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Risto Kaukonen

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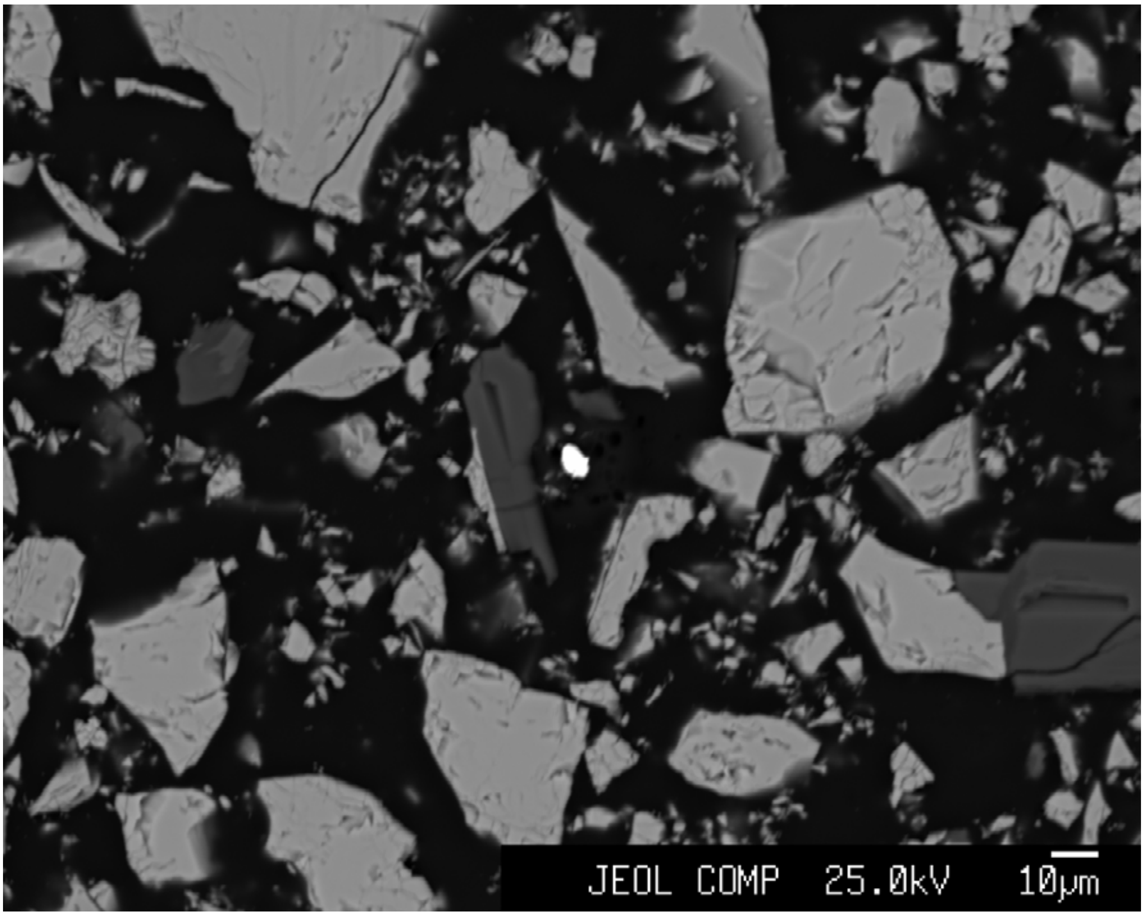
Mineralogy subproject

Final report



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Final report of the mineralogy subproject of the TEKES funded research collaboration project between Mineral Processing Laboratory of the Geological Survey of Finland, Department of Process and Environmental Engineering and Department of Geosciences of the University of Oulu, Finland, Kevitsa Mining, Outotec, Nordic Mines and KSV Instruments.

OULUN YLIOPISTO, OULU 2010

Cover figure: A typical example of how platinum-group minerals (white) occur in the flotation concentrates - as miniscule yet mostly liberated grains. The larger light grey grains are base metal sulfides, the dark grey ones are silicate gangue and the black matrix is the epoxy mount.

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Advanced and sustainable beneficiation of platinum-group minerals in sulfide-poor platinum deposits – BEPGE

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Final report

Risto Kaukonen

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PREFACE

This document is the final report for the TEKES funded research collaboration project aiming to improve the recovery of platinum-group elements from sulphide-poor platinum ores. The initial idea for this type of collaboration project was come up with by the late professor Tuomo Alapieti already in 2005 after getting encouraging results from the beneficiation tests of the silicate-hosted PGE ore of the Hanumalapur Complex of Karnataka, India. These tests had been carried out at the Geological Survey of Finland Mineral Processing Laboratory in Outokumpu. Unfortunately he didn’t live to see this project come into reality, but nevertheless the project finally began in 2008. The collaborating parties were Geological Survey of Finland, Mineral Processing Laboratory, Outokumpu, which had the lead responsibility, Department of Process and Environmental Engineering, University of Oulu and Department of Geosciences, University of Oulu as the main research parties and Outotec, Kevitsa Mining, Nordic Mines and KSV Instruments as business partners providing part of the funding, most of the ore samples and some technical and scientific advice as well as participating actively in the project steering committee.

CONTENTS

BACKGROUND

Most of the world's demand for platinum-group elements (PGE = Ru, Rh, Pd, Os, Ir and Pt) is supplied by extracting these metals from so-called reef-type deposits that occur in mafic layered intrusions. Quite often these deposits also contain significant concentrations of base metal sulfides which may be easily distinguishable by naked eye from the barren country rock. The biggest producers of PGE in the world today are South-Africa and Russia where PGE are being extracted from sulfide-type deposits.

In the 1980's and 1990's new types of PGE deposits were found from Finland and India, namely the SJ Reef of the Penikat Intrusion, the Rytikangas Reef of the Portimo Complex and the Hanumalapur occurrence (Alapieti & Lahtinen, 2002; Alapieti et.al. 2008).) These essentially silicate-type PGE deposits are almost completely devoid of base metal sulfides and the platinum-group minerals (PGM) occur either as inclusions in silicates or around their grain boundaries. The absence of visible base metal sulfides also makes it challenging to locate the borders of the mineralized rock. Nevertheless, these silicate-type PGE deposits may contain very high grades of PGE, even higher than most sulfide-type PGE mines that are operating currently. The challenge for the mining industry is how to mine and extract them efficiently.

Another type of ore deposit where improved PGE extraction technologies may lead to mining operations is the low-grade polymetallic type of base metal sulfide deposits. These types of ore deposits are relatively common in the world, though due to their low grade they may not be economically viable for mining operation for the values of the base metals only. In this type of deposits the PGM may be associated mainly with silicates rather than with sulfides, so from the point of view of beneficiation, even with relatively high base metal sulfide concentrations they would still qualify as sulfide-poor PGE deposits. In Finland for example the Kevitsa Main Ore falls into this last category and thus makes an excellent target for beneficiation studies.

TASKS OF THE MINERALOGY SUBPROJECT

The main tasks of the Mineralogy Subproject were to identify, analyze and characterize the platinum-group minerals in the ore samples and their associations with other minerals in the ore. This was to be done mainly using scanning electron microscopes (SEM) coupled with energy dispersive spectrometers (EDS) at the Department for Electron Microscopy, University of Oulu. The results were to be communicated to the engineers at the Geological Survey of Finland, Mineral Processing Laboratory and at the Department of Process and Environmental Engineering, University of Oulu.

Other tasks included assistance to other subprojects whenever there were issues requiring mineralogical expertise or utilization of SEM/EDS techniques. Also, some of the scientific data and results were to be published at scientific conferences or articles in appropriate scientific journals.

SAMPLES AND ANALYTICAL TECHNIQUES

According to the initial plan we would have samples from four deposits: 1) Hanumalapur Complex, Karnataka, India, 2) Kevitsa Main Ore, Finland, 3) Rytikangas Reef, Finland and 4) Kumiseva, Finland. In the end we had not been delivered samples from Kumiseva, and Hanumalapur was only used as reference material before samples from Kevitsa and Rytikangas arrived. Also, some samples from Laivakangas, Finland, were studied as reference material in the investigation of the effect of microwaves on ore samples. In addition to these, some synthesized mineral specimens were also analyzed.

All samples that were investigated (apart from Laivakangas and the synthesized specimens) were powders, flotation products, both concentrates and wastes. These powders were cast into epoxy mounts (Fig. 1.) the top surfaces of which were polished so that they could be investigated with an electron microscope.

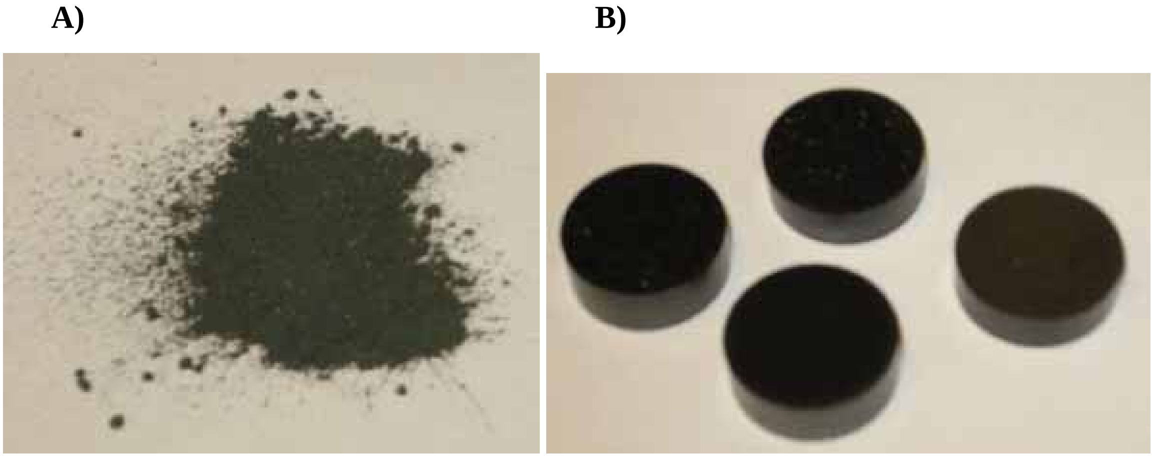


Fig.1. Sample powders (A) were cast into epoxy mounts (B) for electron microscope investigations.

The samples were scanned with an electron microscope looking for tiny bright spots on the back-scattered electron image (BEI), which delivers information about the average atomic number on the material below the electron beam. The higher the average atomic number the brighter the object will appear on the screen. Platinum-group minerals (PGM) have generally very high average atomic numbers and hence usually show up as very bright spots on the BEI. There are, however, other similarly heavy minerals that are not PGM, such as galena and monazite and various others, so each bright spot would have to be analyzed for chemical composition to identify it accurately. Depending on available hardware and software, these tasks of locating and analyzing the PGM qualitatively can be done either automatically or manually. During the course of this project we used both methods and two different instrumentations.

For automated scan a ZEISS UltraPlus SEM/EDS system coupled with INCA software package from Oxford Instruments was used. For manual scan a JEOL Superprobe 8200 was used. In the end we did most of the work with the latter system for various reasons. The JEOL was more readily available for our use as the queue to the ZEISS was usually much longer, up to a couple of months. While manual scan was slower than automated scan for locating the PGM, it was not actually much slower for the entire process of characterizing the PGM and their associations with other minerals than automated scan. This is because human eye can quickly skip barren areas of the sample whereas automated scan follows precise preset routines for scanning the sample and locating the PGM. For barren samples it took about an hour to do an automated scan and maybe an hour and 15 minutes for manual scan. The real work begins after PGM are located. They must be analyzed and identified based on chemical composition, measured for feret (X) and (Y) values for size and statistical calculations and most importantly their associations with other minerals must be characterized. It is that last bit that would have to be done manually to achieve the best and most reliable results even with the most advanced automated systems. To achieve reliable results, chemical analyses of PGM need to be done at a much higher magnification than locating them. For location detection, a magnification between 100x to 400x is common, but for good analyses magnifications of 1 000x to 100 000x should be used. As a rule of thumb when determining a good magnification for PGM analysis, the PGM should fill most of the screen. Hence, large PGM can be analyzed reliably with a smaller magnification than small ones. Neither system at our facilities at the University of Oulu had the option of automatically adjusting the magnification for analysis during scanning, so even with automated scan each PGM would have to be re-analyzed manually with proper magnification for better beam precision and subsequently enhanced analysis accuracy. Another problem with automated scan is encountered with composite grains. Automated programs do not distinguish possible different mineral phases within a single grain adequately and the resulting analysis represents a gibberish mixture of two or more mineral phases, whereas when done manually each phase can be analyzed separately to get the complete picture of the grain, which will also make sense.

The analytical conditions used on the Zeiss were 15kV voltage and 2.3 nA beam current. These were chosen mainly because the EDS system was calibrated for those values. On the JEOL 25kV and 15 nA were used, respectively. Counting times for EDS analyses were as follows: On Zeiss, 2 seconds for identification on automated scan and 60 seconds for manual analysis. On JEOL, 10 seconds for combined manual identification and analysis. These setups were adequate and acceptable compromises between time spent and accuracy and overall quality of analyses. The standards used for calibration were FeS_2 for sulfur, synthetic InAs for arsenic, PbTe for tellurium and pure metallic standards for other elements involved.

PGM INVESTIGATIONS

Karnataka

A few years before the beginning of this project some samples of the Hanumalapur PGE ore (see Fig. 2. for location) were tested for beneficiation purposes at the GTK Laboratory (Mörsky & Kangaskolkka, 2005). The preliminary beneficiation test results of this peculiar ore type, which was considered to be unsuitable or even 'impossible' for concentration by some, were very encouraging with recoveries of well over 50% for both Pd and Pt.

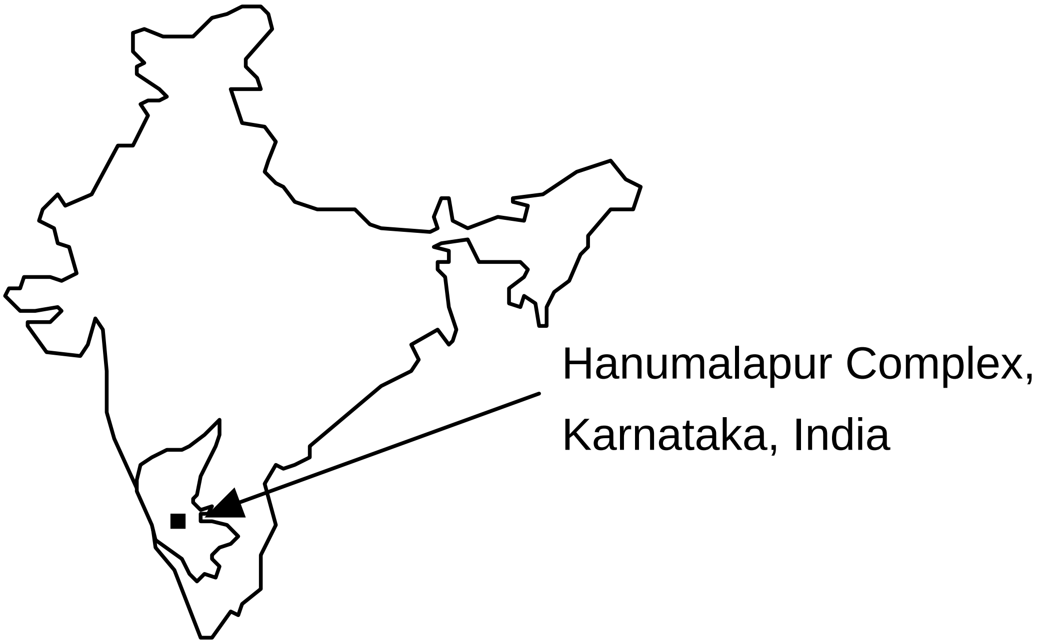


Fig.2. Generalized outline map of India showing a rough outline of Karnataka state and the location of the Hanumalapur Complex.

The samples from Karnataka represented the silicate-hosted PGE mineralization of the Hanumalapur Complex (Kaukonen, 2008). We started the experimental and analytical work with these while waiting for material from Kevitsa. However, we only scanned through a few samples before material from Kevitsa arrived and gave priority to those samples.

The little work we did on this reference material did not go to waste, however, as that data was used for an abstract and a poster to be presented at the 11th International Platinum

Symposium, in June 2010 at Sudbury, Ontario, Canada. Even though we only found a very limited number of PGM grains, these samples proved to be valuable for developing good preprocessing and flotation techniques, as their silicate mineralogy is quite different from most other ore types used for this project. The Karnataka silicate-hosted PGE ore is mostly composed of chlorite which is a very soft mineral. The PGM occur generally as inclusions in silicates or at grain boundaries between silicate and silicate or carbonate. PGE mineralogy is relatively simple consisting of sperrylite as the main carrier of Pt and some antimonides and tellurides carrying Pd.

The work on this reference material during this project proved fruitful as we discovered that one of the key factors for liberating the PGM properly from this type of very soft rock yet retaining the flotation properties is to not grind the rock too fine.

Kevitsa

The samples from Kevitsa (see Fig. 3. for location) arrived shortly after we had scanned through only a handful of the Karnataka samples. Kevitsa was our main target of investigation so we devoted most of our precious SEM time to those samples.

Kevitsa Main Ore is essentially a Ni-Cu sulfide ore with appreciable concentrations of PGE. The main product of Kevitsa is nickel and while we were trying to develop means of improving PGE recoveries a key factor was to not lose nickel in the process. One might question how does a base metal sulfide ore fit into the scheme of sulfide-poor platinum deposits. It actually does, as the PGM themselves are not sulfides but tellurides and arsenides and a great deal of them occur in silicates rather than in sulfides.

There are several ore types in Kevitsa, each with different mineralogical and structural characteristics (e.g. Mutanen, 1997) and a lot of different PGM have been found from the deposit (e.g. Gervilla & Kojonen, 2002; Gervilla et. al, 2003; Gervilla et. al, 2005). The most important PGM in the Kevitsa Main Ore, however, are sperrylite ($PtAs_2$) and a complete solid-solution series between melonite ($NiTe_2$), merenskyite ($PdTe_2$), michenerite (PdBiTe) and moncheite ($PtTe_2$). Other PGM that were encountered in the samples during the course of this project were mainly tiny isolated grains. These PGM included irarsite (IrAsS), sobolevskite (PdBi) and possibly some unnamed phases. Gold grains were also documented.

The samples from Kevitsa represented feed, concentrate and waste. In general terms the concentrates were obviously the most interesting samples as the number of PGM grains found from those were one or two orders of magnitude higher than of the feed and waste. That of course was to be expected and is a good thing, as in general terns it means that PGM are being liberated and recovered from the ore.

Fig. 3. Generalized outline map of northern Finland showing the locations of the Kevitsa Intrusion and the Portimo Complex.

Because the nature of the samples was different, they are not all mutually comparable, and mixing all the data into statistical calculations could lead to erroneous interpretations, the following diagrams and statistical descriptions are based on a set of four concentrates. The data sets of these four samples give a relatively good illustration of the platinum-group mineralogy of the concentrates.

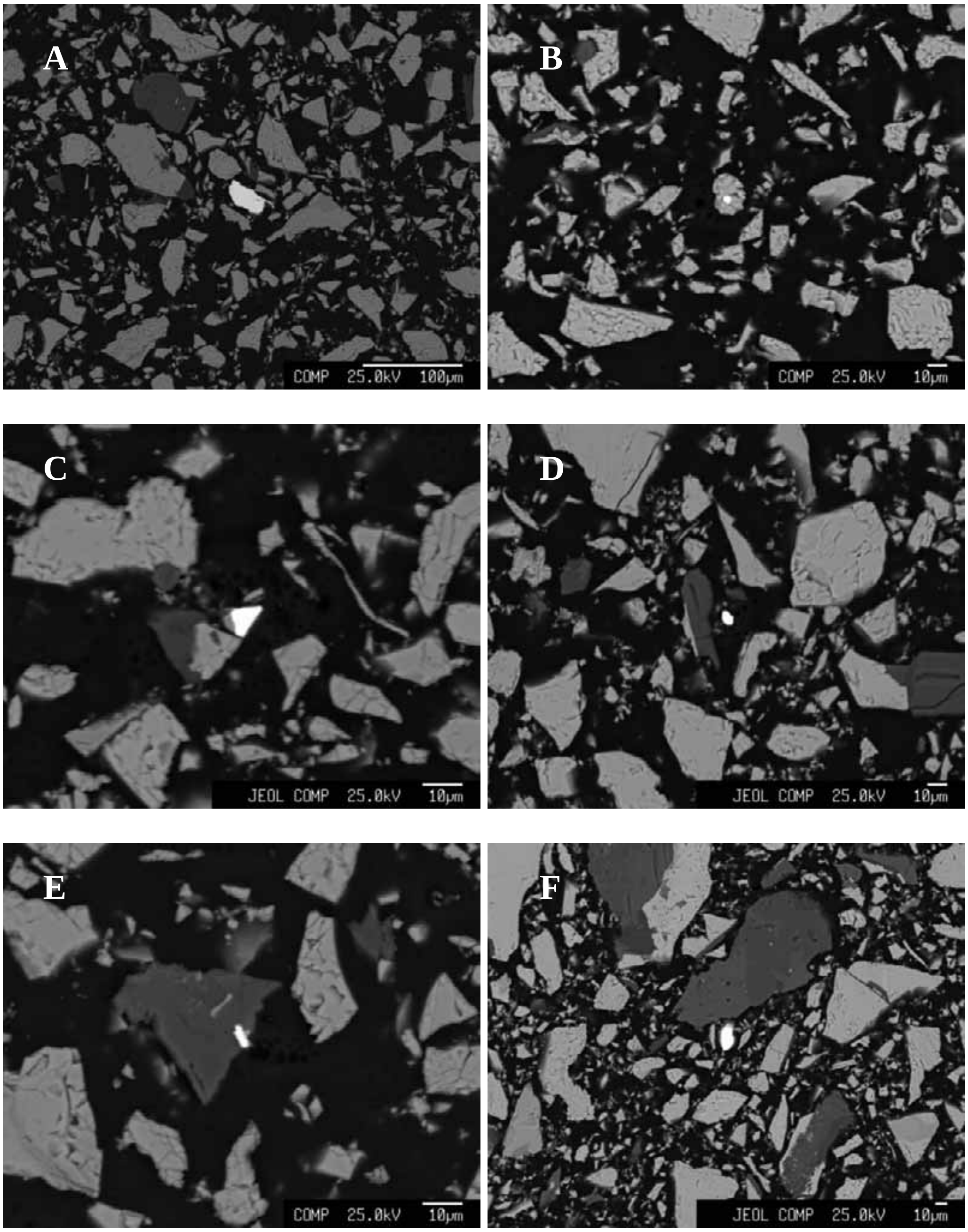


Fig. 4. Back-scattered electron images of some PGM in the Kevitsa Main Ore beneficiation test samples illustrating their different sizes and associations. Grey scale key for all images is: white = PGM, light grey = base metal sulfides, medium grey = magnetite, dark grey = silicates, black = epoxy mount. A) Large grains such as this (ca. 20x50 µm) melonite are usually liberated. B) Small grains such as this (ca. 3x4 µm) merenskyite occur in a wide range of associations. This one is an inclusion in chalcopyrite. C) A small (ca. 6x8 µm) grain of michenerite occurring on grain boundaries between orthopyroxene, magnetite and chalcopyrite. D) It is not unusual to find even small grains such as this (ca. 4x8 µm) michenerite to be completely liberated. E) A small (ca. 1.5x5 µm) grain of moncheite occurring as inclusion in orthopyroxene. F) Along with the telluride PGM, sperrylite is rather common in the Kevitsa Main Ore beneficiation test samples. This one is a ca. 9x16 µm liberated grain.

A total of 278 PGM+gold grains were found from these four samples. One of those grains was irarsite and another sobolevskite. Those two grains are not included in the following statistics. Common textures and associations of the PGM with other minerals of the Kevitsa Main Ore concentrates are illustrated in Fig. 4.

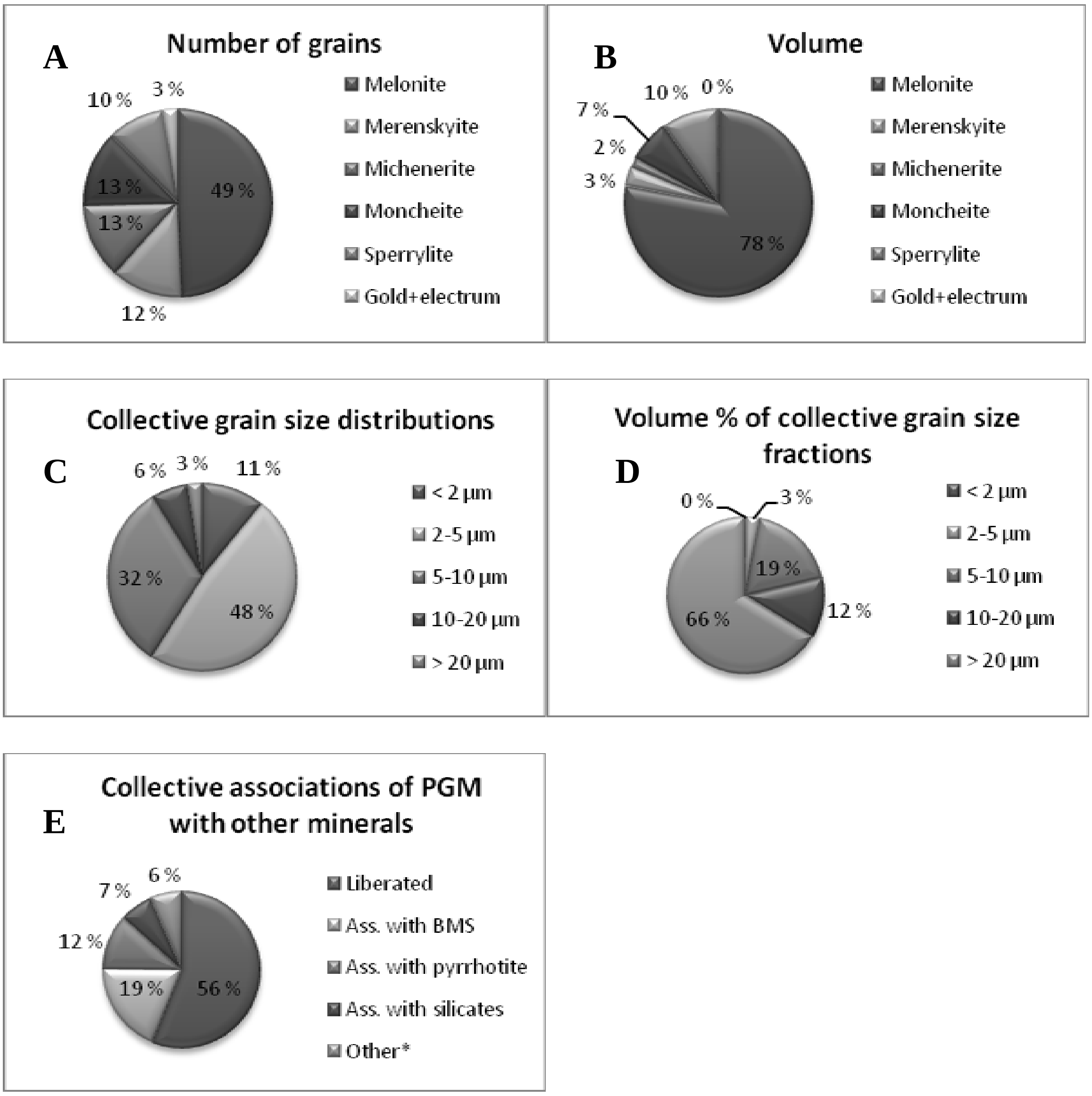
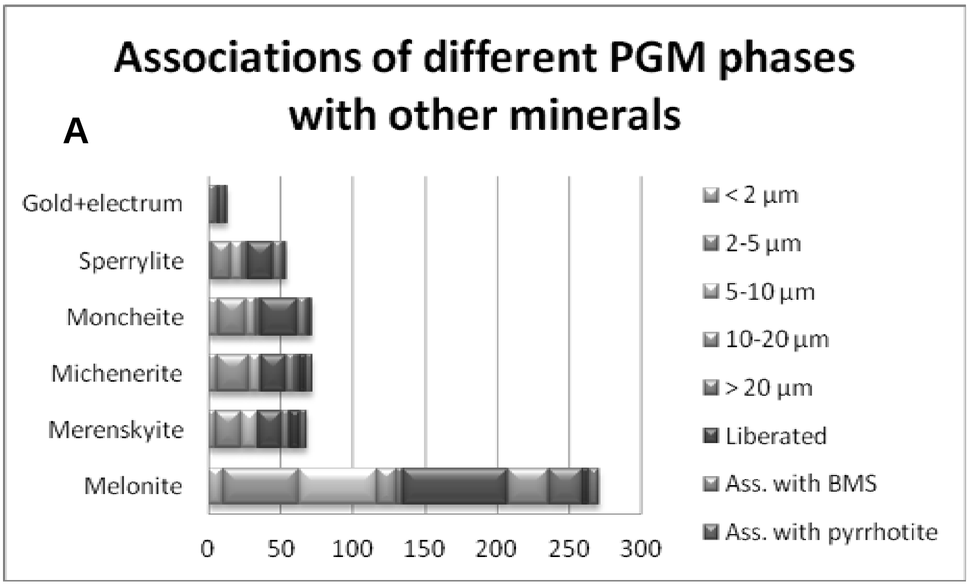


Fig. 5. A) Distributions of different PGM phases by number of grains. The total number of grains is 276. B) Distributions of different PGM phases by calculated reference volumes. C) Distributions of the grain sizes of all the 276 PGM grains encountered. D) Calculated reference volume percentages for different grain size fractions. E) Associations of PGM with other minerals. The term "Other" refers to all other encountered associations of PGM, such as with oxides or at grain boundaries with silicates and sulfides, for example.

Various relevant statistical pieces of information are presented in Figs. 5. and 6. Grain size distributions are presented collectively in Fig. 5C and for each mineral phase in Fig. 6A. Feret X (short) and Y (long) values were measured from each grain and the latter was used as a value indicating the size of each grain. Volumetrical values were calculated from the feret numbers by first calculating an area value for each grain simply by multiplying X by



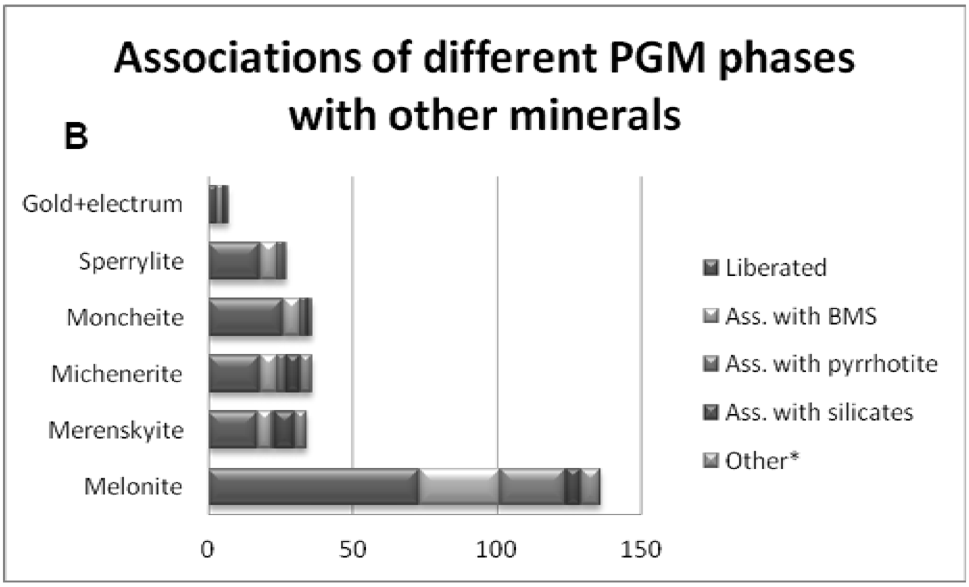


Fig. 6. Figures 5 C and E broken down into indivual mineral phases. A) Grain size distributions of individual PGM phases and gold+electrum. B) Associations of individual PGM phases and gold+electrum with other minerals. Term "Other" as in Fig. 5.

Y and then calculating the radius of a circle of the same area and finally calculating the volume of a sphere with the same radius as the afore mentioned circle. The volumetrical statistics (Fig. 5B.) should be taken with a grain of salt as they can be misleading and any single larger than average grain can make a very big change in that graph. This is illustrated in Figs. 5C and D, as the number of > 20µm grains is only 3% of the total number of grains (Fig. 5C.) yet they constitute 66% of the total volume (Fig. 5D.).

The solid-solution series between melonite, merenskyite, michenerite and moncheite is illustrated in Fig. 7. The analyses show that in the Kevitsa Intrusion there seems to be a complete solid-solution series between not only melonite, merenskyite and moncheite but also between michenerite, as all these minerals contain invariably various amounts of Ni, Pd, Pt, Te and Bi. The solid-solution series seems so complete that naming these minerals can at times go equally correctly to one way or another. Hence, at least from the point of view of beneficiation, it might be practical to treat all four of them as one.

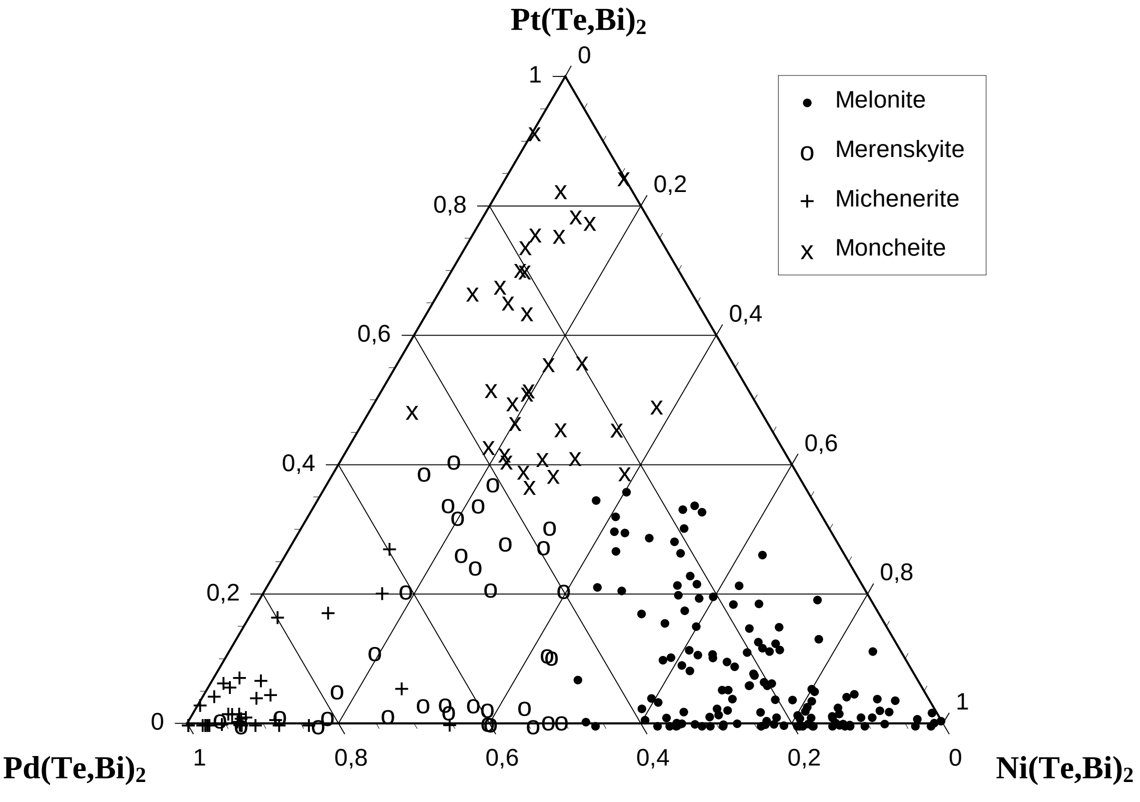


Fig. 7. A ternary diagram illustrating the compositional ranges of the melonite, merenskyite, moncheite and michenerite analyses of the beneficiation test samples of the Kevitsa Main Ore.

Rytikangas

The Rytikangas Reef is located in the Portimo Complex (Fig. 3.). The Reef as a whole is almost totally devoid of base metal sulfides even with Pt+Pd concentrations of 20 ppm (Iljina, 1994). The Rytikangas Reef is one of the best examples of sulfide-poor PGE deposits in the world known to date, along with the SJ Reef of the Penikat Intrusion (Halkoaho, 1994) and the silicate-type mineralization in the Hanumalapur Complex, India (Alapieti et. al, 2008; Kaukonen, 2008).

Only three samples from Rytikangas were delivered for mineralogical investigations. One of them was an ore sample ground to 1.5 mm grain size, one a flotation concentrate and the last one a flotation waste. Given the limited number of samples these samples should probably be considered as reference material, although their value may be significant for providing insights on the relation between liberation of PGM from a relatively hard rock (as opposed to the Karnataka samples) and their flotation properties in a complete absence of base metal sulfides.

Initially only one mounted sample was made from each of the 1.5 mm gravel, the concentrate and the waste. After examining the mounted samples no PGM were found from the waste and only one grain from the gravel, so second mounts were made from the gravel and the waste. The second sets yielded findings of one grain from the waste and 18 grains from the gravel. Because 235 PGM grains were found from the concentrate, and the findings from the gravel and the waste agree with the concentrate, the statistics presented in Figs. 8A-D only include the PGM of the concentrate.

The main PGM in the Rytikangas flotation concentrate are various Pd-antimonides, Pd-arsenides, sperrylite and hollingworthite. There are a lot of different PdSb±As minerals with distinct differences in crystal structure albeit subtle differences in chemical composition. EDS analysis only provides chemical data, which suggests that a whole array of different Pd-antimonides occur together. Hence, for simplicity, these were divided into two groups as depicted in Figs. 8. A and B. The group Pd-antimonides-1 consists of stibiopalladinite (Pd_5Sb_2) and naldrettite (Pd_2Sb) and the group Pd-antimonides-2 comprises isomertieite ($Pd_{11}Sb_2As_2$), mertieite-I ($Pd_{11}(Sb,As)_4$), mertieite-II ($Pd_8(Sb,As)_3$) and vincentite ($(Pd,Pt)_3(As,Sb,Te)$). The arsenides include arsenopaladinite ($Pd_8(As,Sb)_3$), palladoarsenide (Pd_2As), stillwaterite (Pd_8As_3) and a mineral calculating to the nowadays discredited mineral name of guanglinite (Pd_3As), which some consider to be identical to isomertieite (Cabri, 2002).

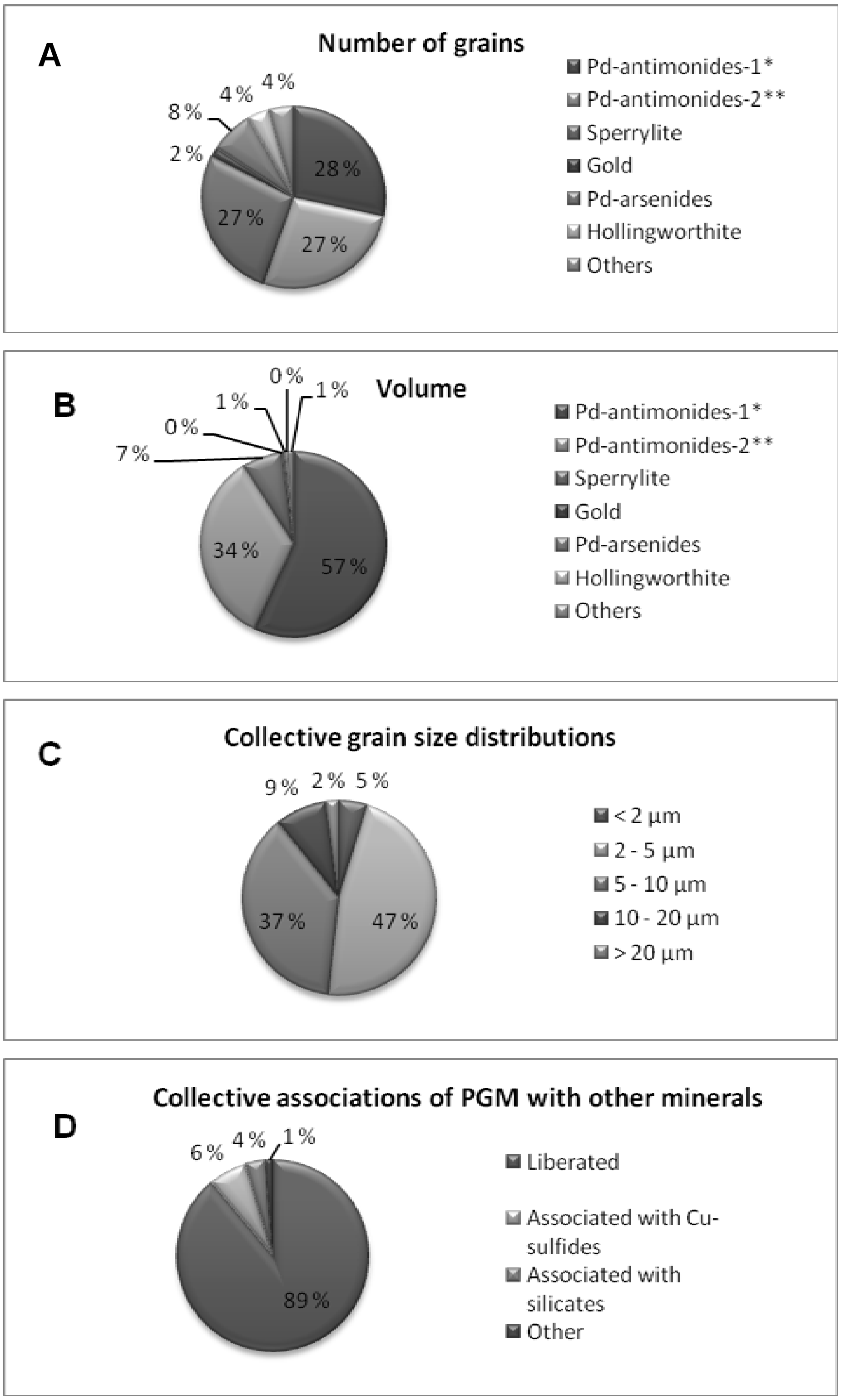


Fig. 8. A) Distributions of different PGM phases by number of grains. The total number of grains is 235. B) Distributions of different PGM phases by calculated reference volumes. C) Distributions of the grain sizes of all the 235 PGM grains encountered. D) Associations of PGM with other minerals. The term "Other" refers to all other encountered associations of PGM, such as with oxides or at grain boundaries with silicates and sulfides, for example. * = Stibiopalladinite+naldrettite. ** = Isomertieite+mertieite-I+mertieite-II+vincentite.

Other PGM that were encountered as tiny isolated grains in very limited numbers were kotulskite (PdTe), majakite (PdNiAs), melonite ($NiTe_2$), merenskyite ($PdTe_2$), michenerite (PdBiTe), and paolovite (Pd_2Sn).

A vast majority, 89 % of all the 235 PGM grains in the Rytikangas flotation concentrate were liberated. This included grains of all sizes. Fig. 9 illustrates some of the textures seen with the aid of an electron microscope.

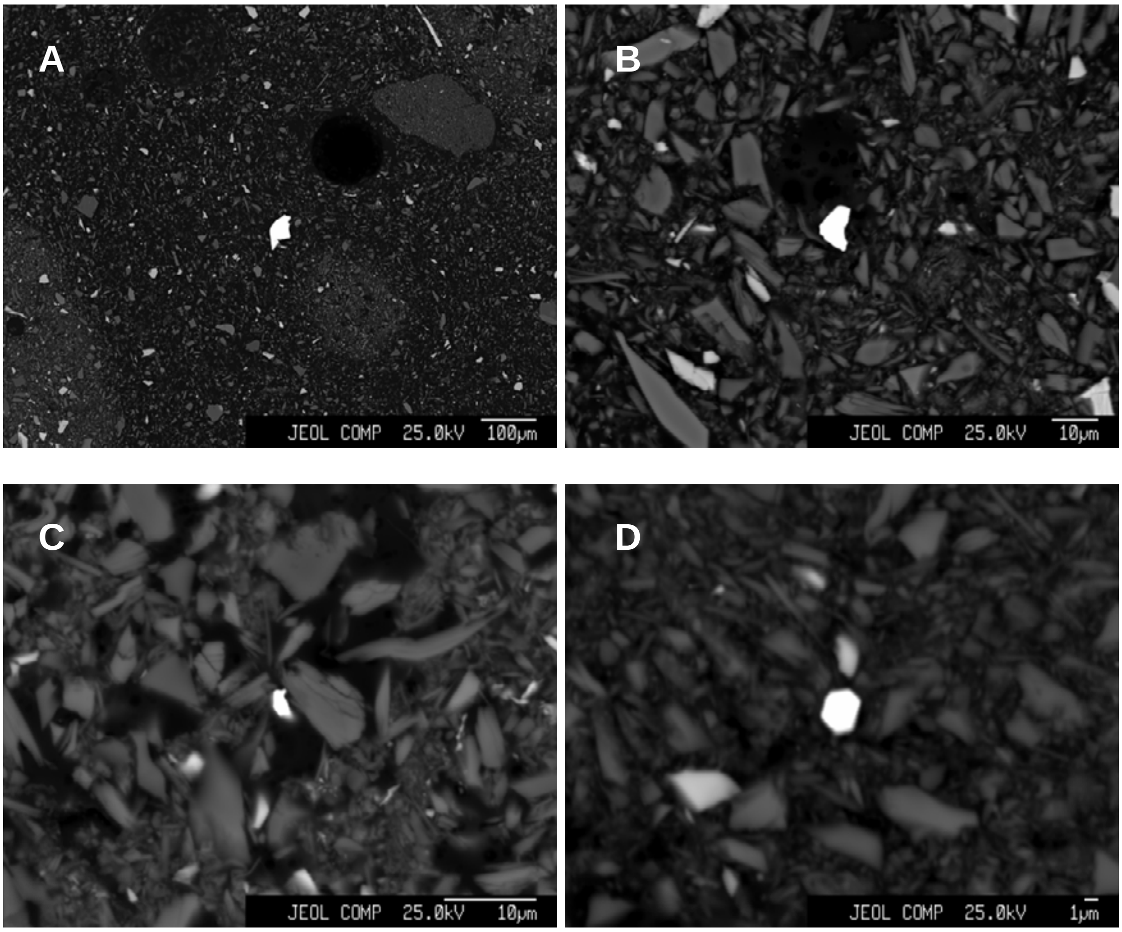


Fig. 9. Back-scattered electron images of some PGM in the Rytikangas Reef beneficiation test sample. Grey scale key for all images is: white = PGM, light grey = base metal sulfides, dark grey = silicates, black = epoxy mount. A) A very large (ca. 30x45 µm) grain of stibiopalladinite. B) A medium-sized (ca. 5x8 µm) grain of sperrylite. C) A tiny (ca. 1.5x3 µm) grain of sperrylite. D) A small (ca. 2.5x3.5 µm) euhedral grain of mertieite-II. All of the above grains are liberated like most of the PGM this sample.

OTHER INVESTIGATIONS

While the main task of the mineralogy subproject was to do the PGE mineralogical examinations of the flotation test samples and communicate that data to the beneficiation engineers, there were other tasks during the course of the project that required either geological or mineralogical expertise or experience with the use of an electron microscope and the interpretation of the images and analyses it can produce from a rough surface. Such situations arose during with the mineral synthesis and microwave studies.

Another “side-track” from the main task was the determination of the PGE content of pyrrhotite in Kevitsa Main Ore.

SEM studies of the synthesized PGM

The mineral synthesis will be explained with more details in another subproject report. However, as it also involved the mineralogy subproject a little, it will be reported here probably from somewhat different perspective.

Once the mineral samples were synthesized we needed to analyze them to make sure the process had been successful and the result was what we had been aiming for. The synthesized nuggets were mounted on aluminum mounts with special connective carbon adhesive tabs and secured with carbon cement. Then they were subjected to carbon coating to ensure connectivity all around. For analytical purposes these were by no means ideal samples as they were usually quite rough on the surface and also somewhat tilted to some direction. We couldn’t mount them properly into epoxy and polish them because we would have lost too much of the precious material in the process, hence some improvisation was necessary.

Figs. 10. A-D present some selected back-scattered electron images of the synthesized PGM. Despite the extremely rough and tilted surfaces at times, we were able to establish a reasonable understanding of the chemical composition for each case, and all but one experiment had been successful.

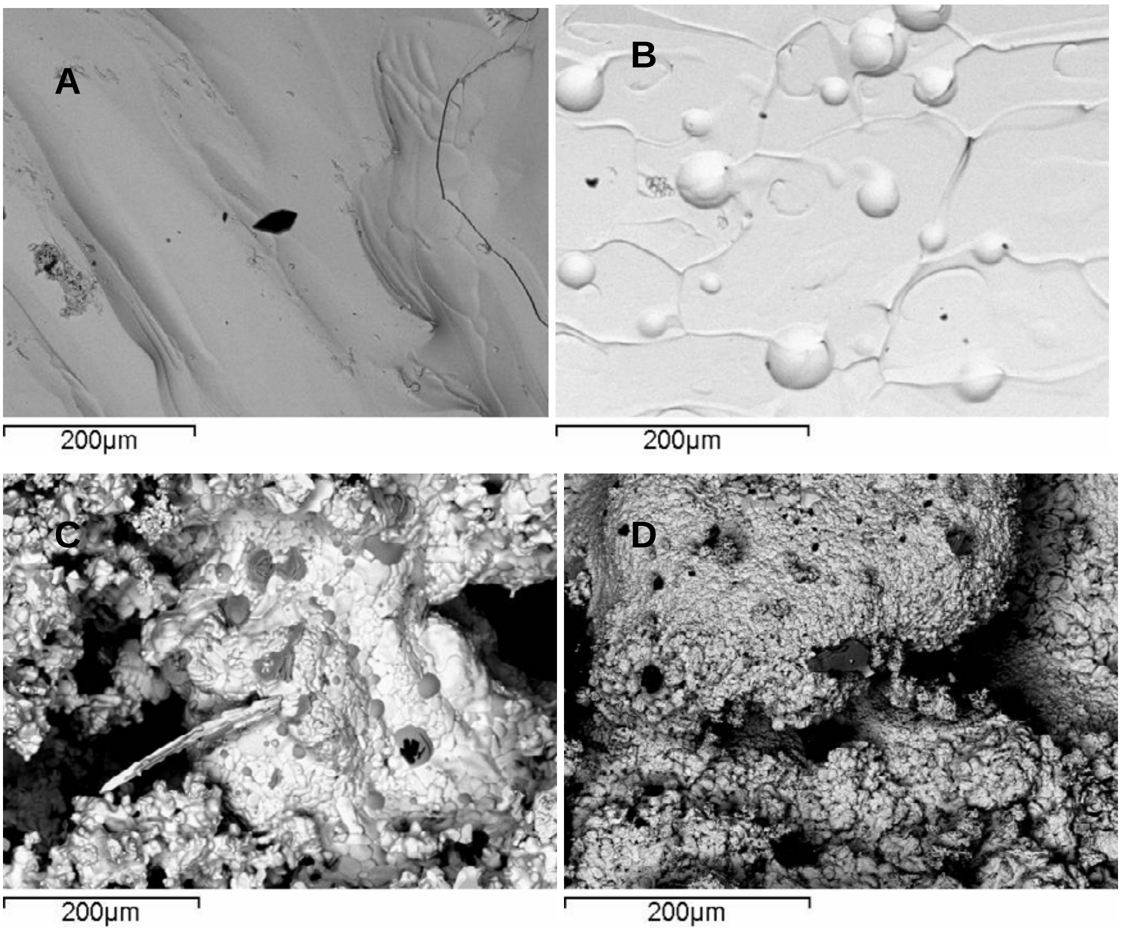


Fig. 10. Examples of synthesized PGM. A) Kotulskite (PdTe), B) Merenskyite ($PdTe_2$), C) Moncheite ($PtTe_2$) and D) Sperrylite ($PtAs_2$).

Studies of rock samples subjected to microwaves

Some rock samples were subjected to microwave radiation to investigate whether that sort of treatment would make a difference for crushing of the rock and liberation of PGM. Small coin-sized slabs were cut from the samples and polished from one side to allow examinations using both conventional ore microscope with reflected light and an electron microscope. The samples were examined and some key easy-to-find areas were photographed before subjecting them to microwaves. After the microwave treatment the samples were examined again. Some of these test images are presented in Figs. 11 and 12.

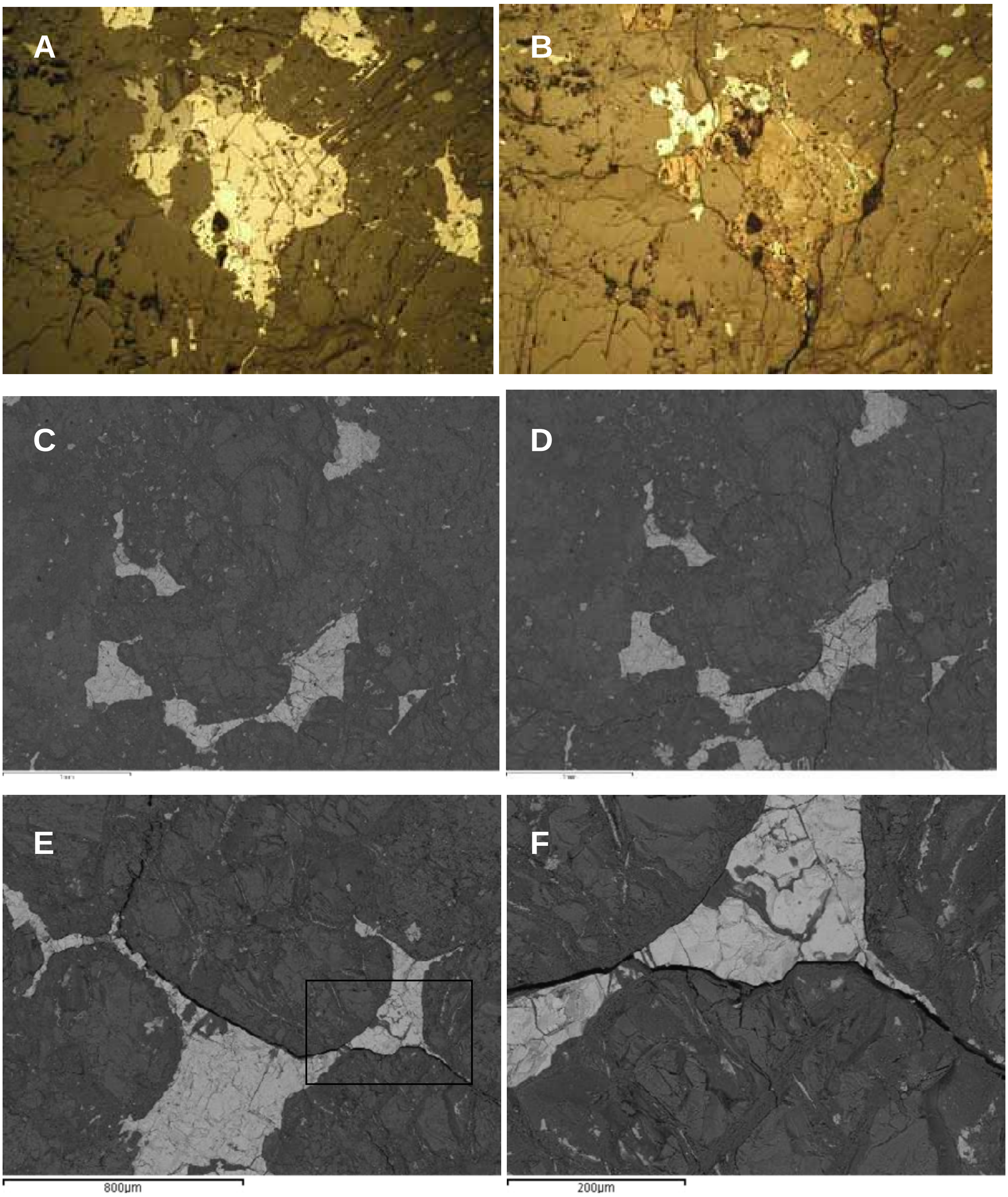


Fig. 11. Some sulfide-bearing ore samples from Kevitsa were subjected to microwaves. A) A composite grain of pyrrhotite, pentlandite, chalcopyrite and magnetite in silicate matrix seen in reflected light with an ore microscope before subjecting it to microwaves. B) The same grain as in (A) after microwave treatment. Large cracks have developed after 40 seconds of microwave radiation and the sulfides are distinctively tarnished. C) A back-scattered electron image of a similar section as above. D) Again large cracks have developed after 30 seconds of microwave radiation. E) Some of the cracks follow distinctly grain boundaries. F) A close-up of the area inside the rectangle in (E).

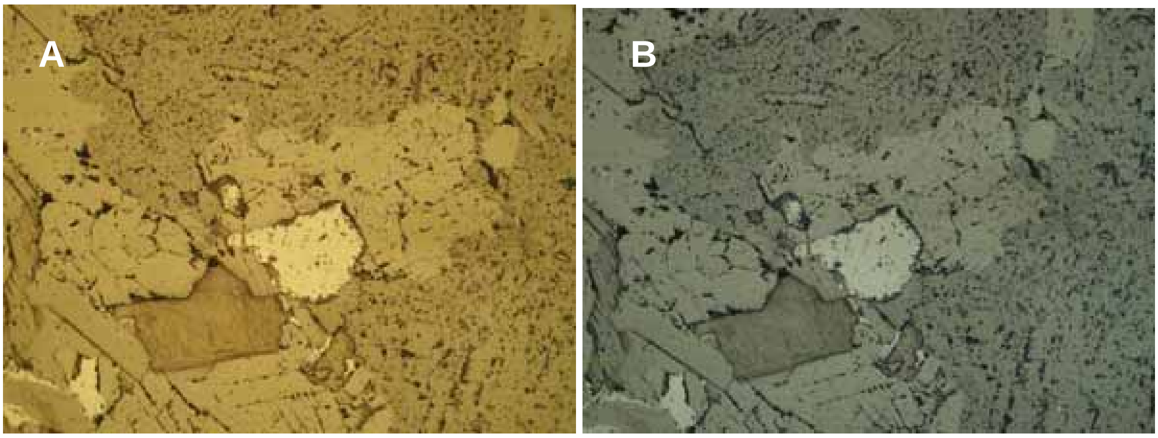


Fig. 12. A sample from Laivakangas seen under reflected light with an ore microscope. A) An image of a section before subjecting it to microwaves. B) The same section after subjecting it to microwave radiation for 120 seconds. Microwaves didn't seem to have any effect on this rock type.

Kevitsa pyrrhotite

There had been previous studies of the PGE content of base metal sulfides and arsenides of the Kevitsa Main Ore (e.g. Gervilla & Kojonen, 2002; Gervilla et. al. 2005). However, these studies did not include pyrrhotite, and that prompted us to perform a routine reconnaissance microanalysis of the pyrrhotite including Pd and Pt in the analysis program. The results were far too optimistic yielding a Pt concentration of over 500 ppm in pyrrhotite. This lead us to recalibrate the instrument and set it better suited for trace element analysis by increasing the counting time and searching for better places to measure the background peaks. Eventually we reached a point where we'd be getting consistent results of about 150-210 ppm of Pt in pyrrhotite and pentlandite but equally consistently below detection limit in chalcopyrite. Pd was consistently below detection limit in all analyses. Theoretically this is wrong as Pd should partition into base metal sulfides more strongly than Pt. So we still didn't believe we had it right. However, as microprobe isn't exactly the best tool for analyzing trace concentrations, we turned to GTK for help. Pyrrhotite was analyzed with their instruments for Pt and the result was indeed below detection limit, which confirmed our doubts. We were also finally able to tweak the setup of the microprobe at the University of Oulu so that it would also yield more accurate results for trace elements and were able to confirm the concentration of PGE in the Kevitsa pyrrhotite to be below detection limit.

SUMMARY AND CONCLUSIONS

The role of the mineralogical examinations in the BEPGE project was distinctively a supporting one all along from the beginning. Hence we didn't have any particular goals set for scientific publications, but were concentrating on gathering and communicating vital mineralogical data for the process engineers.

The most important questions to the mineralogy subproject were:

1) What are the PGM in the samples?

2) How do they occur in relation to other minerals?

3) What are the grain sizes?

The answers to these questions were found after rigorous examinations of the samples and for each case study they are in short as follows:

Karnataka:

1) Sperrylite, Pd-tellurides and Pd-antimonides.
2) 80% liberated, rest with silicates and oxides.
3) More than 50% are 5-10µm, most of the rest are smaller.

Kevitsa:

1) Sperrylite, Pd-Pt-Ni-Bi-Te minerals.
2) 56% liberated, 19% with BMS, 12% with pyrrhotite, 7% with silicates, 6% other.
3) 48% 2-5µm, 32% 5-10µm, some smaller, some larger and much larger.

Rytikangas:

1) Sperrylite, Pd-antimonides, Pd-arsenides, hollingworthite.
2) Almost 90% liberated, rest with Cu-sulfides and silicates.
3) Size distribution is very similar to Kevitsa.

During the course of the project we were able to fulfill our main task which was to establish the PGE mineralogy and the associations of PGM with other minerals of the flotation test samples brought to us.

Some of the data have been published as abstracts in scientific conference volumes. A list of these abstracts is included in an appendix. We also gave an oral presentation at the International Symposium on Magmatic Ore Deposits, ISMO-2009, in Bhubaneswar India, on the complete solid-solution series between melonite, merenskyite, michenerite and moncheite in Kevitsa. Currently we are preparing to give a poster presentation together with researchers from GTK at the 11th International Platinum Symposium in Sudbury, Canada, on the mineralogical investigations conducted during the BEPGE project.

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APPENDIX I

List of publications

Kaukonen, R.J. 2009, The Melonite-Merenskyite-Moncheite-Michenerite system in the Kevitsa polymetallic ore deposit, Northern Finland, International Symposium on Magmatic Ore Deposits, ISMO-2009 Abstracts Volume, Bhubaneswar, India.

Kaukonen, R.J., Luukkanen, S. & Maksimainen, T., 2010, Mineralogical investigations of small scale beneficiation tests of some sulfide-poor PGE occurrences, *Submitted* to 11th IPS, Sudbury, Canada.

Miettunen, H., Kaukonen, R.J., Kokkonen, T., Ojala, S. & Keiski, R.L. 2009, Mineral synthesis and carbon dioxide adsorption on some platinum-group minerals, International Symposium on Magmatic Ore Deposits, ISMO-2009 Abstracts Volume, Bhubaneswar, India.

Miettunen, H., Kaukonen, R.J., Kokkonen, T., Ojala, S. & Keiski, R.L. 2010, The Method for PGM Synthesis, *Submitted* to 11th IPS, Sudbury, Canada.