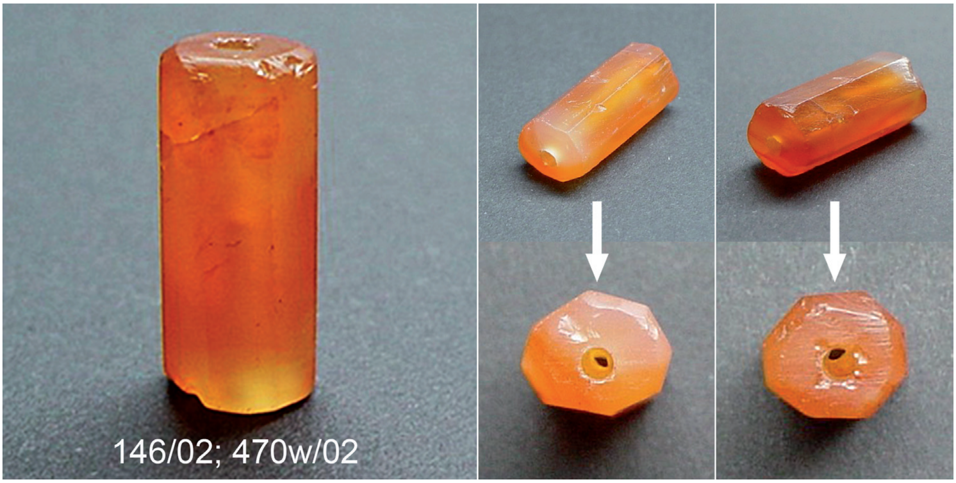


Fig. 7. Carnelian bead in the shape of the octagonal pillar – the Poznań collection

In order to identify the area where the minerals for the production of the artifacts from the Poznań collection were procured, the analysis of their Raman spectra were compared with the spectra of standards. Apart from the identification of the mineral material, the Raman analyses enabled recognition of characteristic inclusions in rock crystal and garnet.

Fig. 8. Cone-shaped cabochon made of the Czech pyrope – the Poznań collection, inventory number 433W/02

The method of examining the inclusions is based on the fact that they occur in all minerals. Their presence results from physical and chemical conditions of the environment of the minerals' crystallization. The analysis of inclusions provides information on the conditions of the minerals' formation and allows recognising inclusions characteristic for a given deposit (Sachanbiński et al. 2008a).

4. RESULTS AND DISCUSSION

First, inclusions were identified with a microscope. The microscopic observations have revealed that the beads from the rock crystal abound in liquid, gaseous and solid inclusions (Fig. 10). Since the microscopic examination enables only recognizing the kinds and the shapes of inclusions, their mineralogical identification was carried out with the micro-Raman method.

Fig. 9. Cabochon made of the Czech pyrope – the Poznań collection, inventory number 439W/02

4.1. Rock crystal artifacts

The results of the micro-Raman analysis show that the Poznań artifacts were made of the rock crystal (Tab. 2) that is characterized by the presence of gaseous and gaseous-liquid inclusions. The bubbles of CO_2 are frequent, while those of H_2O are rare (Fig. 11 and Tab. 2).

4.1.1. Origin of artifacts made of rock crystal

Due to the lack of occurrence of rock crystal in the area of Poznań, local jewelers had to utilize imported mineral raw materials. Deposits of rock crystal closest to Poznań are located in Lower Silesia, where prehistoric artifacts from this stone were produced in most cases from local stones, mostly from the Jegłowa-

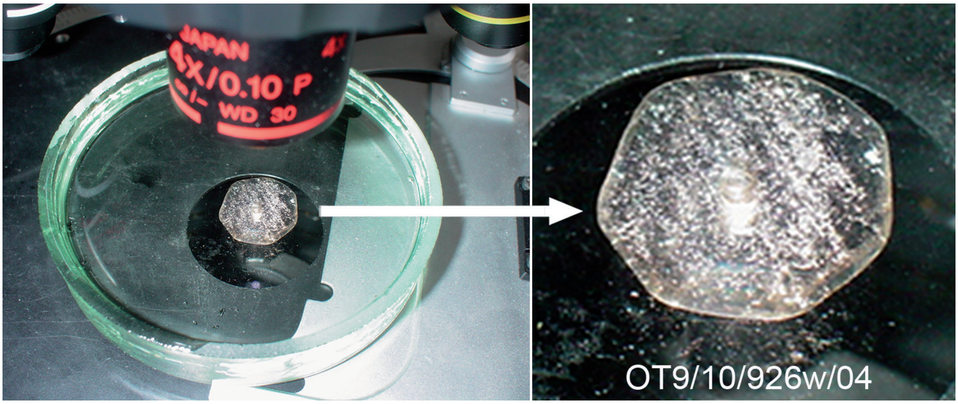


Fig. 10. Inclusions in the bead made of rock crystal – the Poznań collection, inventory number OT9/10/926W/04

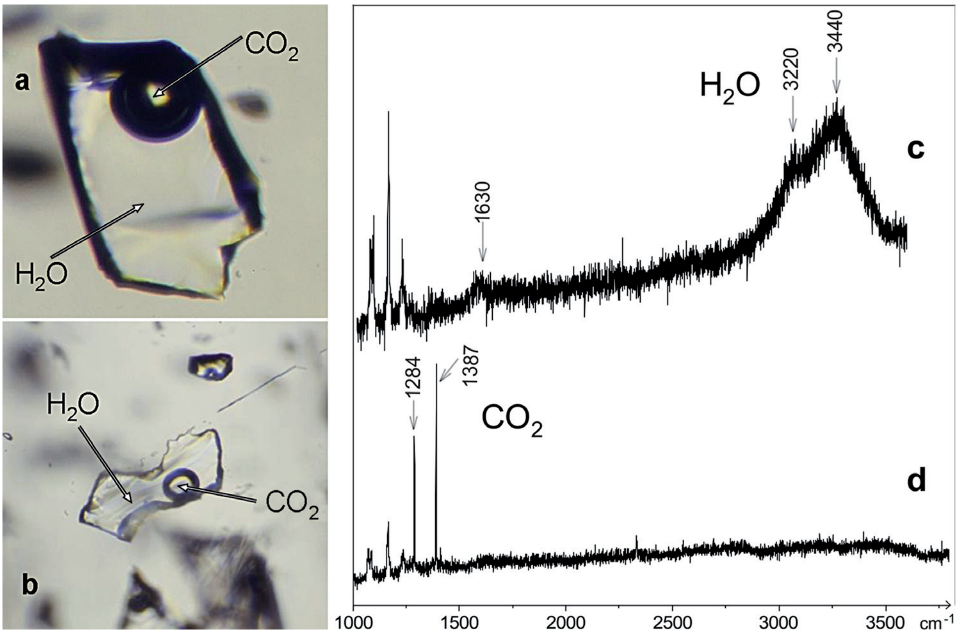


Fig. 11. Liquid-gaseous inclusions (A, B) in the bead made of rock crystal – the Poznań collection, inventory number OT9/10/176W/02
raman spectra of h2o (c) and CO2 (D) of the inclusions in the bead

Tab. 2. Comparison of inclusions in rock crystals from various deposits

	Inventory number	Artefact	Type of cutting	Type of raw material	Inclusions						
					Rock crystal from the Poznań collection	Lover Silesia				The Czech Republic	
						Jegłowa--Krzywina deposit (Sachanbiński et al. 2008)	Taczalin deposit (Sachanbiński et al. 2008)	Rozdroże Izerskie deposit „Stanisław” (Girulski 2011)	Kraków deposit (Girulski 2011)	Sklenĕ Ždar nad Sdzavou deposit	Ceskă Ves u Jeseniku deposit
1	OT9/10/40 9w/04	bead	faceted	rock crystal	CO_2, H_2O	anatase, chlorite, kaolinite, pyrite, Fe hydroxidate, hematite, H_2O gaseous, H_2O liquid	graphite, calcite, dolomite, ankerite, kaolinite, anhydrite, pyrite, hematite, goethite, manganite, CO_2, H_2O	hematite, chlorite, goethite, lepidocrocite, H_2O	calcite, ankreite, dolomite, H_2O	H_2O , CO_2, CH_4	H_2O
2	OT9/10/91 7w/04	bead	globular	rock crystal							
3	OT9/10/92 6w/04	bead	globular	rock crystal							
4	OT9/10/17 6w/02	bead	faceted	rock crystal							
5	OT9/10/39 6w/04	bead	faceted	rock crystal							

Krzywina deposit (Sachanbiński et al. 2008a). One of the biggest European gemstone workshops at the turn of the 10^{th} and 11^{th} century, situated at Ostrów Tumski in Wrocław and producing mainly items from rock crystal, also worked on the basis of this raw material (Kaźmierczyk and Sachanbiński 1978). However, the comparative analysis of the kind of inclusions and their Raman spectra occurring in the rock crystal from Lower Silesia and the rock crystal artifacts from the Poznań collection have revealed their significant differences (Tab. 2). Thus, the artifacts from rock crystal from the Poznań collection must have come from outside Lower Silesia.

Inclusions occurring in rock crystals from the Czech deposits were subsequently analyzed. It is widely recognized that already in the Paleolithic there existed in Moravia an entire industry of mining and working rock crystal based on local deposits, mostly associated with pegmatites (Mrázek 1996). As the comparative material from the Czech Republic, rock crystals from deposits in Sklené near Žďár nad Sázavou and Česká Ves in Jesenik were selected. Identification of inclusions in the Czech quartz (rock crystal) was carried out with gemological methods and micro-Raman spectroscopy (Tab. 2).

In the rock crystals from the Czech Republic, a great number of liquid-gaseous inclusions were identified. Particularly interesting and numerous liquid-gaseous inclusions, frequent of CO_2 and fewer of CH_4, occur in the rock crystals from Sklené near Ždár nad Sázavou (Tab. 2). As the analysis of Table 2 indicates, there is a similarity of inclusions in the artifacts from rock crystals from the Poznań collection to inclusions recorded in rock crystals occurring in the pegmatite from Sklené. The similarity is vivid in a great number of liquid-gaseous inclusions with the predominance of CO_2 and H_2O (Fig. 10 and 11). Hence a conclusion that artifacts from rock crystals from the Poznań collection were produced from quartz occurring in pegmatite from the area of the Czech Republic is justified.

4.2. Cabochons made of garnets

In the Poznań collection there are two special cabochons, blood-red in color, made of garnets (Tab. 1, Fig. 8 and 9). Their examination under polarizing microscope have revealed the presence of a number of inclusions. One cabochon (inventory number 439w/02) contains numerous inclusions of rutile and apatite (Fig. 12) and in spectrometry showed also the presence of magnetite inclusions (Fig. 13a).

In the cone-shaped cabochon (inventory number 433w/02), there is an inclusion of quartz surrounded by numerous strands of needle-like rutile (Fig. 14). The needle-like rutile inclusions are also visible farther from the quartz inclusion (Fig. 15).

Subsequently, garnets from the Poznań collection were examined with micro-Raman spectroscopy. Figure 16b shows the Raman spectra of the cabochon made of garnet. The spectra consist of a number of Raman lines, which location cor-

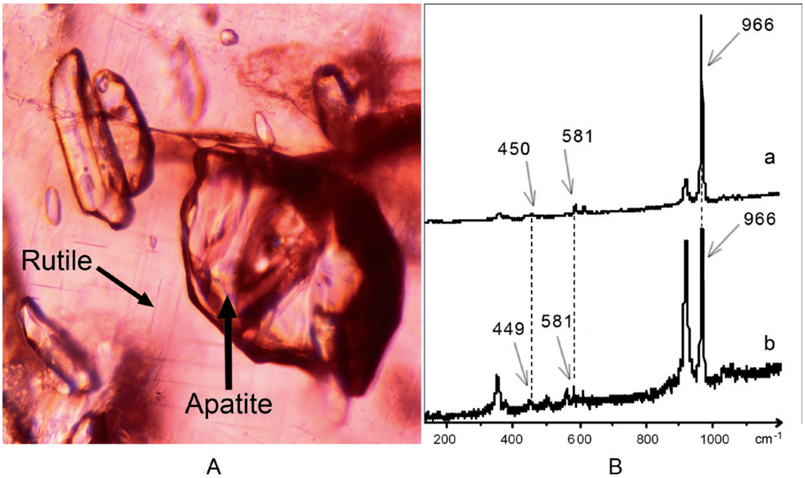


Fig. 12. A – Apatite and rutile inclusions in the pyrope cabochon – the Poznań collection, inventory number 439W/02
B – Raman spectra of apatite inclusions in pyrope:
a – Pyrope cabochon – the Poznań collection,
b – The czech pyrope – the village of vestřev near turnov in north-eastern Bohemia

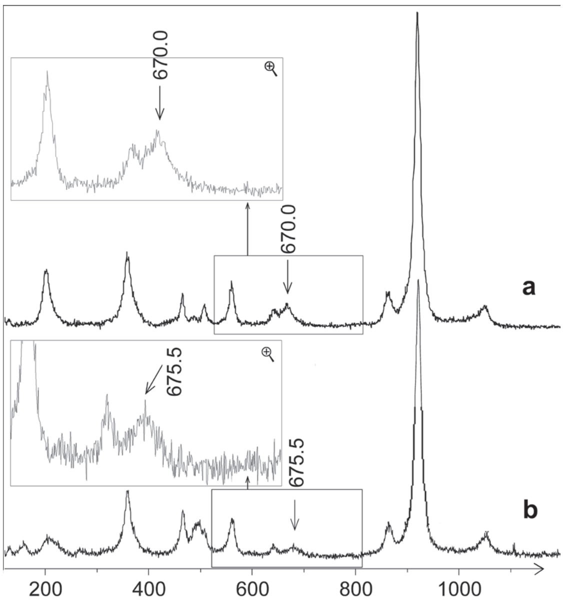
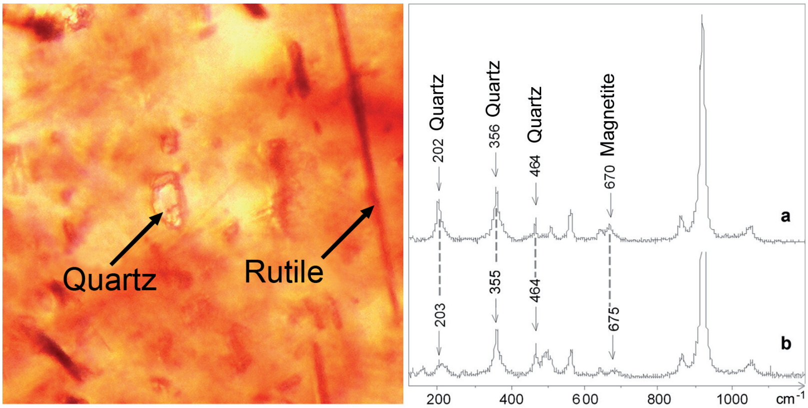
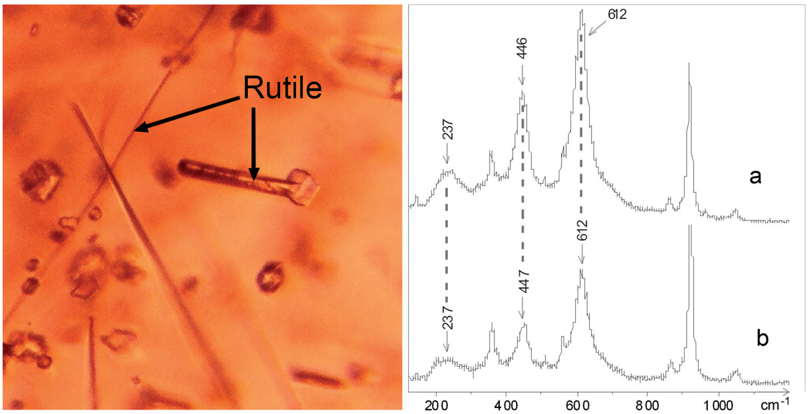


Fig. 13. Raman spectra of magnetite inclusions in pyrope:
a – Pyrope cabochon – the Poznań collection, inventory number 439W/02,
b – The Czech pyrope – the village of vestřev near turnov in north-eastern Bohemia



A B

Fig. 14. A – Quartz and rutile inclusions in the cone-shaped pyrope cabochon – the Poznań collection, inventory number 433W/02
B – Raman spectra of quartz inclusion in pyrope:
a – Cone-shaped pyrope cabochon – the Poznań collection, inventory number 433W/02,
b – The Czech pyrope – the village of vestřev near turnov in north-eastern Bohemia



A B

Fig. 15. A – Rutile inclusions in the pyrope cabochon – the Poznań collection, inventory number 433W/02
B – Raman spectra of rutile inclusions in pyrope:
a – Cone-shaped pyrope cabochon – the Poznań collection (inventory number 433W/02),
b – The Czech pyrope – the village of Vestřev near Turnov in north-eastern Bohemia

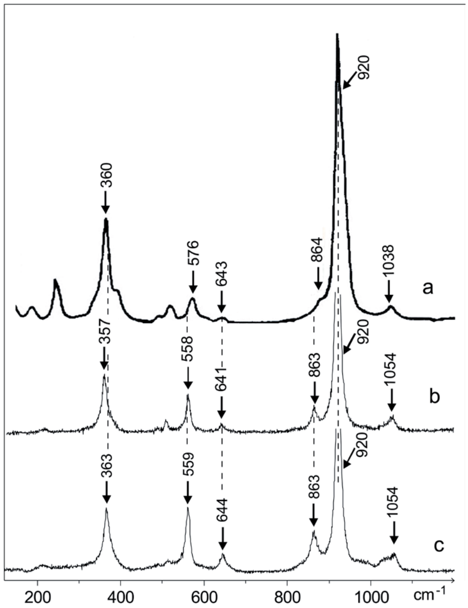


Fig. 16. Raman spectra of pyrope:
a – Pattern of pyrope according to mingsheng et al. (1994),
b – Cone-shaped cabochon made of a czech pyrope – the Poznań collection, inventory number 433W/02,
c – Pyrope – the village of Vestřev near Turnov in north eastern Bohemia

responds precisely to the lines of the pure pyrope (Mingsheng et al. 2008). Hence, cabochons from the Poznań collection can be identified to have been produced from the pyrope variety of garnets.

4.2.1. Origin of garnets

Already macroscopic observation of artifacts produced from red garnets have shown their similarity to the Czech pyrope, widely known in Europe. The majority of Czech garnet deposits belong to weathering deposits (alluvial, deluvial, proluvial) connected to various rock environment, hence some variations in terms of their physical and chemical properties and their presence of various inclusions (Ridkošil et al. 1997; Seifert and Vrána 2005). For the comparative analyses a few examples of red pyrope from a village of Vestřev near Turnov (NE Bohemia) were selected. In the pyrope analyzed, inclusions of rutile were identified (Fig. 15b) together with inclusions of apatite (Fig. 12b), quartz (Fig. 14b) and magnetite (Fig. 13b). A comparison of spectra of the pyrope samples from Vestřev

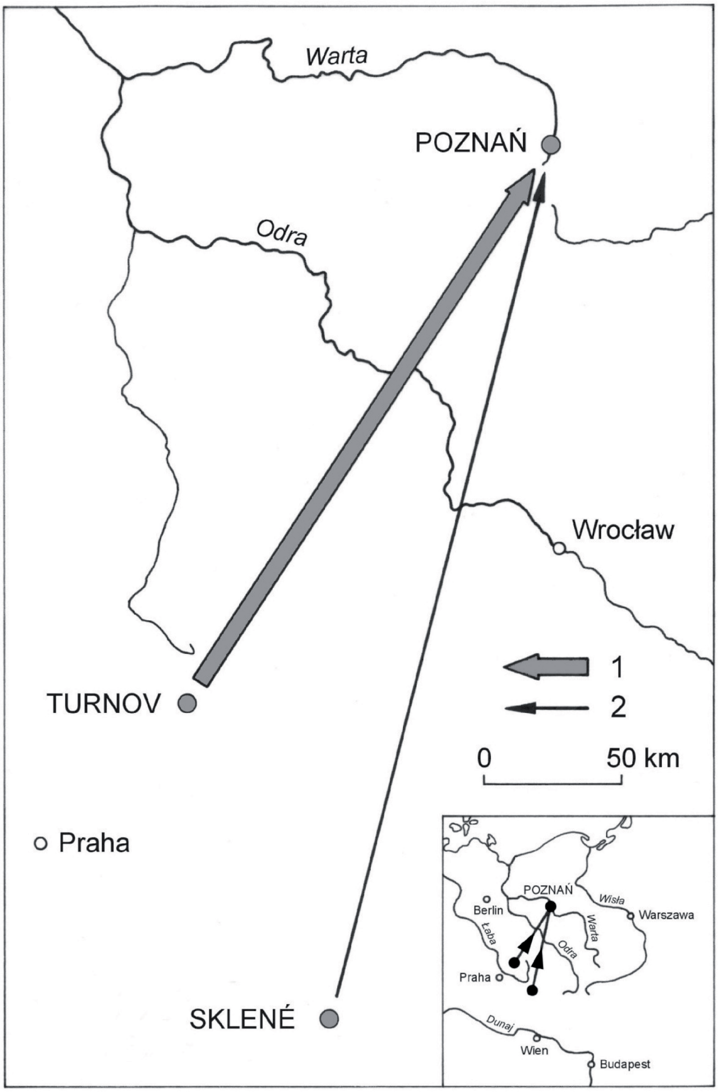


Fig. 17. Directions of distribution: 1 – garnets (pyrope); 2 – rock crystal

with those of the pyrope artifacts from the Poznań collection reveals that the Raman spectra have analogous bands situated at close frequencies (Fig. 16). Moreover, samples of the pyropes from Vestřev and the Poznań collection contain the same type of inclusions. All this proves that pyrope artifacts from the Poznań collection come from the Vestřev deposit situated near Turnov (Fig. 17).

5. CONCLUSIONS

The results of analyses using the micro-Raman method enabled identification of characteristic inclusions of apatite, rutile, quartz and magnetite in the pyrope from the Poznań collection and the pyrope from the deposit of the so called Czech pyropes from a village of Vestřev near Turnov (NE Bohemia). Thus, it has been possible to conclude that the pyropes from the Poznań collection were made of the pyropes mined near the village of Vestřev.

It has also been determined that the beads from the Poznań collection made of rock crystal come probably from the Czech pegmatite deposits, for example in Sklené (Žďár nad Sázavou District).

The conclusion that the early medieval inhabitants of the fortified Poznań settlement used precious stones: pyrope (a garnet) and rock crystal, imported from distant Bohemia, may be used in discussing the localization of the remaining three types of stones of the collection. Although, unfortunately, it has been impossible to identify precisely the place of origin of agate, carnelian and chalcedony, it is plausible to assume that they could have been made of stones from deposits also located in Bohemia, near the Karkonosze Mountains (currently in the Czech Republic).

It is worth mentioning that the majority of artifacts from the Poznań collection come from a workshop of high craftsmanship; the artisans were skilled in stone cutting techniques.

What has been written above allows drawing several important conclusions concerning Poznań and its cultural contacts in the early medieval times, i.e., the times when Poznań was the main seat of the first rulers of the Polish Piast dynasty. During the reign of Mieszko I (d. 992) the stronghold in Poznań was given a form of a four-part complex, with a ducal residence surrounded with ramparts. Mieszko's first Christian wife was a Bohemian princess Dobrawa (d. 977). As it was entered in chronicles, she arrived to meet Mieszko in 965, accompanied by secular and sacral nobles, and surly also by other people providing various services. According to the results of analyses of the evidence, the latter included also a professional jeweller, providing in his workshop jewels for the princess and her court. He manufactured gold objects/goods decorated with precious stones imported from Bohemia. It seems also possible that such Bohemian-style jewels might have influenced the stylistics of the jewellery popular within the Piast-ruled state.

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