# PROVENANCE STUDY ON A COLLECTION OF LOOSE GARNETS FROM A GEPIDIC PERIOD GRAVE IN NORTHEAST HUNGARY*

## EGY GEPIDA KORI SÍRBÓL SZÁRMAZÓ GRÁNÁTLELET PROVENIENCIA VIZSGÁLATA

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### *Abstract*

*Red gemstones identified mostly as garnets generally occurred in the 5th-6th-century Europe as inlay decoration of fine metalwork. Their majority are known in cut and mounted form – loose, unmounted pieces are very rarely found. For that reason, it is of great importance that a few years ago seventeen such loose red gemstones were unearthed at a rescue excavation at Hajdúnánás-Fürj-Halom-dűlő (Hajdú-Bihar County). These gemstones are considered as remains in a robbed grave of a late 5th-century cemetery, i.e. dated to the Gepidic period. The lack of any related goldsmith artefact and the visible different phases of the gem-cutting process allow us to interpret them as independent pieces in a collection. While mounts and cell walls usually make the accurate observation difficult, the loose character of these pieces permitted to perform an extensive investigation in order to identify the mineral species and to determine their possible geological-geographical origin. The results of the gemmological-mineralogical and geochemical analyses revealed that the red gemstones are Fe-rich as well as Fe-Mg-rich garnets, i.e. almandine and intermediate varieties between pyrope and almandine. Concerning the garnet paragenesis, the raw material has experienced medium- to high-grade metamorphism, for the most part at medium pressure and has formed in metapelite source rocks. The comparative analysis of the mineral inclusions and the concentration of the major constituents pointed out that they may have been exploited from alluvial deposits most likely in South India and Sri Lanka.*

*An increasing number of archaeometrical investigations are being worldwide performed in order to deepen our knowledge about the used raw material sources and trade links in the Early Middle Ages, when garnet inlaid jewellery had an unprecedented spread. Nevertheless, interpretation of the results presented in this paper can be considered as the first provenance study related to early medieval garnets found in the present Hungary.*

### *Kivonat*

*Európa 5-6. századi leletanyagában a vörös színű berakások az ötvösmunkák egyik legáltalánosabb díszítőelemei. A többségében gránátként meghatározott ékkövek elsősorban csiszolt, befoglalt állapotban fordulnak elő, a különálló, foglalatlan darabok kivételes leletek. Ennek ismeretében különös jelentősége van annak a tizenhét darab foglalatlan vörös ékkőnek, amely néhány évvel ezelőtt került elő Hajdúnánás-Fürj-Halom-dűlőről (Hajdú-Bihar megye), az M3-as autópálya építéséhez kapcsolódó megelőző feltárások alkalmával. Az elemzés tárgyául szolgáló lelet egy 5. század végére keltezett, gepida kori temető rabolt sírjának egyetlen megmaradt melléklete. Hozzátartozó tárgy hiányában, valamint a megmunkáltság mértékében megmutatkozó különbségek alapján a változatos megjelenésű köveket egy kollekció önálló darabjainak lehet tekinteni. Míg a foglalatok és rekeszfalak sok tekintetben megnehezítik a berakások alapos megfigyelését, a tárgyalt kövek foglalatlan jellege lehetővé tette az átfogó archeometriai vizsgálat elvégzését. Az ásványfaj azonosítása mellett a nyersanyag lehetséges geológiai-geográfiai lelőhelyének meghatározását tűztük ki célul. A gemmológiai-ásványtani és geokémiai elemzések eredményeként a vörös ékköveket Fe-ban, illetve Fe-Mg-ban gazdag gránátként, vagyis almandinként, illetve pirop-almandin elegykristályként lehetett meghatározni. Az ásványi nyersanyag képződése közepes, illetve nagyfokú metamorfózis során, többségében közepes nyomáson ment végbe, metapélit forráskőzetben. A zárványkép és az összetétel szakirodalmi adatokkal való összehasonlítása alapján kitermelésükre alluviális lelőhelyeken került sor legvalószínűbben Dél-Indiában és Sri Lankán.*

*A gránátdíszes ékszerek virágkorának tekinthető 5-6. század nyersanyagforrásairól és kereskedelmi kapcsolatairól alkotott tudásunk elmélyítésére az egész világon folynak archeometriai vizsgálatok. Ezek közül a jelen tanulmány elsőként foglalkozik a mai Magyarország területéről származó kora középkori gránátok provenienciájával.*

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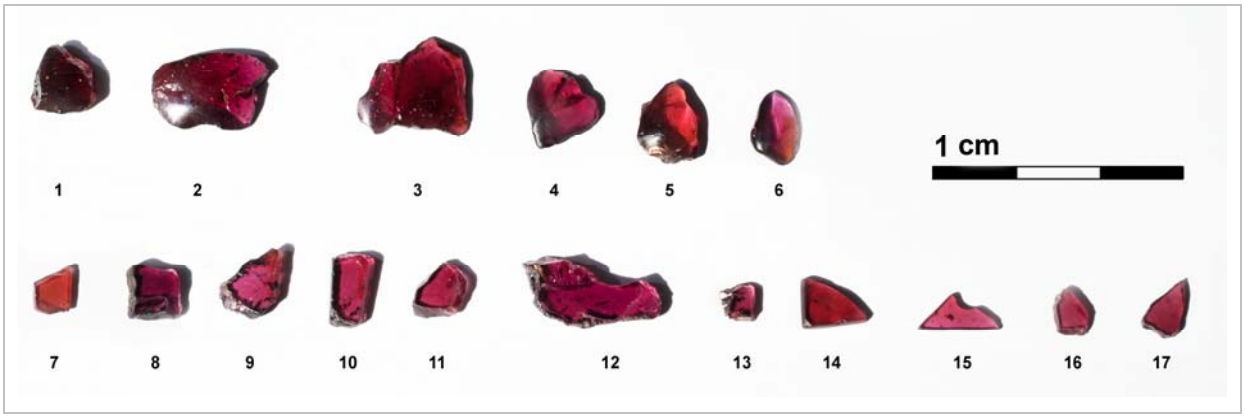


**Fig. 1.:** Collection of the garnets from Hajdúnánás-Fürj-Halom-dűlő (flat cabochons: upper row, No.1-6; flat plates: lower row, No.7-17). Photo: Eszter Horváth

**1. ábra:** A Hajdúnánás-Fürj-Halom-dűlőről származó gránátegyüttes (lapos kabosonok: felső sor, No.1-6; sík lapok: alsó sor, No.7-17). Fotó: Horváth Eszter

KEYWORDS: LOOSE GARNETS, GEPIDIC PERIOD GRAVE, MINERAL INCLUSIONS, CHEMICAL COMPOSITION, PROVENANCE STUDY

KULCSSZAVAK: FOGLALATLAN GRÁNÁTOK, GEPIDA KORI SÍR, ZÁRVÁNYKÉP, KÉMIAI ÖSSZETÉTEL, PROVENIENCIA VIZSGÁLAT

## *Introduction*

The seventeen loose, i.e. unmounted pieces of red gemstone discussed in this paper were unearthed at a rescue excavation at Hajdúnánás-Fürj-Halom-dűlő (Hajdú-Bihar County) in a late 5th-century cemetery (Márkus 2005) (**Fig. 1; 2/a; 4/b**). As the previous archaeological research has shown it, in this period the region and primarily the eastern bank of the Tisza River were settled by an East Germanic tribe, the Gepids (Bóna & Nagy 2002). In fact, the ethnical interpretation is beyond the scope of this paper and intended to be discussed in the monograph of the cemetery. The gemstones are considered as the only remains in a robbed grave, they were found around the disturbed part of the pelvic and femurs (**Fig. 2/b-c**).

Similar red gemstones identified predominantly as garnets are known as primary inlay decoration of the fine metalwork in the early medieval Europe, thus among others in the 5th-6th-century Carpathian Basin. They occur mainly in cut and mounted form, set in either single- or multi-cellwork; prevalent type of this latter is called cloisonné (**Fig. 3**). In contrast, the loose form appears much rarely, hence the assemblage discussed in this paper adds to unique materials (**Fig. 4**), especially considering some further features being also of great importance. Namely, it contains both flat cabochons and flat plates representing different phases of the gem-cutting process (**Fig. 5; Table 1**).


**Fig. 2.:** The German type cemetery with graves laid out in rows at Hajdúnánás and the robbed grave with the collection of garnets. Photo: Márton Makó

**2. ábra:** Germán típusú soros temető Hajdúnánáson és a gránátegyüttest tartalmazó rabolt sír. Fotó: Makó Márton


**Fig. 3.:** Garnet jewellery from Oros (Szabolcs-Szatmár-Bereg County) dated to the end of the 5th century. Examples for multi- and single-cellworks : a) cloisonné b) champlevé. Photo: Eszter Horváth

**3. ábra:** 5. század végére keltezett gránátékszerek Orosról (Szabolcs-Szatmár-Bereg megye). Példák a többrekeszes és egyrekeszes elrendezésre: a) cloisonné b) champlevé. Fotó: Horváth Eszter

**Table 1.:** Optical and physical properties of the gemstones from Hajdúnánás

**1. táblázat:** A hajdúnánási ékkövek optikai és fizikai tulajdonságai

| Sample No. | weight in carat / gram | maximum thickness | maximum length | maximum width | colour tone | reflective index | cutting form | phase of the cutting process |
|---|---|---|---|---|---|---|---|---|
| **1** | 2,08 / 0,41 | 2,7 mm | 8,3 mm | 7,6 mm | orange-brown | > 1,790 | flat cabochon | semi-finished |
| **2** | 4,08 / 0,81 | 2,5 mm | 14,4 mm | 9,3 mm | purple-red | > 1,790 | flat cabochon | semi-finished |
| **3** | 3,76 / 0,75 | 2 mm | 13,5 mm | 12,7 mm | purple-red | > 1,790 | flat cabochon | semi-finished |
| **4** | 1,87 / 0,37 | 2,1 mm | 9 mm | 9 mm | purple-red | > 1,790 | flat cabochon | semi-finished |
| **5** | 1,93 / 0,38 | 2,5 mm | 10,1 mm | 7,4 mm | purple-red | 1,763 | flat cabochon | semi-finished |
| **6** | 0,99 / 0,19 | 1,7 mm | 9,3 mm | 6 mm | purple-red | 1,782 | flat cabochon | semi-finished |
| **7** | 0,46 / 0,09 | 1,3 mm | 5,1 mm | 4,4 mm | orange-brown | 1,759 | flat plate | finished |
| **8** | 1,60 / 0,32 | 2,3 mm | 6,1 mm | 6 mm | purple-red | 1,781 | flat plate | semi-finished |
| **9** | 1,16 / 0,22 | 1,6 mm | 9,4 mm | 7 mm | purple-red | 1,780 | flat plate | semi-finished |
| **10** | 1,29 / 0,25 | 1,7 mm | 9,2 mm | 5,1 mm | purple-red | 1,786 | flat plate | finished |
| **11** | 0,91 / 0,18 | 1,7 mm | 6,6 mm | 6 mm | purple-red | 1,782 | flat plate | semi-finished |
| **12** | 3,93 / 0,78 | 2,3 mm | 15 mm | 9,5 mm | purple-red | 1,782 | flat plate | semi-finished |
| **13** | 0,39 / 0,07 | 1,5 mm | 4,5 mm | 4,3 mm | purple-red | 1,781 | flat plate | semi-finished |
| **14** | 0,80 / 0,15 | 1,2 mm | 7,7 mm | 6 mm | purple-red | 1,783 | flat plate | finished |
| **15** | 0,54 / 0,11 | 1,1 mm | 9,9 mm | 7 mm | purple-red | > 1,790 | flat plate | finished |
| **16** | 0,36 / 0,06 | 1 mm | 5,8 mm | 3,8 mm | purple-red | 1,781 | flat plate | semi-finished |
| **17** | 0,51 / 0,10 | 1 mm | 7,1 mm | 4,7 mm | purple-red | 1,780 | flat plate | semi-finished |

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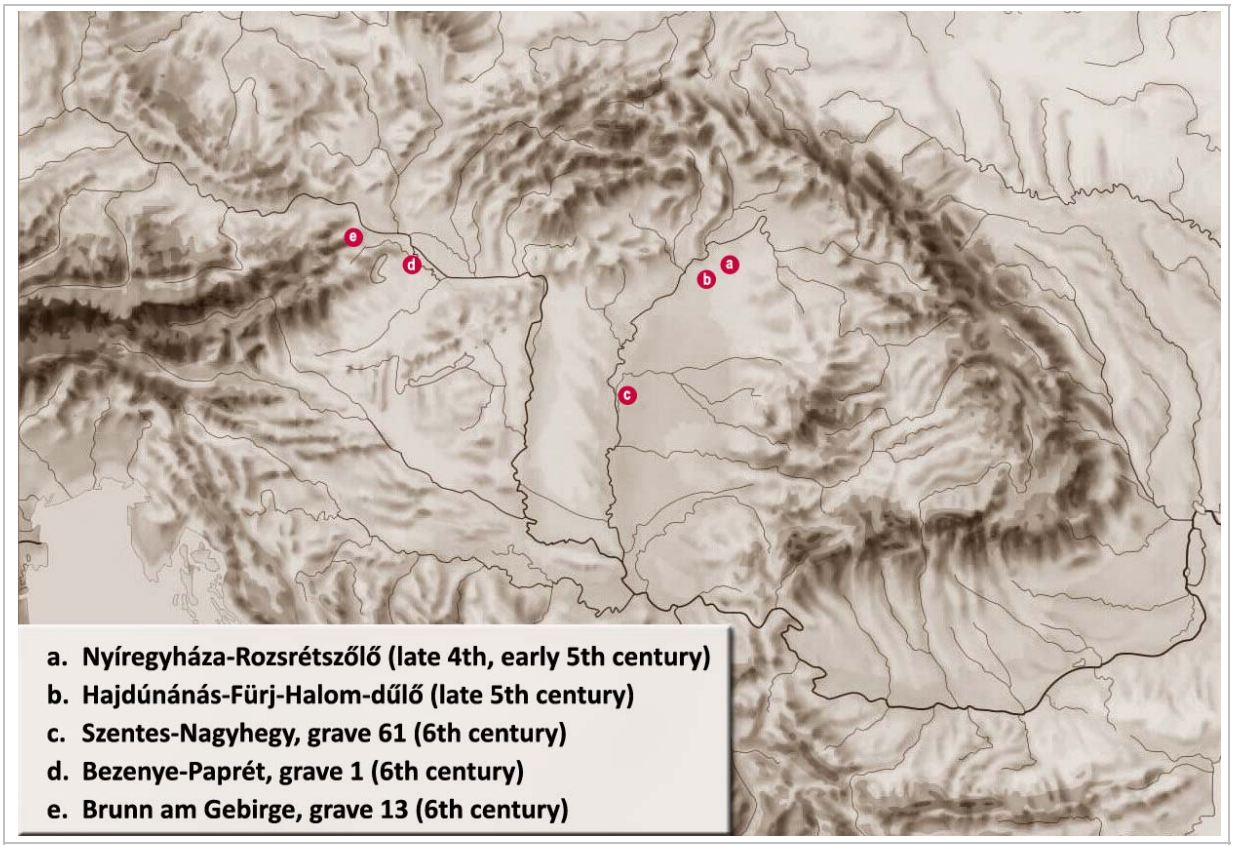


**Fig. 4.:** Early medieval loose garnets found in the Carpathian Basin. References: a) Pintye in press b) Márkus 2005 c) Csallány 1904 d) Bóna 1956, 191-193. e) Aspöck & Stadler 2003, 182-183.

**4. ábra:** Kora középkori foglalatlan gránátleletek a Kárpát-medencében. Irodalom: a) Pintye s.a. b) Márkus 2005 c) Csallány 1904 d) Bóna 1956, 191-193. e) Aspöck & Stadler 2003, 182-183.

All of the six flat cabochons and seven of the flat plates look like semi-finished products where final steps of shaping were not carried out. Besides, the other four plates can be regarded as finished products with regular shapes and cut edges. All of these details and as an addition the lack of any related goldsmith artefact in the grave allow us to consider them as independent pieces collected together. Based on their coincident position a not preserved purse or bag made of some organic material may also be supposed even in spite of the total disorder of the bones.

In this study our main research objectives were to identify the garnet species and to determine their possible provenance, i.e. their geological-geographical origin. Aside from this paper only scanty literature exists about the Carpathian-Basin related to the provenance issue of early medieval garnet material (Arrhenius 1985; Horváth 2008; Ionescu & Hoeck 2008; Fritsch et al. 2010). Great majority of the previous mineralogical studies are typically restricted to the identification of the particular mineral species and their discrimination from glass imitations (Alföldi 1932, 65-70; Fettich 1932, 71-72; Horváth 2006; Ionescu et al. 2010). Either it did not aimed attention at the geographical origin at all or the necessary measuring conditions were not attainable: advances in these analyses were not achieved. Regarding the Hungarian archaeometrical research in particular, garnet provenance studies have been more and more established in the past few years. Due to the latest developments in the archaeometrical research concerning analogous material, significant new results served as a reference base for our comparative analysis (Calligaro et al. 2002; Périn et al. 2007; Calligaro et al 2008; 2010; Gilg et al. 2010). In order to make the Carpathian-Basin not remaining a white spot any more, relevant results started to be published; focussing in this first paper on one of the most remarkable assemblages.

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**Fig. 5.:** a) facet rough edges on two semi-finished pieces (No.2 and No.9) b) wheel-cut edges on a finished piece (No.15). Photo: Eszter Horváth

**5. ábra:** a) megmunkálatlan, nyers perem két félkész darabon (No.2 és No.9) b) csiszolókerékkel kialakított perem az egyik kész darabon (No.15). Fotó: Horváth Eszter

## *Methodology*

Mounts or cell walls of the inlay decorated jewels usually make the accurate observation difficult (**Fig. 3**). Consequently, the loose character of the gemstones from Hajdúnánás was fundamental to perform an extensive archaeometrical investigation. This survey was achieved in several places with various purposes. In order to determine the possible raw material sources both gemmological-mineralogical and geochemical characteristics were analysed. These examinations were carried out at the Electron Microprobe and Microscope Laboratories of the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest. During the in situ analyses only non-destructive and non-invasive methods were applied in accordance with the archaeological requirements (for exact parameters of the different analyses see **Table 2**).

Following a careful cleaning we were focussing on the optical and physical properties of the gemstones. Their colour, transparency and luster were observed in a macroscopic way and their surface damages through a binocular stereomicroscope. Besides, the refractive indices were measured by a gemmological refractometer. The mineral inclusion analysis was performed under normal and polarized light applying a petrographic microscope. Due to the relatively small thickness of the pieces (1-2.7 mm) as well as their polished flat-cut surfaces on the bottom and in most cases also on the top, they could be studied quite simply, similarly to thin sections by transmitted light. Various internal features were observed and identified morphologically and they were documented by excellent quality microphotographs.

Following the gemmological-mineralogical observations our investigation included a microanalytical technique in order to determine the elemental composition of the garnet matrix. The electron microprobe analyses were carried out by a scanning electron microscope equipped with energy dispersive spectrometer.

**Table 2.:** Exact parameters of the analytical investigations

**2. táblázat:** A vizsgálatok pontos paraméterei

| **Binocular Zoom-stereomicroscope** |
|---|
| type: Nikon SMZ 800 |
| **Polarizing Petrographic Microscope** |
| type: Nikon Labophot2-Pol |
| objectives: 4x, 10x, 20x, 60x |
| microscope camera type: Nikon DS-Fi1 |
| camera software: Nikon Elements D 3.2 |
| sample preparation: none |

| **Scanning Electron Microscope** |
|---|
| type: AMRAY 1830 |
| detector: energy dispersive (EDS) |
| spectrometer: EDAX PV 9800 |
| data processing software: Moran Scientific |
| cathode: wolfram |
| acceleration voltage: 20kV |
| beam current: 1 nA |
| beam diameter: ~ 100 nm |
| measurement time: 100 s (lifetime) |
| sample preparation: masking, carbon-coating |
| vacuum evaporator: JEOL JEE-4B |

As it was mentioned above, the discussed gemstones have finished surfaces, and it made any supplemental polishing unnecessary; what is the commonly adopted but destructive preparatory step in case of geological samples. Obviously, it was essential in order to preserve original tool marks left by the early medieval gem-processing. Quantitative analyses required only carbon-coating and for practical reason only a small area was evaporated on all specimens.

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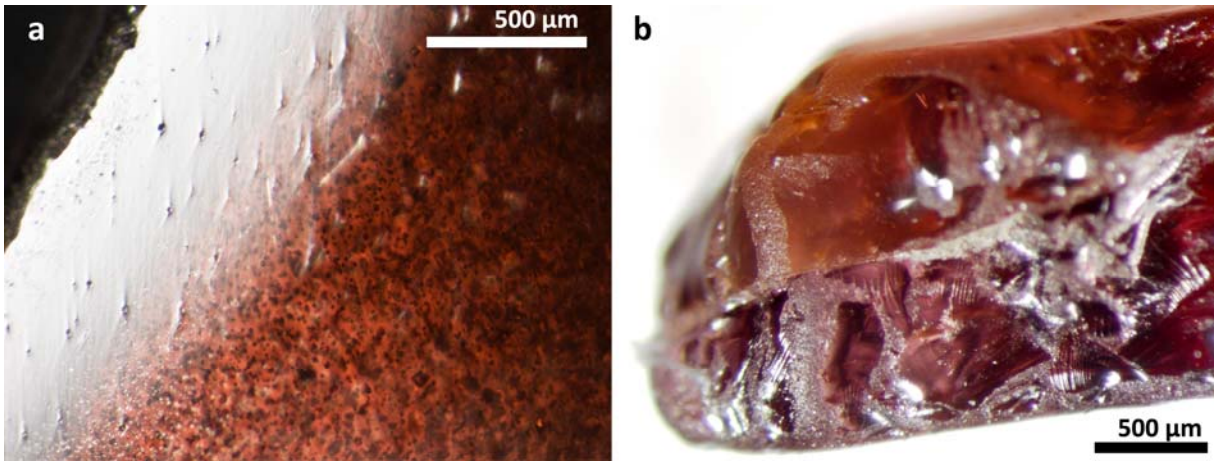


**Fig. 6.:** a) luster of the highly polished surface (No.7) b) conchoidal fractures on a facet rough edge (No.9). Photo: Eszter Horváth

**6. ábra:** a) finoman polírozott felület fénye (No.7) b) kagylós törések a természet által kialakított peremen (No.9). Fotó: Horváth Eszter

During the preparation works a metal plate served as a base for mounting and a conductive carbon tape was used for fixing and masking the specimens. The carbon-coating and carbon tape was easily removed from the surfaces immediately after the examinations by ethanol and a gentle manual rubbing. Using the SEM-EDS system, the detection limit was at about 0.1 weight%, hence trace elements represented below this concentration could not be displayed (e.g.: Ti, Cr, Y, etc). The measured elements were the major constituents of the garnet (Mg, Al, Si, Ca, Mn and Fe); their oxide-forms were calculated by a data processing software.

In order to refine our measurements standardisation was necessary to perform. In the light of the calculated cation numbers, the accessible international standards showed to be less appropriate. For that reason, an inner sample was used: in this case a volcanic garnet, found in Middle Miocene dacite in Visegrád Mountains (North from Budapest) served as a standard. Garnets of this dacite are very homogenous and almost inclusion-free, as previous studies have pointed it out (Harangi et al. 2001); our sample has already been several times measured by a wavelength dispersive X-ray spectrometer (EPMA-WDS system). Data evaluation was facilitated applying an Excel spreadsheet made by Locock (2008). This spreadsheet allowed us to calculate the molar proportions of garnet end-members from chemical analyses: 29 end-members (15 species and 14 hypothetical) were evaluated in each particular cases. Furthermore, the amounts of $Fe^{2+}$ and $Fe^{3+}$ were calculated by stoichiometric constraints as these quantities could not have been measured during the EDS analyses. Finally, the quality of our measurements was controlled employing a simple scoring algorithm (Locock 2008, 1776-1777). The archaeometrical interpretation of the results was based on a comparative analysis presented below in the discussion.

## *Results*

### Results of the gemmological-mineralogical observations

Flat cabochons and thin plates from Hajdúnánás have a lustrous deep red colour with purple or orange-brown tone. Their highly polished surfaces make visible a relatively high reflectivity implying a vitreous or adamantine luster (**Fig. 6/a**).

**Fig. 7.:** Naturally faceted garnets from alluvial deposit before processing works

**7. ábra:** Alluviális lelőhelyről származó, megmunkálás előtt álló gránátok természet által kialakított fazettákkal

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**Table 3.:** List of the detected mineral inclusions: (+) morphologically; (#) also by chemical composition
**3. táblázat:** Az ásványzárványok listája: (+) morfológiailag meghatározott; (#) kémiai összetétel alapján ellenőrzött

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Long, curved anisotropic needles (sillimanite) | | # | | | | | | # | # | # | | # | | | + | | + |
| Plate-like pleochroic brown crystals (biotite) | | | + | # | | | | # | + | # | | | | | # | | |
| Plate-like anizotropic colourless crystals (muscovite) | | + | | + | | + | | + | + | + | + | + | | | + | | |
| Crystallographically oriented needles (rutile) | + | + | # | + | | | | | | + | + | | + | + | + | + | + |
| Singular long needles (rutile) | | | | | + | | | | # | # | | # | | | | | |
| Isometric or plate crystals with tension halos or pleochroic brown radioactive halos (zircon and / or monazite) | # | # | # | + | + | # | # | # | # | + | + | # | # | # | + | + | # |
| Tiny elongate crystals with hexagonal end-section (apatite) | + | + | + | | + | | + | | + | | | + | | + | | + | + |
| Large irregular opaque plates (ilmenite) | | | # | | | | | + | + | + | + | + | + | + | | | + |
| Large isometric or irregular anisotropic crystals (quartz) | # | | | + | | | # | + | | + | # | + | + | | # | | |
| Singular long needles (quartz) | | | | # | | | + | # | | # | # | | | | | | |

The measured refractive indices revealed that the stones have isotropic optical character and all of them are garnets (**Table 1**). The majority of pieces showed values typical for almandine, whereas two pieces (No.5 and No.7) represented intermediate varieties between pyrope and almandine, named also rhodolite in the gemmology, which is however not a recognised mineralogical term. Primarily on the semi-finished pieces but even on the finished ones several tiny damages were observable along the edges such as smooth breaks with concentric rings resulting in shell like, conchoidal fractures (Fig. 6/b). Edges without any marks of cutting may preserve the original size of the raw grains. This observation implies that the garnets had a facet rough character before their processing, which suggests their alluvial origin (**Fig. 7**).

All of the garnets are transparent however, they have a wide range of internal features: several relatively large (1-2 mm) mineral inclusions as well as filled internal fractures were noticeable already in macroscopic view. The microscopic investigations permitted us to identify them morphologically together with a number of other tiny inclusions. As a next step, inclusions detected at the surface could be measured by the SEM-EDS system as well. These observations provided principal information about geological environments and P-T conditions of the garnet paragenesis and about the source rocks. Majority of the inclusions detected in the garnets points to a crustal origin and metamorphic formation. The most apparent mineral inclusions are the oriented rutile needles, usually forming dense, complex networks of intersecting crystals (**Fig. 8/a-b**). Since they could be formed in various P-T conditions, they can be regarded as accessory minerals rather than indicators for the source rocks. From this point of view curved needles of sillimanite as well as brown pleochroic biotite and colourless muscovite plates can be considered as the most important inclusions. They indicate medium- to high-grade metamorphism at medium pressure (**Fig. 8/c**-f). While sillimanite needles and biotite grains refer to both amphibolite and granulite facies, muscovite inclusions manifest rather amphibolite facies metapelites (metamorphosed clay-rich sedimentary rocks) as source rocks (Spear 1995). Besides, several further mineral inclusions were identified morphologically and by their chemical composition: irregular opaque ilmenite plates, xenomorphic and acicular quartz crystals, elongate apatite crystals with hexagonal end sections, prismatic or nearly isometric zircon crystals surrounded by tension and pleochroic radioactive halos as well as brown monazite crystals also with radioactive halos (**Fig. 9/a-d, f**) (for the detailed list related to the particular specimens, see **Table 3**).

It must be emphasised that from the aspect of the mineral inclusions there are hardly any significant differences between pieces identified as almandine and as pyrope-almandine. The discrimination is based foremost on the measured refractive indices but primarily on the results of the geochemical analysis presented below.

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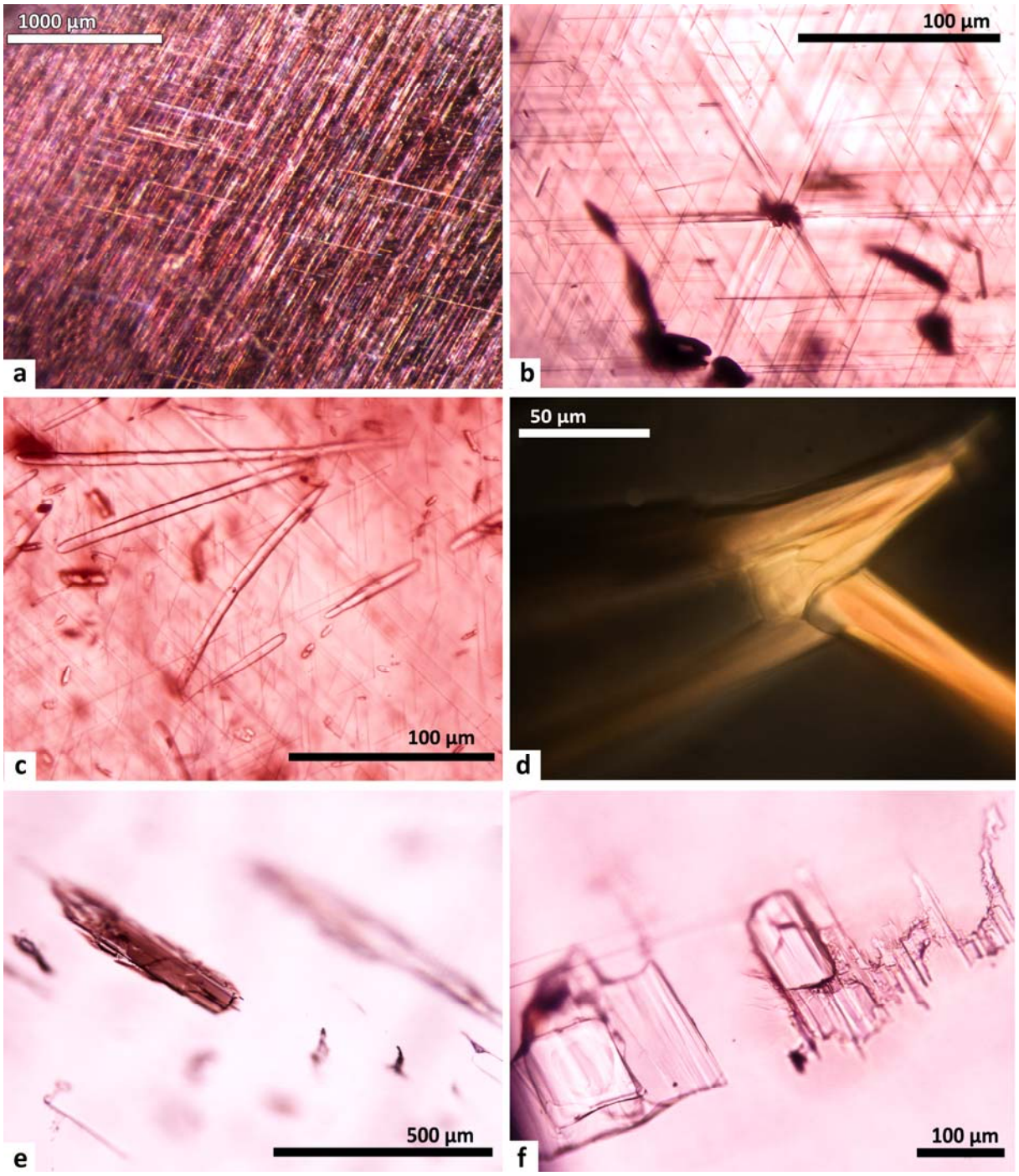


**Fig. 8.:** Micrographs of the detected mineral inclusions in the garnets from Hajdúnánás a-b) intersecting rutile needles: No.17, 1N and No.3, 1N c-d) sillimanite needles: No.2, 1N and No.9, +N e) biotite plate No.15, 1N f) muscovite plates No.15, 1N. Photo: Eszter Horváth

**8. ábra:** A hajdúnánási gránátok ásványzárványairól készült mikrofelvételek: a-b) egymást metsző rutil tűk rendszere: No.17, 1N és No.3, 1N c-d) szilimanit tűk: No.2, 1N és No.9, +N e) biotit lemez: No.15, 1N f) muszkovit lemezek: No.15, 1N. Fotó: Horváth Eszter

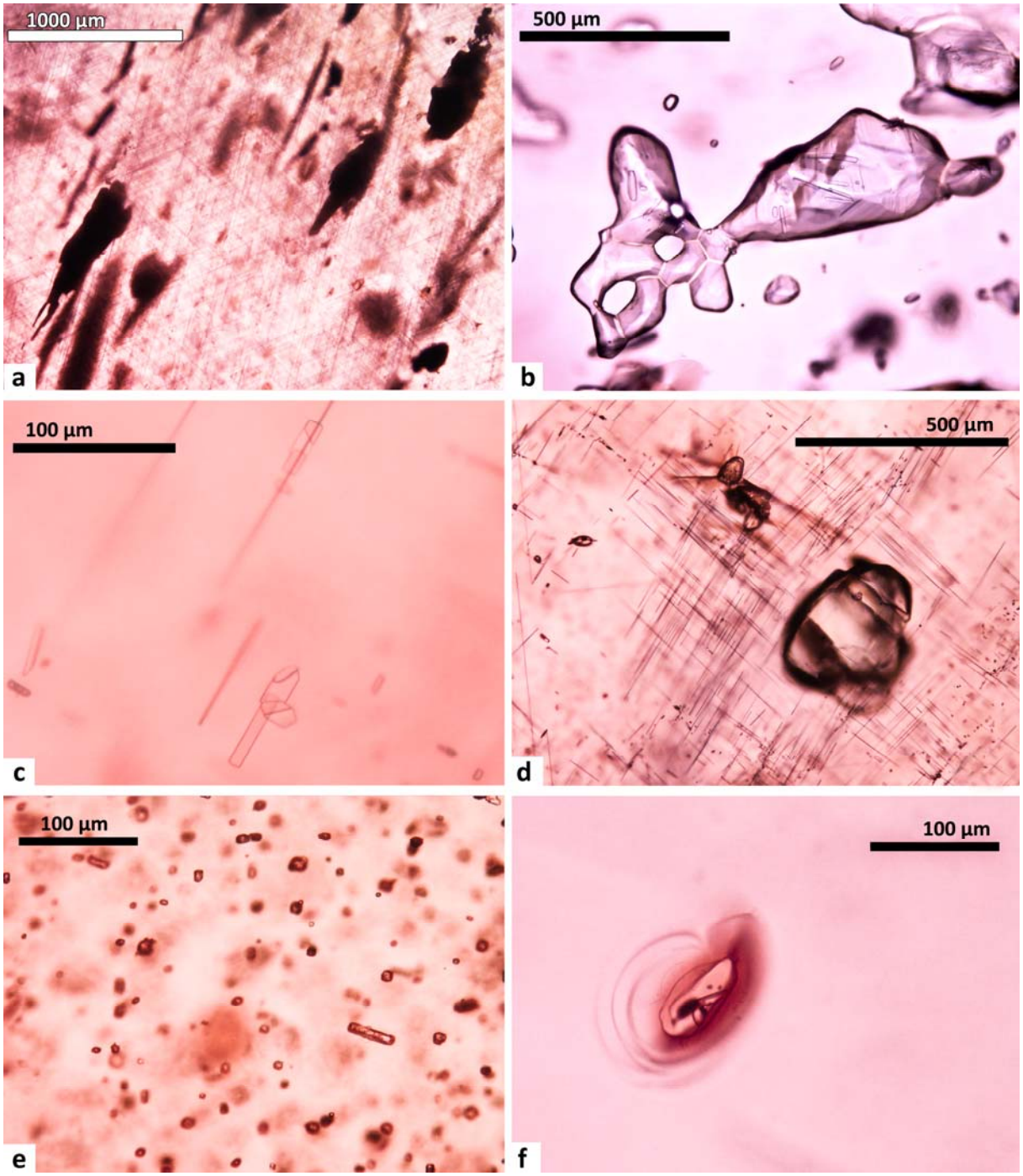


**Fig. 9:** Micrographs of further mineral inclusions in the garnets from Hajdúnánás a) ilmenite plates: No.3, 1N b) quartz crystal: No.12, 1N c) apatite crystals: No.14, 1N d) zircon crystals: No.14, 1N e) unidentified anisotropic crystals: No.7, 1N f) monazite crystal: No.10, 1N. Photo: Eszter Horváth

**9. ábra:** A hajdúnánási gránátok további ásványzárványairól készült mikrofelvételek a) ilmenit lemezek: No.3, 1N b) kvarc kristály: No.12, 1N c) apatit kristály: No.14, 1N d) cirkon kristályok: No.14, 1N e) ismeretlen anizotróp kristályok: No.7, 1N f) monacit kristály: No.10, 1N. Fotó: Horváth Eszter

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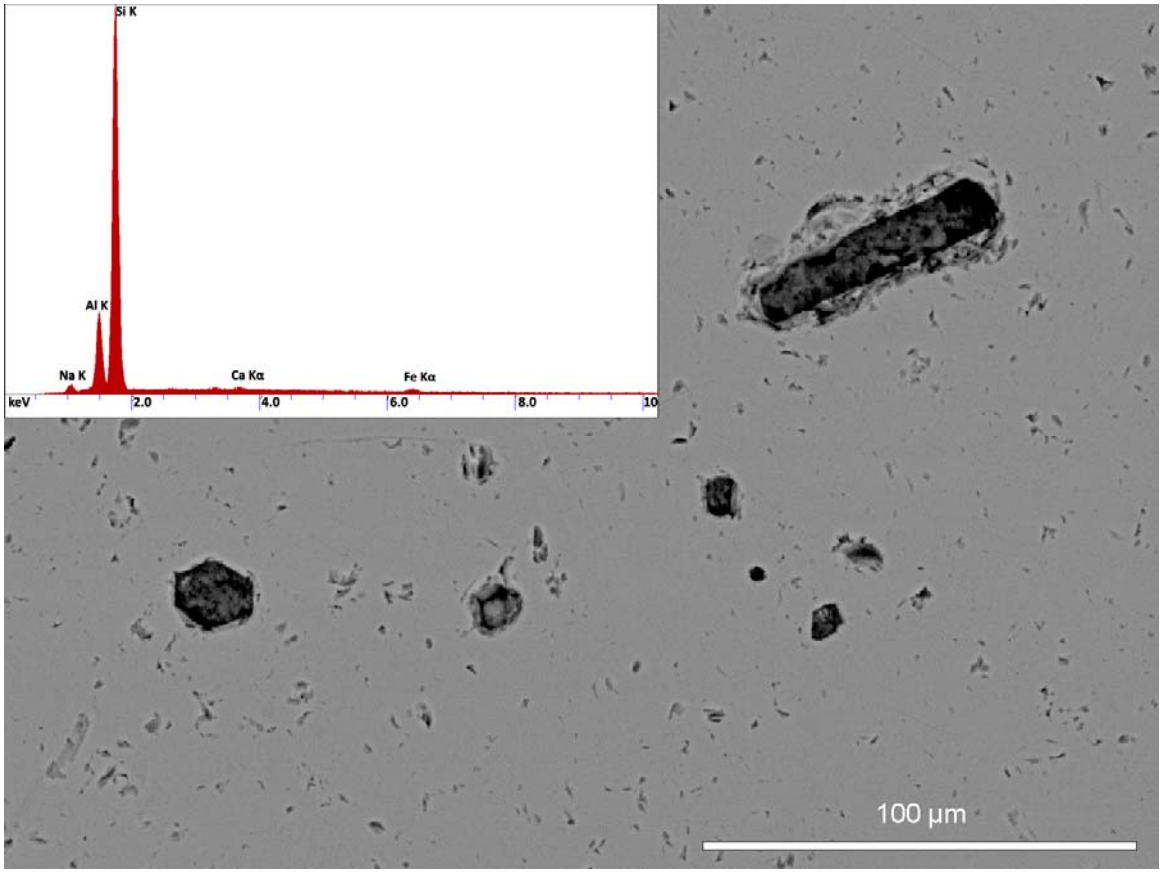


**Fig. 10.:** BSE image and EDS spectrum of the unidentified anisotropic crystals (Fig. 9/e). Photo: Zsolt Bendő

**10. ábra:** Az ismeretlen anizotróp kristályok (9/e ábra) BSE felvétele és EDS spektruma. Fotó: Bendő Zsolt

In fact, there is only one specific type of inclusions occurring exclusively in specimens No.7, with a considerable density (**Fig. 9/e; 10**). These isometric, anisotropic small crystals are preliminary supposed to be jadeite but an attested identification is waiting for a dispersive Raman spectro-photometric analysis.

As the laser light penetrates through the garnet matrix and it can be focussed on even the tiny mineral inclusions, the confocal Raman microscope proves to be the most appropriate for the identification (Calligaro et al. 2002; Smith 2005; Bersani et al. 2009).

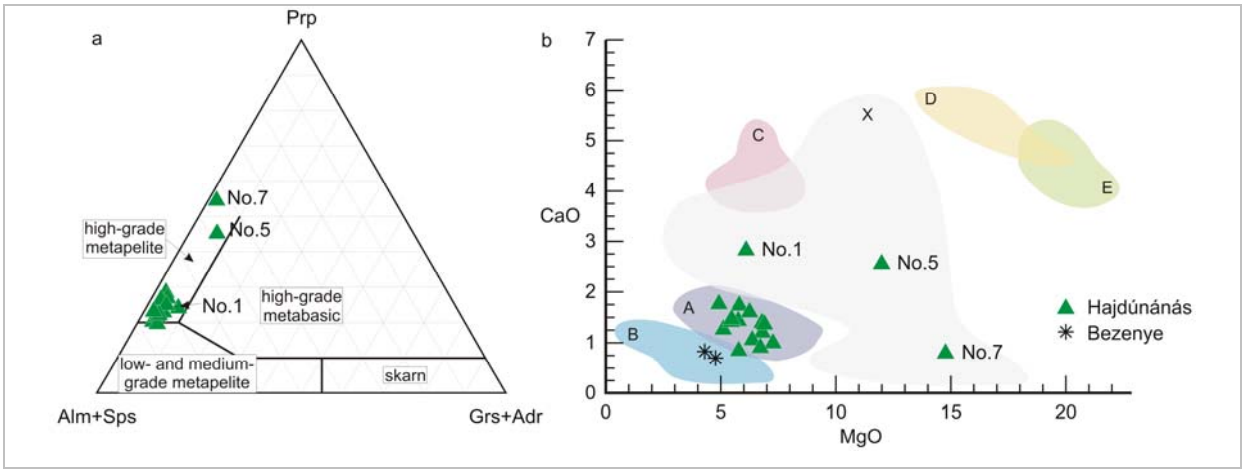


**Fig. 11.:** a) ternary plot with the end-member composition b) CaO/MgO plot, classification is based on Calligaro et al. (2008) modified by Gilg et al. (2010) c) metamorphic source rock characteristics of garnet as deciphered from its major element chemistry (modified after Morton et al. 2003)

**11. ábra:** a) a szélsőtag-összetétel háromszög diagramon b) CaO vs. MgO diagram, a rendszerezés alapja: Calligaro et al. (2008), Gilg et. al (2010) által módosítva c) a gránátkristályok főelem összetétele és metamorf forráskőzete közötti kapcsolat (Morton et al. 2003 alapján módosítva)

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**Table 4.:** Results of the SEM-EDS analyses: chemical composition (in weight %) and the molar proportions of garnet end-members; LD: limit of detection

**4. táblázat:** A SEM-EDS vizsgálatok eredményei: kémiai összetétel (tömeg %) és a gránát szélsőtagok moláris aránya; LD: kimutatási határ

| | No.1 | No.2 | No.3 | No.4 | No.5 | No.6 | No.7 | No.8 | No.9 | No.10 | No.11 | No.12 | No.13 | No.14 | No.15 | No.16 | No.17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 37,95 | 37,71 | 37,78 | 37,68 | 39,69 | 37,84 | 40,46 | 38,20 | 38,28 | 37,76 | 37,99 | 38,28 | 38,10 | 37,51 | 37,81 | 37,56 | 37,70 |
| $Al_2O_3$ | 20,50 | 20,96 | 20,72 | 20,70 | 22,23 | 20,82 | 22,73 | 21,33 | 21,38 | 20,41 | 20,84 | 21,66 | 21,17 | 20,33 | 20,38 | 20,18 | 20,78 |
| FeO (calc) | 28,45 | 31,54 | 31,58 | 32,21 | 22,61 | 30,68 | 20,69 | 31,44 | 31,54 | 31,71 | 30,53 | 30,32 | 31,00 | 33,83 | 31,45 | 31,07 | 31,66 |
| $Fe_2O_3$ (calc) | 1,97 | 0,70 | 1,38 | 1,38 | 0,79 | 1,26 | 0,24 | 0,52 | 0,59 | 2,20 | 1,62 | 0,10 | 0,78 | 1,84 | 2,16 | 2,32 | 1,36 |
| MnO | 2,41 | 2,79 | 1,48 | 1,31 | 0,21 | 1,99 | 0,34 | 0,55 | <LD | 0,73 | 1,00 | 1,39 | 1,41 | <LD | 0,56 | 2,19 | 2,01 |
| MgO | 6,10 | 5,11 | 5,76 | 5,45 | 11,99 | 5,80 | 14,77 | 6,81 | 7,27 | 6,37 | 6,79 | 6,90 | 6,72 | 4,92 | 6,25 | 5,47 | 5,78 |
| CaO | 2,82 | 1,26 | 1,43 | 1,41 | 2,55 | 1,73 | 0,79 | 1,20 | 0,99 | 1,05 | 1,39 | 1,36 | 0,90 | 1,76 | 1,60 | 1,46 | 0,84 |
| Total | 100,20 | 100,07 | 100,13 | 100,14 | 100,07 | 100,12 | 100,02 | 100,05 | 100,05 | 100,23 | 100,16 | 100,01 | 100,08 | 100,19 | 100,21 | 100,25 | 100,13 |
| cation numbers | | | | | | | | | | | | | | | | | |
| Si | 2,99 | 3,00 | 2,99 | 2,99 | 2,99 | 2,99 | 3,00 | 3,00 | 3,00 | 2,98 | 2,99 | 3,00 | 3,00 | 2,99 | 2,99 | 2,99 | 2,99 |
| Al | 1,90 | 1,96 | 1,93 | 1,94 | 1,97 | 1,94 | 1,99 | 1,97 | 1,97 | 1,90 | 1,93 | 2,00 | 1,96 | 1,91 | 1,90 | 1,89 | 1,94 |
| $Fe^{2+}$ | 1,87 | 2,10 | 2,09 | 2,14 | 1,42 | 2,03 | 1,28 | 2,06 | 2,07 | 2,10 | 2,01 | 1,99 | 2,04 | 2,26 | 2,08 | 2,07 | 2,10 |
| $Fe^{3+}$ | 0,12 | 0,04 | 0,08 | 0,08 | 0,05 | 0,08 | 0,01 | 0,03 | 0,04 | 0,13 | 0,10 | 0,01 | 0,05 | 0,11 | 0,13 | 0,14 | 0,08 |
| Mn | 0,16 | 0,19 | 0,10 | 0,09 | 0,01 | 0,13 | 0,02 | 0,04 | 0,00 | 0,05 | 0,07 | 0,09 | 0,09 | 0,00 | 0,04 | 0,15 | 0,14 |
| Mg | 0,72 | 0,61 | 0,68 | 0,64 | 1,35 | 0,68 | 1,63 | 0,80 | 0,85 | 0,75 | 0,80 | 0,81 | 0,79 | 0,58 | 0,74 | 0,65 | 0,68 |
| Ca | 0,24 | 0,11 | 0,12 | 0,12 | 0,21 | 0,15 | 0,06 | 0,10 | 0,08 | 0,09 | 0,12 | 0,11 | 0,08 | 0,15 | 0,14 | 0,12 | 0,07 |
| sumcat | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 | 8,00 |
| End-members | | | | | | | | | | | | | | | | | |
| Spessartine | 0,05 | 0,06 | 0,03 | 0,03 | 0,00 | 0,04 | 0,01 | 0,01 | 0,00 | 0,02 | 0,02 | 0,03 | 0,03 | 0,00 | 0,01 | 0,05 | 0,05 |
| Pyrope | 0,24 | 0,20 | 0,23 | 0,21 | 0,45 | 0,23 | 0,54 | 0,27 | 0,28 | 0,25 | 0,27 | 0,27 | 0,26 | 0,19 | 0,25 | 0,22 | 0,23 |
| Almandine | 0,62 | 0,70 | 0,70 | 0,71 | 0,47 | 0,68 | 0,43 | 0,69 | 0,69 | 0,68 | 0,67 | 0,66 | 0,68 | 0,75 | 0,68 | 0,67 | 0,69 |
| Grossular | 0,03 | 0,02 | 0,01 | 0,01 | 0,05 | 0,02 | 0,01 | 0,02 | 0,01 | 0,00 | 0,00 | 0,04 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 |
| Andradite | 0,05 | 0,02 | 0,03 | 0,03 | 0,01 | 0,03 | 0,01 | 0,01 | 0,01 | 0,03 | 0,04 | 0,00 | 0,02 | 0,05 | 0,05 | 0,04 | 0,02 |
| Skiagite | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,02 | 0,00 | 0,00 | 0,00 | 0,00 | 0,01 | 0,02 | 0,01 |
| Majorite | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |


**Fig. 12.:** Garnet slices from Bezenye-Paprét and their typical mineral inclusions: apatite and zircon crystals. Photo: Eszter Horváth

**12. ábra:** Bezenye-Paprétről származó gránátlapok és tipikus ásványzárványaik: apatit és cirkon. Fotó: Horváth Eszter

**Results of the geochemical analyses**

The chemical analysis was performed in order to deepen our knowledge about the possible geological origin of the garnets. The resulting SEM-EDS spectra display characteristics of the pyralspite garnets, i.e. Fe-rich almandines as well as Fe-Mg-rich pyrope-almandines. Garnet is not a single mineral, but a group of isomorphous minerals with the general chemical formula $X_3Y_2(SiO4)_3$, in which "X" and "Y" represent sites in the crystal structure occupied by bivalent (X: $Ca^{2+}$, $Mg^{2+}$, $Fe^{2+}$, $Mn^{2+}$) and trivalent (Y: usually $Al^{3+}$, $Fe^{3+}$, $Cr^{3+}$) ions.

The garnet group is divided into two series representing solid solution of end-members with the combination of $X^{2+}$ and Y3+. The pyralspite series contains pyrope ($Mg_3Al_2(SiO_4)_3$), almandine ($Fe_3Al_2(SiO_4)_3$) and spessartine ($Mn_3Al_2(SiO_4)_3$) while the ugrandite series contains uvarovite ($Ca_3Cr_2(SiO_4)_3$), grossular ($Ca_3Al_2(SiO_4)_3$) and andradite ($Ca_3Fe_2(SiO_4)_3$) end-members. Although within these two series the variation in composition is fairly complete and continuous, between the pyralspite and ugrandite end-members there appears to be a less continuous variation (Deer et al. 1997, 468-470).

Regarding the composition in general, the specimens from Hajdúnánás have an extremely low MnO concentration (**Table 4**), in a few cases this value was even below the detection limit (max: 2.79%, spessartine proportion: 6.36%). Besides, they have a low CaO concentration as well falling below 3%, their grossular + andradite proportion falls below 8%. There are only two specimens (No.1 and No.5) with a relatively high CaO concentration and one of them has additionally a considerable MgO concentration as well (No.5). On the garnet compositional ternary plot fifteen of seventeen garnets fall approximately into the same group (**Fig. 11/a**). Their pyrope proportion is varied between 19.49 and 28.28% and their almandine proportion between 62.49 and 71.26%. On the other hand, there are two considerably different garnets left showing a higher pyrope proportion (No.5: 44.89%; No.7: 54.41%). Accordingly, in view of the MgO/CaO plot there are three specimens, i.e. No.1, No.5 and No.7, conspicuously differing from the majority (**Fig. 11/b**).

Concerning the geological environments of the paragenesis and the source rocks, the following conclusions may have been drawn. The measured low Mn content implies at least a medium-grade metamorphism and in the same way, the calculated pyrope proportion points out to at least amphibolite facies source rocks (Miyashiro 1953; Miyashiro & Shido 1973). The generally low Ca content confirms the results of the gemmological-mineralogical observations and refers on metapelites as source rocks (**Fig. 11/a**) (Miyashiro 1953; Deer et al. 1997; Morton et al. 2003). Furthermore, the metamorphic pressure is supposed to be lower than the eclogite facies, since garnets originated in eclogite facies rocks have already a decreased Fe content while their Mg content is even more increased (Deer et al 1997). There are only two exceptions, specimens No.5 and No.7, which due to the higher Mg content may have been formed within high-grade metamorphic conditions at least, most likely in granulite or perhaps already in eclogite facies rocks.

Summarising the results of the extensive inclusion analysis and the compositional analysis, it can be concluded that the raw material of the discussed garnets has experienced medium- to high-grade metamorphism for the most part at medium pressure. Their source rocks were most likely metapelites formed in the sillimanite zone: in the great majority of the specimens at the higher temperature part of the amphibolite or the lower temperature part of the granulite facies (P-T estimates: 550-700 °C and 4-8 kbar) and in case of two specimens (No.5 and No.7) at higher grade of the granulite facies or possibly at lower pressures of the eclogite facies.

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**Fig. 13.:** Garnet cabochon from Szentes-Nagyhegy and some of their typical mineral inclusions: rutile, monazite and ilmenite. Photo: Eszter Horváth

**13. ábra:** Szentes-Nagyhegyről származó gránát kaboson és néhány tipikus ásványzárványa: rutil, monacit and ilmenit. Fotó: Horváth Eszter

## *Discussion about the provenance – the comparative analysis*

In order to determine the possible provenance of the garnet raw material a comparative analysis was performed on our results and the relevant literature data. Since amphibolite and granulite facies metapelites are widely distributed all around the world even with similar garnet composition, criteria of fingerprinting were needed to be specified. On the one hand it is evident that in archaeological point of view only the territory of the Old World can be considered. On the other hand, the character of the pieces from Hajdúnánás plays a more important role restricting the candidates to the well accessible and gem quality garnet provenances. The occurrence of the relatively large (a few cm), transparent, not zoned and not cracked garnet crystals with small inclusions is already fairly limited both in number and space. All further criteria are provided by the previous archaeometrical research and in the following we are focussing on observations concerning the early medieval archaeological material.

### Garnets in Early Medieval Europe

Provenance study related to the early medieval garnet jewellery has already a long history in Europe. Among the numerous analyses performed so far, results measured in Würtzburg, Mainz, Paris and latest in Munich prove to be significant (Greiff 1999; Quast & Schüssler 2000; Calligaro et al. 2008; Gilg et al. 2010). During the last fifteen years several thousand specimens representing not only archaeological assemblages but even geological samples from currently known deposits and mines were investigated resulting in a reference base. Consequently, earlier research is of great value contributing to the determination of garnet material used in the Early Middle Ages. On the basis of the specific mineral inclusions, trace element contents and slight differences in the concentration ratios of the major elements, five different garnet types or clusters were discerned dated to the Merovingian period. Moreover, there is an additional sixth type considered rather as a large heterogeneous group requiring still further categorisation. Due to the achieved characterisations, only restricted areas from India, Sri Lanka, Bohemia, Portugal and Scandinavia are to be considered as the most possible sources (Calligaro et al. 2008, 120-127, Pl. I.2; Gilg et al. 2010, 91-100, Fig. 7.). As the majority of the examined garnets belong to archaeologically dated artefacts, the temporal distribution of the one-time garnet use was also to be demonstrated. This chronological study led to some promising conclusions and developed the clustering towards a typochronological classification. It was concluded that garnet jewels produced in different time were decorated with particular combinations of garnet types (in this case type refers to the geological origin, Quast & Schüssler 2000, 87-90; Calligaro et al. 2008, 128; Gilg et al. 2010, 94-96.).

Regarding the identified inclusions and measured chemical compositions, pieces from Hajdúnánás have close analogies among garnet inlays of the 5th- and early 6th-century jewellery analysed in Western Europe. Although in our SEM-EDS results the Cr and Y contents were below the detection limits, this deficiency was compensated by a comprehensive inclusion analysis. Namely, the advantageous accessibility of these loose pieces made the detection of the inclusions more significant in the provenance study. As a result of our investigation, the discussed garnets are obviously corresponding with one of the clusters as well as the heterogeneous group discerned within the Merovingian period material. This is established on the MgO/CaO plot (see green triangles on **Fig. 11/b**) representing the relationship between the compositions and the possible sources. On the one hand, the majority of the garnets, namely fourteen pieces of almandine fit to Cluster A in Gilg et al. (2010) i.e. Type II in Calligaro et al. (2008). On the other hand, the three pieces left in the collection were similar to the intermediate pyrope-almandine garnets belonging to the heterogeneous Group X of Gilg et al. (2010) called Type III by Calligaro et al. (2008). It is considerable, however, that in view of

the measured refractive indices one of them was obviously identified as almandine (No.1) suggesting that Group X garnets are even more diverse that it was shown before. While Cluster A almandines are corresponded most likely to South Indian provenance, Group X specimens are usually parallel with garnets from Sri Lankan deposits (referred on an unpublished database compiled on the basis of geochemical literature by Susanna Greiff). The geological origin of alluvial garnet deposits from the southern Indian coastal sediments was discussed among others by Sabben et al. (2002). Based on chemical compositional analyses they have clarified that pieces from one single deposit could have been originated from different source rocks: metapelites and a particular type of charnockites were apparently discerned (Sabben at al. 2002, 285). In this way, the possible source rock of the garnets from Hajdúnánás could be even more determined definitely excluding some Sri Lankan and Indian charnockites.

**Further garnet material from the Early Medieval Carpathian-Basin**

As it was pointed out in the introduction, our analysis presented in this paper has only a few published analogies from the Carpathian Basin. For comparison another group of loose pieces is discussed here, the almandine plates unearthed at Bezenye-Paprét, in a 6th-century Langobardic cemetery (Győr-Moson-Sopron County, see the point on the map **Fig. 4/d**). These seven pieces (one of them is preserved in two fragments) can be considered as ready-to-set inlays (**Fig. 12**). As opposed to those ones from Hajdúnánás, they must have been mounted previously (Horváth 2008, 62-63.). Their mineral inclusions, furthermore their chemical compositions measured in case of two selected pieces are in accordance with the typical 6th-century inlay material, i.e. almandine garnets with poor chromium content, characterised by Calligaro et al. (2008) as Type I and by Gilg et al. (2010) as Cluster B (**Fig. 11/b; 12**). According to these latest archaeometrical results, the raw material of Cluster B garnets from Bezenye may have been exploited in North India most likely in the area of Rajasthan.

Analytical results of the loose garnets from Hajdúnánás and Bezenye imply that garnet material of the 5th-6th-century Carpathian Basin was parallel to those used in the contemporary Merovingian area. This correspondence is unambiguous considering both the garnet types and their temporal distribution indicating the same raw material sources and trade links. However, it is important to emphasise that the majority of the mounted red inlays is still waiting for a detailed characterisation raising several questions. At the moment, it is only supposed that Cluster A garnets generally used in the 5th century were continuously imported to the Carpathian Basin also in the 6th century, especially when large or cabochon cut inlays were needed. Namely, as the latest survey has pointed out, the original crystals of Cluster B garnets possessed cleavages tend to fracture, wherefore thin slices set in cloisonné work dominated among the 6th century jewels (Gilg et al. 2010, **Fig. 4.a**). A nice cabochon cut piece found in a 6th-century Gepidic grave at Szentes-Nagyhegy (Csongrád County, **Fig. 4/c**) would affirm this assumption because its detectable mineral inclusions are comparable with Cluster A and Group X garnets (**Fig. 13**). On the other hand, it is still unexplained whether the goldsmith's works produced in the Langobardic Pannonia may likewise contain garnets of Cluster A or Group X. In their case chemical analyses will play the decisive role as the cell walls hinder the comprehensive observation of the mineral inclusions.

## *Conclusions*

In the early medieval Europe red garnets were generally used as inlay decoration of fine metalwork. Regarding the identified garnet types from the 5th-6th-century Carpathian Basin and their temporal distribution, raw material sources proved to be the same as in the contemporary Merovingian area. Our study has revealed that the investigated gemstones are almandine and pyrope-almandine garnets. Summarising the results of the gemmological-mineralogical and geochemical analysis it can be stated that the raw material of pieces from Hajdúnánás formed in medium- to high-grade metamorphic source rocks, most probably amphibolite and granulite facies metapelites. Considering the facet grade rough edges on the semi-finished pieces it can be concluded that they may have been exploited from alluvial deposits. On the basis of the comparative analysis particularly South India and Sri Lanka are presumed as their provenance. Further localisation could be confirmed by monazite dating as well as additional Raman analysis of mineral inclusions.

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[*] A version of this paper was first presented at IMA2010, the 20th General Meeting of the International Mineralogical Association in Budapest (Horváth 2010). In this study we are focussing on the issue of provenance as results of the technological analysis concerning the reconstruction of the gem-cutting process, the applied equipment as well as the organisational aspects of this activity are intended to appear in a forthcoming paper

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