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ULRIKE SOPHIE VON LEVETZOW´S JEWELS COLLECTION: IDENTIFICATION AND RESTORATION

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Abstract
The precious jewels collection of Ulrike von Levetzow was thoroughly studied and restored. The collection consists of a multi-row necklace, paired bracelets, a ring, two earrings and a belt buckle stored in an original etui. Besides the high quality of manufacturing of all pieces, the main value consists in used materials. The collection was made of 469 pieces of unusually big Bohemian garnets (chrome pyropes), which were bigger than 8 mm. Usually, Bohemian garnets are smaller than 3mm. Moreover, the jewels were made of high purity gold (up to 22.5 carats) which was revealed by XRF analyses. The collection was deeply investigated. The gemmological survey was comprised of a study of inclusions and a refractive index, Raman and UV-VIS-NIR spectroscopy. All of the methods confirmed that the whole collection was made of Bohemian garnets from the Třebívlice area Central Bohemian Uplands. In pursuance of the restoration, it was necessary to make 7 new beads. First of all, we were searching for the most expedient technique to make new beads because the original manufacturing techniques are not known, or the tools were lost. Subsequently, many ways of drilling and cutting of garnets were tried and the best one was used for making of new beads. Of course, the etui was restored, as well.

Keywords*: Bohemian garnet; Jewel; Inclusion; Raman spectroscopy; UV-VIS-NIR spectroscopy, XRF*

Introduction

The jewels collection of *Theodore Ulrike Sophie von Levetzow* (* 4th February 1804 – † 13rd November 1899) was probably made at the turn of the 18th and 19th century [1-3].

It is a high-quality unique set of jewels. Its value consists in high quality processing as well as in the size of the Bohemian garnets used. Usually, Bohemian garnets are smaller than 3 mm [4, 5] but in this case beads of size of almost 1.0cm were found (Table 1). The whole collection is composed of a multi-row necklace, paired bracelets, a ring, two earrings and a belt buckle in original etui (Fig. 1).

Originally, the *Franz Joseph Count of Klebelsberg-Thumburg* gave the jewels to his wife, Meclenburg noblewoman Amalie von Klebelsberg as a wedding present in 1843. Ulrike von Levetzow (known as the last love of the poet J.W. Goethe) inherited the collection after her mother Amalie in 1868 [2-5]. The first proof of the existence of necklace and bracelets comes from 1806 when the jewels were marked by re-hallmark [6, 7].

Whole collection seems to be made from Bohemian garnets. Because of extraordinary size of all stones the whole collection was searched to confirm or disprove if the collection is made from real Bohemian garnets, from different type of garnets or some fake materials.

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Fig. 1. Complete jewels collection of Theodore Ulrike Sophie von Levetzow
(Necklace, two bracelets, ring, belt buckle and two rings)
in the original etui after the restoration (photo P. Škácha)

Bohemian garnets were often imitated by many other materials of similar colour, mainly with glass and other types of garnets (e.g. pyrope, almandine) or with synthetic materials (e.g. synthetic cubic zirconia ZrO_2, corundum Al_2O_3, spinel $MgAl_2O_4$). These materials were used because the original Bohemian garnet are quite small (generally under 5 mm) while the other granates can have bigger size. Next reason of counterfeitening is price. Bohemian garnets are still quite expensive (mainly the bigger ones) while other materials are cheaper [8, 9].

Bohemian garnets just as other geological materials have many specific properties, e.g., refractive index, birefringence, optical properties, reaction under absorption Hanneman ruby filter and Chelsea filter, UV luminescence or size of the raw grains. All these basic parameters or methods are usefull for identification of Bohemian garnets. Except of material identification, it is possible to determine the specific place of origin based on the inclusion study [8, 10].

Of course, chemical composition is determinable but destructive methods are used so it is not useful or practicable in conservation of jewels. Moreover, the chemical composition of Bohemian garnets is very similar and it is not possible to determine the geological origin of the garnets only based on the chemical composition [8].

The group of garnets contains almost 30 types of minerals and their general formula is $^{[8]}X^{2+}{}_3{}^{[6]}Y^{3+}{}_2(^{[4]}ZO_4)_3$. The most frequent garnets are pyropes ($Mg_3Al_2(SiO_4)_3$) or almandines ($Fe_3Al_2(SiO_4)_3$). In case of pyrope, part of the Mg^{2+} ions can be replaced by Fe^{2+} and Ca^{2+} and part of the Al^{3+} can be replaced by Cr^{3+}. The chromium causes the typical bloody red colour of Bohemian garnets. In case of almandine, the red colour is caused by Fe^{3+}. Almandine was used very often for making of the jewels and can be misdiagnosed as Bohemian garnets [5].

Pyropes containing chromium are signed as chromium pyropes (Cr-pyropes) and they occure only in a few localities in Czech Republic, Unated States (Arizona), Tanzania and Russia (Yakutsk) [11]. In the Czech Republic, the Bohemian garnets used as gemstones occure only in the three regions – Central Bohemian Upland (in the surrounding of the Třebívlice village), Bohemian Paradise and Giant Mountains foothill (around Vestřev village) and last deposite is around the town Kolín [4, 10].

The Bohemian garnets are considered as national gemstones and they have been widely used in goldsmithery. Nowadays, the stones bigger than 5 mm are considered as rare and the stones bigger than 6mm are extremely rare and expensive. Because of their rareness and price, they are often replaced with similarly coloured Cr-pyropes (mainly from Tanzania and Russia), with other types of pyropes (e.g. from Mongolia, Thailand or Nigeria) or with cheaper almandines. Arizonian Cr-pyropes (so called anthill garnet) have not been industrially mined and used in goldsmithery. Cr-pyropes from Yakutsk and mainly Tanzanian ones are more often in goldsmithery. Their size is 5–8 mm so they have been used as imitation of Bohemian garnets [11].

During the restoration it is necessary to know which material was used, which material should be use or if the restored object was repaired in past or if it is not counterfeit [11]. That's why, the identification pyropes type using physical-chemical methods should be very helpful for jewels restoration process.

Sorting of the Cr-pyropes according to geographic origin is feasible due to different refractive index, UV fluorescence, chromium content and by UV-VIS-NIR spectra. Determination of specific origin within Czech Republic is possible based on the different shape and composition of inclusions [10, 11].

The UV flueorescence is suitable to recognise of garnets and glass imitation. Garnets are inert under UV light while the glass beads (widely used in historical goldsmithery) evince fluorescence in short-wave light [11].

The refractive index helps us distinguish pyropes from other type of garnates, but it does not help distinguish the proveneance. Generally, pyropes have refractive index (n_D) 1.740–1.755 and namely the Bohemian garnets have n_D 1.748–1.755 [11].

Qualitative determination of chromium content is possible by Raman spectroscopy. Cr-pyropes have five charactesistic peaks in the range ~4160–4420cm^{-1} which came from chromium ions [11].

UV-VIS-NIR spectroscopy is method usefull to distinguish Bohemian garnets (Cr-pyropes from Czech) and Cr-pyropes from other localities. Bohemian garnets have highly specific spectra where only one absorption maximum at 575nm is observed. Contrary to that, other Cr-pyropes from Arizona, Tanzania and Yakutsk have similar spectra. In those cases, two maxima at 445 and 575nm are observed. The spectrum with only one absorption maximum at 510–540nm belongs to the pyropes without chromium [11].

One of the basic gemological techniques is inclusion study. The Cr-pyropes inclusion greatly differ each other depending on proveniance. Due to the shape and composition of inclusions it is possible to determine specific origin of the gemstone [11].

The combination of all above mentioned methods helped us exactly determine the origine of each studied bead. It is possible to sign the gemstone as Bohemian garnet if: the refractive index is 1.748–1.755, contains chromium, does not have fluorescence under UV light, has only one absorption maximum around 575nm in UV-VIS-NIR spectrum and has the typical shape of inclusions [4, 5, 9, 11].

Mainly the beads bigger than 4 mm should be precisely searched to affirm or disprove their composition and proveneance as it was done in this study [11].

Moreover, seven beads losted from the necklace in the past, had to be made newly. It means that the way of the original garnets cutting and drilling had to be found first. Afterwards, new beads were prepared and the collection could be completely restored.

Materials and methods

Methods of the material investigation

Fluorescence

Beads were observed under incident and reflected light using Hanneman absorption ruby filter and under UV light (254, 366 and 400nm) to preliminary material determination. In total, 350 pieces of beads were examined.

Comparative material

Original beads were compared with standards of Bohemian garnets from Podsedice and Třebívlice area (Central Bohemian Upland).

Study of the inclusions

For the inclusion study a gemmological microscope OptiGemII and a gemmological stand microscope (own design) with darkfield, transmitted, reflected and UV light (UVLW 365 nm) were used. Inclusions were studied especially in drilled stones.

Measurement of refractive index

The refractive index n_D was measured using a gemmological refractometer with range 1.30–1.81 n_D. Methylene iodide saturated by sulphur and stabilized by copper (n_D 1.790) was used as an immersion liquid. Because of the methylene iodide toxicity, it was necessary to wash each bead with acetone or toluene after measurement.

Raman and photoluminescence spectroscopy

The measurement was performed using a GL Gem Raman PL532 spectrometer equipped with a Nd:YAG laser using a second harmonic frequency (532nm ~ green laser). The spectrometer was coupled with a Toshiba TCD1304AP detector (CCD 3648 pixel, 8 × 200μm). The spectral range was 100–5540cm^{-1} and the resolution were 10cm^{-1}. The diameter of analysed points was 10–15μm with 10-fold magnification.

UV-VIS-NIR spectroscopy

UV-VIS-NIR spectroscopy was done by the GL Gem Spectrometer with spectral range 300–1000nm. The spectrometer was coupled with Toshiba TCD1304AP detector (CCD 3648 pixel, 8 × 200μm).

X-ray fluorescence (XRF)

The X-ray fluorescence device was equipped with a micro focusing X-ray tube X-Beam: Power flux (XOS) and a semiconductor detector SDD (Amptek). The diameter of a measured point was 0.1mm, voltage was set to 50kV and a current of accelerated electrons was equal to 0.2mA. The characteristic radiation from each measured point was recorded for 1 minute. Obtained data were assessed by a WinAxil software. The total number of measured points was 109.

Optical microscopy

An optical microscope LEICA MZ75 and a FTIR spectrometer Nicolet type IMPACT 400 were used for textile strings determination.

Experimental production of new beads

Comparative and testing material

All technological steps were firstly tried and verified on experimental Cr-pyrope and pyrope-almandine testing samples from Tanzania. These testing samples were chosen because their physical and mechanical properties are almost identical with properties of Bohemian garnets. Moreover, Tanzanian Cr-pyropes are much cheaper than Bohemian garnets and their size is comparable with grains used on the jewels. When the drilling and cutting technologies were mastered, the seven new beads from Bohemian garnets were made for the completion of the necklace.

Study and documentation of original and newly made beads

The beads were studied and documented by an OptiGemII gemmological microscope, by a polarizing microscope (Leica) and by a gemmological stand microscope (own design) with darkfield, transmitted, reflected and UV light (UVLW 365nm).

Drilling technique

Several methods of drilling were proposed: (a) drilling by a diamond bit, (b) drilling by a tubular diamond drill, (c) drilling by an ultrasonic drill, (d) ultrasonic drilling with subsequent wiping off the drilled trace by a tubular drill, (e) drilling by a dental diamond bur-drill.

Cutting technology

The beads were cut using an original table cutter (more than 100 years old). The machine equipped with sand grinding stone using and all-wooden quadrant (approximately 150 years old) was used.

Polishing

Polishing was performed by a tin (Sn) polishing disc. A water suspension of aluminium oxides (Al_2O_3) was used as a polish.

Results and Discussions

Art-historical research

The great collection of jewels (Fig. 1), so-called parure, is placed in an original etui and it consists of 462 pieces of extraordinary big (Table 1) garnets, probably Bohemian garnets. It follows from the historical research that seven beads from necklace were lost in past. Originally, the collection contained 469 pieces of gemstones signed as Bohemian garnets. All parts of the parure are typical case of Empire style jewels [12]. The style of jewels is not uniform which indicates a different period of origin.

The number of gemstones was re-counted. Each piece of jewel was weighed, and all garnets were measured. The results are listed in Table 1.

Table 1. The characteristics of individual pieces of the collection

Jewel	Weight (g)	Number of garnets (pieces)	Size of garnets (mm)
Necklace	141.30	331 + 1	Beads: 7 – 8 × 5 – 6.5 Cap: 9.8 × 7.8
Bracelet 1	26.30	60 + 1	Cap: 8.5 × 7
Bracelet 2	25.70	60 + 1	Cap: 7.5 × 6.8
Belt buckle	9.50	3	7.8 × 6.5; 8 × 6.3; 7 × 6.5
Ring	2.80	1	7.6 × 6.9
Earrings	11.60	4	7.5 × 6.4; 8 × 7

It seems to be clear, that beads were cut in two ways at least (Fig. 2). It is possible to find tiny differences on the facet’s distribution (Fig. 2). Similarly, the way of beads drilling is different. Most of them are drilled through only from one direction as was typicall at the turn of the 18th and 19th century [13]. Several beads were drilled in a different way. It is obvious that these beads were drilled from both of the opposite sides and drill holes meet each other in the middle of the bead. Nowadays this way of drilling is common. Because of two ways of cutting and drilling, it is possible to say that the garnets come from several older jewels. The garnets were probably not found at the same time. Due to the size of the garnets, it is presumable that garnets were being collected for very long time. The beads size is from 5mm to almost 1cm (Table 1). Average size bigger than 5mm is considered as rare as we mentioned above.

The multi-row necklace is formed of five rows (Fig. 1) of drilled, irregularly cut, egg-shaped or spherical Bohemian garnets. The necklace rows consist of 332 pieces of garnets (originally it consisted of 339 beads) ended by golden tubes fastened to the decorative clip. The clip has a rectangle shape with a bevelled frame. The red elliptical facet garnet is set up in the centre of the cap. The radial rim of the garnet and the frame of the cap features are typical for the Empire style jewels [12]. The re-hallmark „B“ (Fig. 3) is visible on the fastening. This type of re-hallmark was used for golden objects in Prague only in 1806-1807 [6, 7].

Two paired bracelets are visually the same (Fig. 1). Both of them consist of three rows of garnets ended with golden tubes in the same way as the necklace. Each row contains 20 beads, it means there are 60 beads for each bracelet (Table 1). The beads are of the same shape, size, cut and quality as the stones of the necklace. The re-hallmark „B“ (Fig. 3) is visible on the both fastening as well. Because of these similarities, it can be supposed that the bracelets and the necklace were made at the same time.

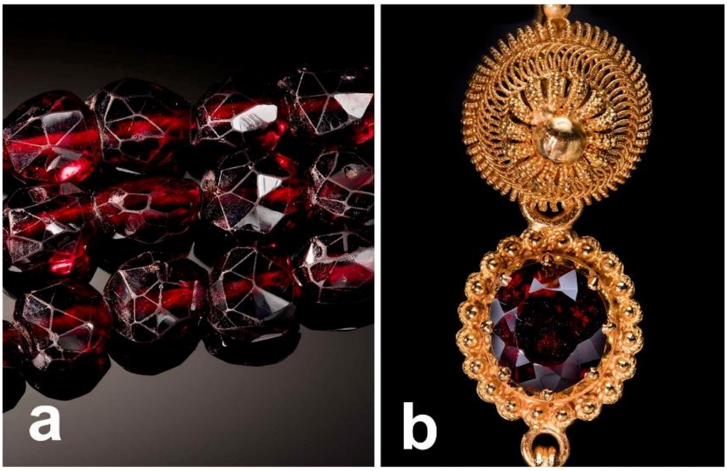

Fig. 2. Different way of cutting: a) bracelet; b) earing – precisely cutted and polished pyropes (photo P. Škácha)

Fig. 3. Re-hallmark "B" on the fastening of the bracelet 1 (photo R. Hanus)

The *buckle* (Fig. 1) is composed of three rosettes. All rosettes have the same framing as the necklace and bracelets fastenings. Garnets are inserted into the centre of each rosette and the technique of cutting and setting up is identical as in the case of the necklace and bracelets. The buckle does not have a hallmark.

The cannetille technique [12] was used for the *ring* (Fig. 4) production. The collet with garnet is on the top of the ring. The facets are elliptical. This garnet is extraordinarily scratched (Fig. 4) and it is the most damaged piece of the whole collection. In contrast to the garnet, the metal part of the ring does not have almost any defects. The hallmark absence points out two teories. According to the first one is possible that the ring is newer than necklace and bracelets. The second theory follows from the damage of the garnet. It is presumablethat the ring was seriously damaged, so the gold part of the ring was made newly.

Fig. 4. The extraordinarily scratched garnet (photo P. Škácha)

The earrings (Fig 1) differ from the rest of the collection. They are made in a pendeloque style [12] and they are composed of more parts. The quality of garnet cutting is perfect being much higher than the cutting quality of the rest of garnets (Fig. 2). There is no evidence of a damage on the facets. The earings, as well as ring and bucle, do not have a hallmark. It is beyond doubt that the earrings were created later than the rest of the collection. They are technically faultless and they appear to be a work of Italian jewellers who imitated ancient jewels [14, 15].

Gemmological research

As first, beads fluorescence was observed. The colour and fluorescence characteristics of all drilled grains are identical, so we presumed that the collection was made from the single material instead of a mixture of different materials, e.g. glass or other garnets [16, 17].

The refractive index n_D measurement is one of the most essential methods in the research of the gemstones. It is possible to determine if the material is pyrope or another material. The method is not helpful for determination of the Cr-pyropes proveneance because values of n_D are very similar. The refractive index value of Cr-pyropes is 1.74–1.755 when n_D of Bohemian garnets is 1.748–1.755 [10, 11, 18, 19].

It was not possible to measure all gemstones because of a poor cutting or an improper geometry of the measured grain. In total, 93 pieces of cut and drilled garnets were measured. All studied pyropes had refractive index value in the range of 1.748–1.750 which is in compliance with values for Cr-pyropes. On the grounds of the results, it is possible to say that the whole collection was made from Cr-pyropes.

Raman spectroscopy is a suitable method for material analysis of garnets. It is possible to detect the presence of chromium which is a characteristic element contained in Bohemian garnets [20].

The wavenumber at 100–1500cm^{-1} is important for material distinguishing (glass, pyrope) while the region at 4000–4500cm^{-1} is crucial to detection of the Cr^{3+} The typical wavenumber of chromium is at ~ 4160 and 4420cm^{-1}. Raman spectroscopy immediately uncover the basic composition of the garnets including the Cr^{3+} presence. For instance, similarly as Bohemian garntes ruby coloured pyropes from Mongolia, pyrope-almandines from Tanzania, Mosambique or Madagascar, do not contain Cr^{3+} so they have different Raman spectra [20].

The figure 5 shows that Raman spectra of measured beads are completely coincident with the spectra of Bohemian garnets standard from Třebívlice area. From the spectra, it is evident that gemstones contain Cr^{3+}. We confirm above statement reached from measurement of refractive index that measured gemstones are Cr-pyropes.

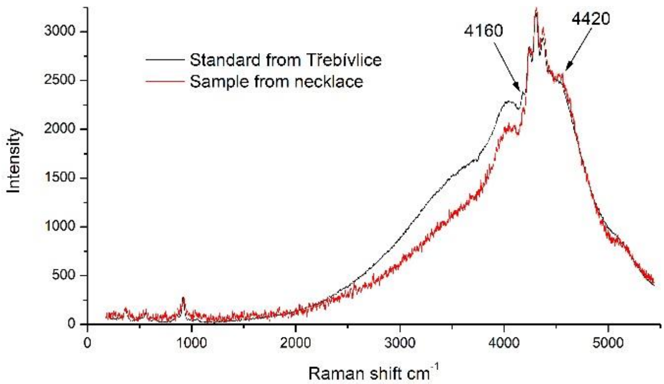

Fig. 5. Raman spectra of Bohemian garnets standard from Třebívlice area and one representative bead from necklace of collection of Ulrike jewels

Above mentioned methods are useful for certifying or distinguishing of Cr-pyropes from different materials. Unfortunately, the methods are not helpful to determine specific place of origin. For determination of proveneance the UV-VIS-NIR spectroscopy can by utilize. This type of spectroscopy is an essential method for the detection of the chromophore element in the crystalline structure. According to shape of the spectrum and the position of absorption maxima is possible to ascertain the garnets origin. Pyropes without Cr^{3+} content evince only one maximum in range 510–540nm. Cr-pyropes from Arizona, Tanzania and Yakutsk evince very similar shape of absorption curve with two maxima at 445 and 575nm. Bohemian garnets (Cr-pyropes) absorbance maxima occur at 575nm. Moreover, this type of Cr-pyropes have small minima at 678–688 nmm [10, 11, 20].

As it was mentioned above, all stones have a visually identical colour as Bohemian garnets and as we confirmed above, all measured gemstones are Cr-pyropes. All the measured stones have almost identical spectra with only one maximum at 575nm. Obtained values are comparable with the standard (Fig. 6) of Bohemian garnet from Třebívlice area (Central Bohemian Uplands region). Also, small minimum at range 676–688 was found in case of all samples. Method can be employed for distinguishing of the Czech Cr-pyropes (Bohemian garnets) from other ones. UV-VIS-NIR spectroscopy is not suitable to distinguish localities within the Czech Republic.

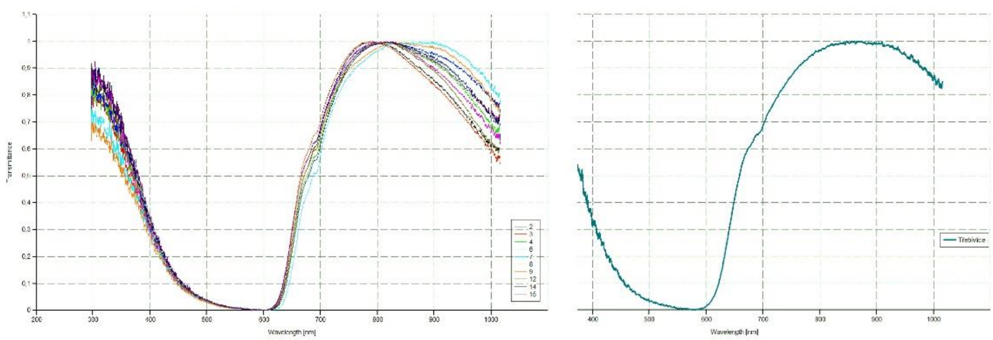

Fig. 6. UV-VIS-NIR spectra of Bohemian garnet standard from Třebívlice (right) and beads from bracelet 1 (left)

Each type of a pyrope has characteristic *inclusions* (shape and composition) depending on the place of the origin. Except of the origin, inclusion study can reveal if the garnet is natural or synthetic [9, 20].

As was mentioned in Introduction, in the Czech Republic the Bohemian garnets are found at three locations (Fig. 7e). Garnets from each locality has different shape and composition of inclusions. Because of that we are able to determine the specific origin almost each Bohemian garnet. Inclusions of Bohemian garnets from the region of Central Bohemian Uplands (Třebívlice) are described as a "squashed fly" (Fig. 7c). They are made by tension cracks of zircon while rutile needles are not present. Bohemian garnets from Kolín area contain higher number of inclusions. They are made by ilmentite, olivine, spinel, apatite and mainly by rutile. The inclusions create tiny needles ordered often into the characteristic lattice (Fig. 7a). Tha last region of the Bohemian garnets mining in CZ is area of the Bohemian Paradise and the Giant Mountains foothill. Inclusions of this type of garnets are created with small empty cavities (Fig. 7b) [8, 10, 20].

As one can see from the figure 7, the shape of inclusions in searched garnets (Fig. 7d) is typical for Bohemian garnets from the Central Bohemian Uplands (Fig. 7c). It looks like "squashed fly" [10].

We confirmed that inclusion study is one of the most essential and important gemmological methods utilize for the Bohemian garnet's origin determination.

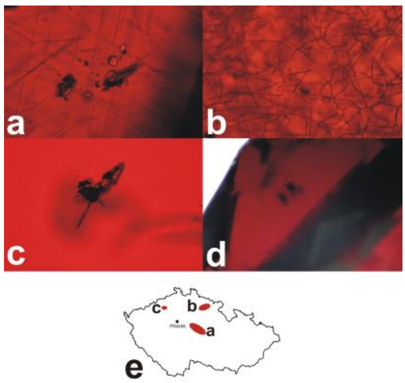

Fig. 7. Inclusions of Bohemian garnets:
a) standard from Kolín region in the Central Bohemian region;
b) standard from foothills of Krkonoše;
c) standard from Třebívlice (Central Bohemian Uplands);
d) inclusion inside one of the beads from the collection;
e) map of the Czech Republic with the localities of pyrope deposits were letters are equivalent of localities (photo R. Hanus)

Except of the gemstone deep study, we focused on the characterisation of metal parts of jewels as well. *The XRF* technique was chosen because of its non-destructivness, very low limit detection and accurency which allows us very precise determination.

Based on the previous literary research [4, 12, 14, 21, 22], we presumed that all metal parts of the jewels should be made of gold. Täubl [1] describes in his study that the 18 carats gold (750/1000) was used. His conclusion is based on so-called „scratch" test. However, different conclusion can be deduced from the re-hallmark „B" (Fig. 3). This hallmark had been used for golden objects in Prague (CZ) in 1806–1807. A patent of the emperor Joseph II. defined the legal purity of gold subsequently: 767/1000 (18 carats + 5 grains), 545/1000 (13 ct + 1 gr) and 326/1000 (7 ct + 10 gr) [6, 7].

XRF analysis revealed the content of gold, silver, copper etc. It is necessary to consider, that the results are only semi-quantitative because the analysed area was very small and in many cases the surface was uneven. The determined element content can be thus influenced negatively by these hardly definable conditions. Table 2 shows an average content of metals for each of the jewels.

XRF analysis confirmed the previous presumption, that the metal parts are made of gold, respectively from alloy composed of gold, silver, and copper. Only in the case of the one necklace spring bar (point 103) was found out an iron-nickel (Fe-Ni) alloy. It is probable that the necklace was damaged, and the spring bar was destroyed or lost. Afterwards, the golden spring bar was replacement with new one wich was made from cheaper Fe-Ni alloy.

Obtained results show (Table 2) that the collection was made of a gold alloy of a high purity. The lowest purity (19 ct) was found in Bracelet 1 while the highest purity (22.3–22.5 ct) was determined in the case of Earrings. It means that earings were made almost from pure gold (which purity is 24 ct).

Table 2. Average content of each metal, purity of alloy and purity of alloy in carats

	Purity*	**Purity (carats)**	**Average content of metal in w%**		
			Au	**Ag**	**Cu**
Necklace	869/1000	20.84	86.91	11.05	8.30
Bracelet 1	796/1000	19.09	79.59	13.67	17.43
Bracelet 2	862/1000	20.67	86.23	10.48	6.84
Belt buckle	913/1000	21.89	91.33	2.42	4.9
Ring	908/1000	21.77	90.84	7.52	3.63
Earring 1	930/1000	22.30	93.03	1.96	3.2
Earring 2	938/1000	22.49	93.81	1.54	3.64

*Note: The first number corresponds to the number of gold parts. Number of rest parts to the 1000 is composed from silver and/or copper. For instance, in case of necklace, the alloy is composed from 869 parts of gold and 131 parts of silver and copper.

Making of new beads

As was mentioned above, seven beads from necklace were lost in past. We decided (after the discussion with owner) that we make new beads for completation of the necklace. This step was great challenge because nowadays, technologies of drilling and cutting are different. Moreover, it took a few years to reach seven new Bohemian garnets of adequate size. Both processes were risky and we had to eschew injury of new garnets. Firstly, we had to mastered both technologies (drilling and cutting). For these purposes, testing materials from pyrope-almandine and Cr-pyrope were used. The seven new Bohemian garnets were drilled and cut only when both steps were mastered.

All beads from the necklace were investigated using microscope to obtain detailed information about technology used for their production in the past.

We found out we are not able to ensure the identical technology of *drilling*. It is cause by lack of practice with original tools and a huge risk of destruction of new Bohemian garnets. Moreover, the drilling tools do not exist nowadays. Therefore, we looked for the most similar technology. As a consequence of mentioned facts, we decided to search for alternative manufacturing technique instead of employment of an original one which was used in the past. We have chosen and tried five different modern equipment and techniques of drilling.

At first, the drilling was tried out on testing samples. Based on the obtained results we determined that holes the most comparable with the original ones were achieved by employment of the ultrasonic drilling followed by a subsequent treatment of the drilled trace by the tubular drill. Although modern drilling techniques and instruments were used, we followed a historical procedure applied on original pieces and thus holes were drilled two-stepwise – from one side of a grain into its centre and subsequently from an opposite side in the same manner to obtain a straight hole passing through an entire bead. Finally, ultrasonic drilling combined with tubular drill provided the holes almost indistinguishable with original ones.

When we mastered the drilling technology we focus on the cutting. The original Bohemian garnets were **cut** as a so-called “double-faced rose” cut where the facets are arranged in a row and are finished by six triangular facets. The purpose of this type of facets distribution was to obtain as large bead cut as possible (Fig. 2a). The gem cutters strived to obtain a maximum yield of the material. It means minimalize the material loose as well as size of final beads. Facets on the original beads have very uneven shapes (Fig. 2a and Fig 8). These facets irregularities fully respect the size, shape and rareness of the material. Reduce minimally the size of the original grain due to cutting was the main purpose of this cutting technology.

Individual edges between the facets are not precisely ground off and they are let in a natural state (Fig. 8) or they are only slightly wiped off (not polished). If the edges had been fully cut, a lot of material would have been lost which was undesirable at the time of their creation. Nowadays, this way of cutting is completely unacceptable in Europe, but it can be found rather often in India, Nepal or Sri Lanka [18]. On the other hand, it is greatly important from the historical point of view, because it reflects the period of creation of the jewels. The different appearance of beads indicates that they were cut at different periods. It cannot be excluded that some drilled beads were used earlier as a part of other older jewels.

Firstly, the cutting was tried out on testing samples. When the the technology was mastered, we cut the real Bohemian garnets (drilled previously).

Finally, the size of the original and newly made beads was measured. The length of original beads range between 5.78–8.20mm while new ones are 6.62–8.17mm length. The width of original beads range between 5.40–6.84mm while new ones have 5.94–6.62mm in width. The last one, the depth, range from 3.77 to 6.42mm for original beads and from 4.11 to 4.78mm for new ones.

All seven new beads look very similar as the original ones (Fig. 8). It is not possible to distinguish them by the eye as well as under microscope. We solved this problem with inscription which is visible only under the microscope.

Fig. 8. Newly cut pyrope-almandine beads compared with original beads (bracelet 1). (photo P. Hladký)

All newly made beads are marked to be unequivocally distinguishable from the old ones. The beads have an inscription „NOVÝ KUS 2018“ (in English “New piece 2018”) on the one facet (Fig. 9).

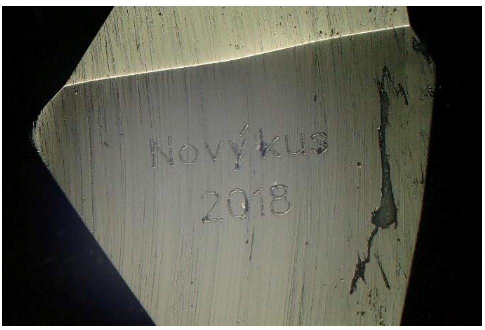

Fig. 9. Inscription on facet one of the new beads. (photo R. Hanus)

Conservation works

As was mentioned above, the bracelets and necklace are formed in rows on the strings. The rows are finished with metal sping bars. Some of these spring bars were slightly opened or completely changed (case iron-nickel alloy sping bar). Moreover, as follow from museum archives, seven beads from necklace were lost in past. Because of these discrepancies we are almost sure that some interventions on the jewels were done in past. At least the strings were changed few times.

We decided that, except the material research, the whole collection will be restored. It means that new beads were produce (see above) and the decay sping bars were replaced alike strings. Of course, the etui was restored too.

As XRF analysis results show, the jewels were made of high purity gold which was higher than 19 ct (Table 2). Only one *spring bar* from the necklace was made of iron-nickel alloy (Fe-Ni). Probably, the original golden bar was destroyed or lost, and a new piece was made of this alloy. It was decided that this spring bar will be replaced by a new one. Except of this spring bar, we found next four damaged spring bars which were replaced as well. New spring bars were made of a high purity gold (18ct, T. O'Donoghue).

Because of the high exclusivity of the collection we supposed that *silk strings* were most likely used [12]. Based on the research reports from archive documents, it is presumable that the strings are not authentic with regards to the jewels. According to museum archive reports, the strings were changed several times. The last recorded change was done in 1966. These changes could explain the spring bars decay. Firstly, strings were searched by infrared spectroscopy. Material was determined as cotton-viscose mixture. It is evident that strings are not original because viscose was firstly used as textile material in 1884. After the discussion we decide replace the cottone-viscose strings with new ones made from silk.

At the end, also *the etui* was restored. It follows from museum records the etui was made to order in the first part of 19th century. The beautiful box has an auriform shape and the upper part is of a convex shape. The bottom part is flat. The whole etui is covered by leather and furnished with fitting. The interior of the etui is covered with a light, blue-coloured velvet and shiny fabric.

The fabric cover was dirty, with rust stains (up to 4mm in diameter) and there were some fibres missing. Dust and dirt were carefully removed by a vacuum cleaner and rust stains were removed as well. Cracks were reinforced by a Japanese paper. A 4% solution of Tylosa MH 6000 in distilled water was used as a glue.

A metal fitting was made of brass. It was completely without any serious damage. Only verdigris was found in bends. Fittings were carefully cleaned; verdigris was removed mechanically. Screws were tightened as a protection against losing them. All metal parts of the etui were finally treated with a beeswax.

The whole etui is covered with a very thin, purple-dyed glove-making *leather*. Borders of the etui are decorated with gilt, blind stamping lines. Moreover, the cap is decorated with a thin gilt ornamental line. The leather was fouled by dust. Borders and the bottom part were scratched. Small pieces of leather were missing in some places or they were slightly torn.

The level of the leather degradation was examined by the determination of a shrinkage temperature and the measurement of pH values. Based on the shrinkage temperature and the pH value, the appropriate way of leather treatment can be chosen. A few fibres (from unstuck leather) were removed for the shrinkage temperature testing. The shrinkage temperature was 74°C which corresponds to a vegetable tanned leather in a very good condition (without degradation). This is in accordance with the pH measurement which showed value of 4.3 corresponding to values for non-degraded leather [23]. Based on the results, the leather could be cleaned by foam made of a 1% water solution of an anion active surfactant Alvol. The unstuck pieces of the leather were mounted after cleaning using a 4% solution of Tylosa MH 6000. Finally, a greasy mixture was applied, and the leather was polished by a cloth.

Conclusions

Based on the detailed survey of the whole collection it is likelihood that necklace and bracelets originate from at least two different jewels collection, which were disassembled and new jewels, nowadays known as „the Jewel collection of Ulrike von Levetzow“, were made of these beads. The garnets from caps of the necklace and bracelets as well as earings probably come from another period in comparison with the rest of the collection pieces. Drilled holes were not polished. All drilled pyropes are rarely big and they are cut very poorly. The style of cutting reflects the period in which the jewels were made. Contrary to the cutting, the earrings are an example of a very precise goldsmith´s work from very-fine gold wires, plaited into mesh. The quality of work does not have any analogue in the Czech region.

All measured drilled pyropes have a refraction index, inclusions, Raman and photo luminescence spectra and UV-VIS-NIR spectra coincident with the standard of Bohemian garnets from Třebívlice area (Central Bohemian Uplands). Thanks to XRF analysis, it is known that the whole collection was made of high purity gold alloy. The lowest determined purity was 19 carats (Bracelet 1) and the highest one was 22.5 carats (Earring 2).

The whole collection was very circumspectly restored including cleaning of the etui, search for the best material for strings to replace older ones or manufacturing of missing garnet beads which were lost in the past.

Using the above-mentioned methods, we confirmed that the entire collection was made of Bohemian garnets from Třebívlice area. Due to the size of the individual stones, this is a very rare set of incalculable financial and historical value.

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