PAPER 14

Electric-Pulse Disaggregation (Epd), Hydroseparation (Hs) and Their Use in Combination for Mineral Processing and Advanced Characterization of Ores
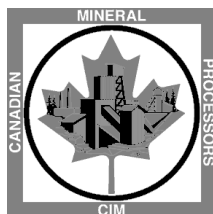
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ABSTRACT

EPD (Electric Pulse disaggregation) and HS (hydroseparation) are exceptional technologies for research, concentration, evaluation, and mineral extraction of specific minerals such as precious metals (Au, Ag, PGM), kimberlites (extraction and concentration of indicator minerals), zircons and baddeleyite (recovery of objects for geochronology), and even gemstones (method of evaluation and production of the 100% gemstone concentrate of ideal crystals) etc. EPD is used for recovery of pristine undamaged crystals of diamond, emerald, ruby, sapphire etc, including large crystals. It was tested on various hard ores and was especially successful for recovery of "soft" minerals from "hard" matrix. EPD products are very convenient for HS processing, resulting in representative concentrates of all heavy minerals including the finest particles (5-10 μm). The combined EPD and HS method enables high sensitivity (20 ppb) for evaluation of precious metal ores providing objective information about original grain size, associations, and recovery using a very small amount of sample (1-3 kg). Latest developments of EPD and HS techniques at CNT Mineral Consulting Inc. include the HS-21 hydroseparator (50 kg/hr) and the Spark-21 EPD (5 t/hr), which enables use of both techniques for prospecting and mineral processing of industrial size samples of certain ores.

INTRODUCTION

The main task for mineral processors is to find a reliable technology for testing of mining feasibility and the efficiency of mineral extraction procedures. Among various mineral processing approaches of extraction and concentration there are two alternative cost-effective methods that can be described as the most environmentally benign and complementary: electric-pulse disaggregation and hydroseparation. These techniques were tested on many different ore types and process products with great success providing a precise and comprehensive mineralogical determination of different accessory precious metal and other useful minerals constituent in rocks, ores, and tailings.

This article describes several examples of EPD and HS use: native gold from the Kostomuksha deposit (Karelia, Russia), a Ag-Au deposit in South America, zircons from ancient ultramafic igneous rocks of SW Greenland, bauxites of West Australia, PGM from the Driekop dunite pipe and gemstones (ruby, sapphire, emerald and demantoid) from different deposits.

ELECTRIC-PULSE DISAGGREGATION (EPD)

Since the early 1960s electric-pulse and electro-hydraulic methods were developing in Russia (e.g., Yutkin, 1961, Andres, 1977, 1989, 1995, Andres and Bialski, 1986, Andres et al., 2001). There were over 200 Russian (and Soviet) patents granted for methods and devices during these years for technical decisions in this field used in different areas, ranging from medicine to metallurgy. Special departments developing electric-pulse and electro-hydraulic techniques and devices working in four former Soviet governmental institutions were active until early 1990s. The history of the use of this method for geology and mineral processing beginning in the 1970s, but there was no serial or commercial production of such equipment. Publications that are more recent used earlier versions of EPD (e.g., Lastra et al., 2003, Shibayama et al., 2003, and Shuloyakov et al., 2003). The exceptional properties of electro-hydraulic and electric-pulse effects for mineral processing purposes were used by specialists

of CNT Mineral Consulting Inc. from 2002. Since then, the first commercial EPD device for mineral processing (CNT EPD Spark-2) became available.

Electric-pulse disaggregation (EPD) is a mineral separation technique that liberates all mineral grains from any rock irrespective of its lithology or grain-size distribution. Normal mechanical crushing of whole-rock samples is replaced by the rending effect of an explosion (Fig. 1), which is produced by applying an electric current from a high-voltage power source. A voltage greater than the 100 kV necessary for the electrical breakdown of rock samples is achieved by using capacitors that are charged in parallel but discharged in series. The sample sits in a water bath and the rapid distribution of electric pulses through the sample leads to explosions, which occur preferentially along grain boundaries (zones of weakness). As a result, individual, undamaged mineral grains can be recovered in their original shape and form regardless of grain size.
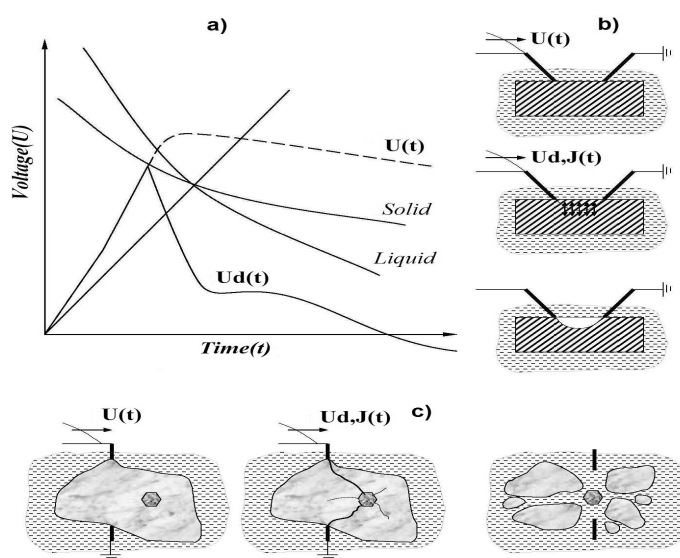

Figure 1: The principle of electric pulse disaggregation: a- volt-second characteristics for different state of matter; b- the breakdown and disaggregation sequence for one surface; c- the breakdown and disaggregation sequence for material fragments. U(t) – voltage pulse causing no electrical breakdown; Ud(t) - voltage pulse causing electrical breakdown in solid; Solid - U-t- characteristics of the breakdown processes in solid; Liquid - U-t- characteristics of breakdown processes in liquid.

A number of industrially and scientifically important minerals occur in a wide range of rock types as very subordinate (<1%), mostly unevenly distributed components; these are the so-called accessory minerals. Often they are precious metal-bearing phases, such as Au-Ag-minerals and platinum-group minerals (PGM), or industrially important minerals, such as diamonds, or they may be minerals carrying rare-earth and/or radioactive elements. Accessory minerals provide much information on their host rocks, for example, on its isotopic composition, absolute age and genesis. Apart from the fact that they are sometimes representative or characteristic of a particular type of ore or ore body, accessory minerals may be used as exploration guides and to assist in the study of ore-forming processes. However, to gain such information it is necessary to recover a concentrate of the accessory minerals. This usually requires a time-consuming process of crushing, in the course of which

the recovered accessory mineral fraction may become contaminated by other components or the minerals are broken and their original forms are destroyed. The EPD quickly releases all mineral grains in their natural size distributions and preserves their original shapes, so further concentration of different grain-size fractions can be achieved by gravitational, electromagnetic, flotation or other methods. The EPD can be used to release individual mineral phases or aggregates which provides an opportunity for detailed study of their morphology and shape, crystal structure, physical and textural features, and chemical composition.

Technical description and specifications of the CNT EPD Spark 2

The compressive force of normal mechanical crushing is replaced in EPD by the tension that is caused by the rending effect of an explosion (Fig. 1). The tension is created by the direct application of an electric current to the rock sample.
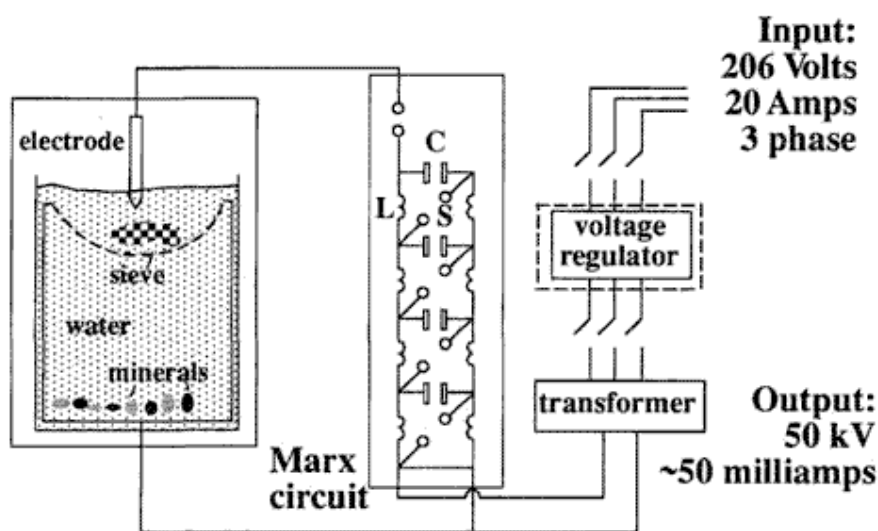

Figure 2: Generalized circuit diagram of electric-pulse disintegration apparatus showing basic components. Capacitors, *C*, are charged in parallel and discharged in series. Other electrical components: *L*, inductance coil; *S*, spark gap. Sieve size (in water bath, *left*) is varied according to grain size of sample.

A generalized circuit diagram (Fig. 2) shows the basic components: a high-voltage power source is used as input to a Marx circuit, which consists of a number of pulse capacitors. The capacitors, which are charged in parallel, allow the build-up of a voltage that is much higher than the input voltage, the increase depending on the number of capacitors in the circuit.

The electric discharge is triggered by means of "spark gaps", which, in practice, consist of two steel balls separated by air. When the spark gaps are triggered, the array of capacitors discharges in series. Inductance coils regulate the timing of the discharges. The discharge time for the circuit is approximately 1 ms at 20 kV and 0.1 ms at 40 kV. The technical specifications and operating parameters of the CNT Spark-2 are given in Table 1,

The water bath (Fig. 3) in which the sample is immersed acts as the last capacitor in the system. With the instrument mentioned above, at "low" voltages <50 kV the electrical

discharge initially passes through the water bath and the electrons travel around the rock. At >50 kV, however, the rock breaks down electrically. The breakdown is achieved when the electric current increases rapidly in a widening discharge channel that is filled by high-density plasma with the density of solid material. The plasma exerts a physical pressure on the rock, which results in an explosion. The explosion occurs preferentially along zones of weakness in the solid material (rock) and along the grain boundaries of mineral phases, particularly when the minerals have different electrical conductivities (Fig. 1). The discharge moves through the rock along grain boundaries because they present a better conducting path. The product consists of unbroken, individual mineral grains in their original shape and form, regardless of grain size.

Figure 3: EPD CNT Spark-2 (Ottawa): The Chamber, Marx Generator and Controls.

Use of the method may sometimes cause secondary contamination. Melted electrode material (i.e. from the steel, copper or aluminum used as the electrodes) can be found in the finest grain-size fraction but it can be removed magnetically in the case of magnetic stainless-steel EPD electrode were used. Less commonly, melted accessory minerals from the sample may appear in the finest fraction, although they are easily identified by scanning-electron microscopy (SEM) or electron-microprobe images. Particularly careful attention should be given to this phenomenon when natural mineral parageneses are reconstructed.

The EPD Spark-2 is assembled from high-voltage equipment of different capacities. In addition, EPD-chambers of different design, materials, and volume are now available for crushing.

Recovery of gemstones and diamonds by EPD crushing

Apart from purely scientific tasks, CNT Spark-2 EPD is also used for recovery of pristine undamaged crystals of diamond, emerald, ruby, sapphire etc, including large crystals (Fig. 4, a, b, c). The EPD device CNT Spark-2 has been working for nearly two years (20 hours/per day working cycle) at a mine site near Korkodino village (Urals) recovering nearly 200 kg per day of gem-quality garnet (demantoid) from productive rocks (Fig. 5).

Primary stage EPD recovery of the unbroken crystals of emerald from quartzite on the surface of the sample (left) and final production of 100% EPD concentrate of pristine emerald crystals from the same rock sample (right) is shown in Figure 4a.

Table 1: EPD Spark-2 Technical Specifications and Operating Parameters

PARAMETERS OF EPD SPARK-2	UNITS/RATE
Sample quantity per chamber loading (kg)	up to 15
Maximum sample size (mm)	up to 150
Maximum particle size of crushed products (mm)	<1 to 20
Required voltage (V)	220-380
Alternating current frequency (Hz)	50-60
Power consumption (kW/hour)	2-5
Height/width/depth (cm)	200/200/200
Weight without safety grid (kg)	up to 200
Water consumption/sample (L)	40
Productivity (kg/hour)	10 to 300
Working temperature range (ºC)	+10 to +30
Hours continuous operation (hours/day)	12

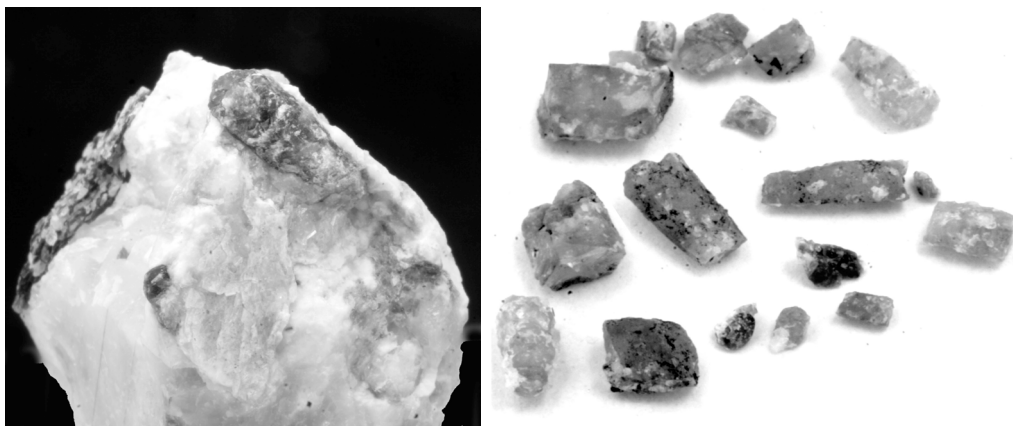**Figure 4a: The Efficiency of EPD Recovery of Emeralds**

Figure 4b: The Efficiency of EPD Recovery of Sapphire

Figure 4b shows the primary stage of EPD recovery showing relief of the unbroken crystals of sapphire on the surface of the rock sample (left) and final production of 100% EPD concentrate of pristine sapphire crystals from the same rock sample (right).
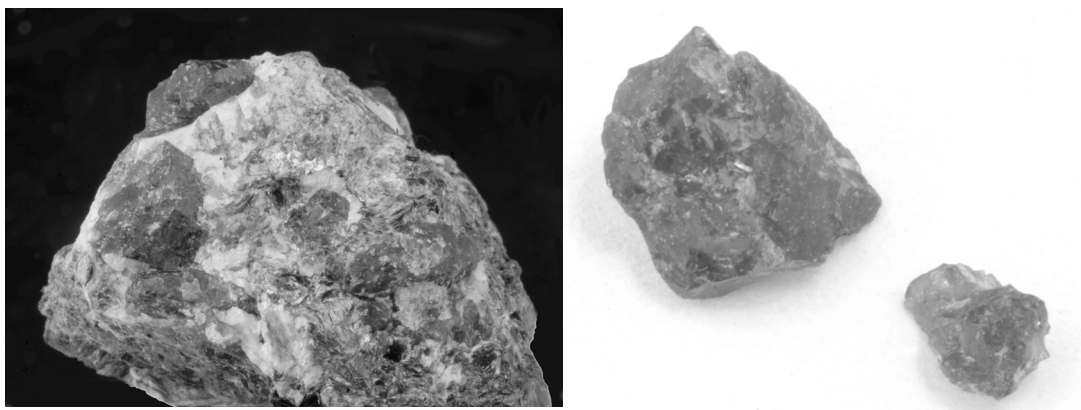

Figure 4c: The Efficiency of EPD Recovery of Ruby

Figure 4c shows the primary stage of EPD recovery of the unbroken crystals of ruby on the surface of the rock sample (left) and two gem-quality ruby crystals from the same rock sample (right).

Figure 5: An EPD production of 100% concentrate of demantoid crystals from productive rocks. The EPD crushed rock with dark demantoid crystals on the top as it thrown off the sieves (left) and one crystal on the host rock surface ideally preserved (right).

HYDROSEPARATION AND HS DEVICES IN USE

The commercially available hydroseparators (HS) (HS-01, HS-02, HS-11, HS-21) were invented to process solid water-insoluble powdered samples to produce representative "heavy-mineral HS concentrates" of particles that follow Stokes' law when settling in a carefully controlled upward pulsating water stream. Ideally, to be applicable for HS, powdered particles should have densities between 3 and 20 g/cm^3 and grain sizes of less than 0.3 mm, including industrial flotation size fractions (-45 µm).

All above mentioned devices, which are covered by several Russian and one Canadian patent, may be described as consisting of two separate parts: a Water Flow Regulator (WFR) and a Glass Separation Tube (GST) which have different size and design (Fig. 6). The WFR modulates the water flow according to different regimes that are experimentally determined by working on many different size fractions produced from samples of different origin and type. These regimes are dependent on the efficiency of the hydroseparation process (monitored visually under a binocular microscope) and are controlled by software designed for a PC to achieve the best efficiency of separation.

Figure 6: Hydroseparator CNT HS-11 at the German Geological Survey (Hannover)

The hydroseparation process moves the light fraction upwards in the GST with water, eventually collecting a vessel (beaker) under the GST. The heavy concentrate collects inside the GST at its base. Different sizes of GST are used for separation, depending on the grain-size and the required productivity of processing/amount of the loaded sample. Also, the latest design of GST, supplied together with the HS-11 and patented separately (Rudashevsky and Rudashevsky 2007), is equipped with a moving valve placed in the horizontal knee of GST. This invention allows better separation and higher productivity for a wider range of size fractions of the powdered samples.

The usual criteria for successful separation by means of laboratory-scale HS devices (HS-01, 02, 11) apply with respect to representative sample size and number. In general, the weight of the primary sample is principally a function of the overall homogeneity of the sampled material and the abundance and grain size of the "heavy" minerals to be determined. Typical samples weigh in the range from 10g to 2kg. Naturally, one should be guided by experience to decide how much material should be used for hydroseparation. However, from the authors' experience with the technique, it is necessary to have from 100 to 300 g of each size fraction (especially for the finest fractions, as they are the most informative to work with). The final concentrate of 5 to 20 mg is produced from preliminary concentrates after processing of standard aliquots of about 100g. Such aliquots are processed part by part by loading into the GST in the form of a slurry and portions of pre-concentrates are collected in

another vessel under the GST. The GST is suspended over a wide tray to avoid any loss of material that can be returned to the GST, if needed.

The concentration by hydroseparation is done with practically no loss of mineral grains. In different tests, mineral concentrates had 100 to 10,000 times the original proportions of the desired minerals. The technique has been applied successfully to samples having as low as 0.1-1.0 ppm of the phase forming elements of the desired minerals. The technique has been tested on many types of samples which are difficult to separate using normal techniques, and some examples include: PGM in chromite ores; PGM-Au bearing low-sulfide ores of layered intrusions and tailings; disseminated Cu-Ni ores; black shales; carbonatites; tailings from orthomagmatic sulphide deposits; native gold ores; Pt-bearing phases in ocean Mn-Fe crusts on basalts; kimberlites (to define diamond indicator minerals); low grade Ni-PGE ores, bauxites etc. Some examples of publications using HS include Cabri et al., 2005a, 2005b, 2006, 2007, Lastra et al., 2005; McDonald et al., 2005; Rudashevsky et al., 2002.

COMBINED USE OF EPD AND HS

In general, the proposed combined EPD and HS technique makes it possible to: study the crystal morphology, mineralogy and mineral chemistry of PGM and gold of different rock types containing low concentrations of these minerals; enhance the chances of finding accessory minerals for study by the Scanning Electron Microscope and the Electron Microprobe for identification and characterization of accessory heavy minerals (e.g., PGM, gold, zircon, baddeleyite, etc); carry out prospecting and technological mapping at a phase level from small samples (100-200 g); detect the occurrence of useful minerals and elements in possible secondary mineral deposits (process products such as mine tailings, industrial slag, etc); produce ultraclean separates of accessory minerals (e.g., zircon, baddeleyite) for geochronology without using toxic chemicals and reactants which may leach or crush desired minerals; separate intact crystals and/or crystal fragments of various gemstones.

The combined EPD and HS technique has been applied for the following tasks: to determine the identity of accessory minerals, their grain-size distribution, and their mineral associations; important information for economic evaluation and extraction; to contribute to better understanding of the paragenesis of deposits through detailed studies of accessory minerals; to separate of zircon, baddeleyite and PGE-mineral concentrates for age determinations; to make analysis of losses in tailings from concentration mills; analysis of Au & PGM in placers and source host rocks; to study of products from different stages of mineral processing; to study of environmental pollution (heavy-metal pollutants in solid phases). Two recent examples in the literature of the combined use are Cabri et al. (2007) on a gold ore and Oberthür et al. (2007 on a Pt ore.

EXAMPLES OF USE OF EPD AND HS IN CHARACTERIZATION OF ORES

The availability of fully patented commercial hydroseparators of HS series and first electric-pulse disaggregator CNT EPD Spark-2 has extended the list of a successful tests produced by different research teams around the world. Some examples of results of different research projects illustrating the use of combined EPD and HS techniques for different ore types are the following examples.

PGE mineralization from the dunite pipe Driekop (South Africa)

A sample weighing 676 g from Driekop platinum pipe (Bushveld Complex, South Africa) was submitted to CNT Mineral Consulting Inc. for mineral processing by means of combined EPD and HS technology (Oberthür et al., 2007). This sample was previously studied in 9 polished sections under optical microscopy and SEM, which resulted in 7 polished sections without any PGM grains. One polished section contained 2 grains of sperrylite (20 and 50 μm) and the last one contained 7 PGM grains forming a group (area 3x5 mm) of particles partly associated with sulphides (pentlandite): hollingworthite (RhAsS), sperrylite (PtAs$_2$), ruarsite [(Ru,Pt)AsS] and laurite [RuS$_2$]. Maximum diameters of PGM grains varied between 20 and 150 μm (Oberthür et al., 2007).

The EPD product of this sample is formed mainly by euhedral olivine and chromite grains (Fig. 7). The list of minerals recovered from the EPD product using a CNT HS-11 consists of 15 PGMs (over 500 grains from 5 size fractions in interval between –63 to 315 μm): Sperrylite (sp) 90-95% (of total assemblages) (Fig. 8); Pt-Fe alloy (Pt,Fe), 3-5% (Figs. 8, 9); Stibiopalladinite (Pd$_5$Sb$_2$, spd), 1-2%; Hollingworthite (hol), 1-2%
All other PGMs of the list are exotic for the studied sample and were attached to the margin of the main PGM grains of this sample, sperrylite, and Pt-Fe alloys. It should be noted that grains of the following minerals were preserved due to the delicate nature of EPD processing of the studied sample:

Table 2. Trace PGM Found In the Sample

Mineral	Label used/chemistry
Osmium	Os, (Os,Ru)
Ruthenium	(Ru,Os)
Laurite	lr
Arsenopalladinite or stillwaterite?	Pd$_8$(As,Te,Sb)$_3$,
Cherepanovite	(Rh,Ru)As
Pallododymite	(Pd,Rh)$_2$As
Rhodarsenide	(Rh,Pd)$_2$As
Naldrettite?	(Pd,Pt)$_2$(Sb,As)
Tulameenite	Tul
Tetraferroplatinum	PtFe
Pentlandite	With Rh, Ru

Native gold from Kostomuksha deposit (Karelia, Russia)

The mineralogy of a gold-sulphide-arsenopyrite ore sample from the Kostomuksha iron deposit region provided by Dr V.Ya. Gorkovetz (Mining Institute, Karelian Scientific Center, Russian Academy of Sciences) was studied by SEM in HS products from various non-magnetic fractions (40-300 μm) after EPD processing. The computer controlled hydroseparator CNT HS-11 produced a 100x concentration of native gold grains together with other ore minerals. Selection of >150 native gold grains from HS concentrates shows a grain-size distribution of 1-154 μm (average 33μm). Gold occurs as free grains (46.0%) in Figure 10, intergrowths with arsenopyrite (14.2%), löllingite (19.7%), and native bismuth (17.1 %), the latter three shown in Figure 11, and association with pyrrhotite (0.9%) and chlorite/apatite (2.0%).

Native gold was easily recovered because EPD crushing created "open" intergrowths with löllingite, arsenopyrite, native bismuth, or completely free grains. High gold recoveries should be possible using traditional gravity and flotation followed by cyanidation. Preservation of primary undeformed acute-angled grains of native gold and relatively large "soft" grains of Au+Bi among compact arsenopyrite grains in HS concentrates after EPD demonstrates the exclusive possibilities of this technology for extraction and concentration of gold.

Test sample from hard Ag-Au ores

The accuracy of EPD crushing can be illustrated on the example of its use for the processing of the specific ores containing "soft" accessory ore minerals enclosed in "hard" matrix gangue minerals. For a Ag-bearing ore with a hardness of 95 (test sample from South America), EPD processing was very efficient resulting good recovery of the large (30-300 μm) soft euhedral crystals of chlorargyrite (hardness - 2.5) and iodargyrite (hardness - 1.5) (AgI and AgCl ~ 0.1-1% of total volume) from the surface of very hard gangue mineral (quartz – 95 % of total volume) as avoided mechanical interference between these minerals. Indeed, it is hard to underestimate such an important aspect of EPD for processing of this type of ore with "soft" minerals in "hard" matrix rocks that are expensive to crush by conventional means. Further, SEM studies of heavy mineral HS concentrates of EPD product of these ores resulted in a wide range of data providing exceptional information on the morphology, real grain size, and associations of Ag mineral grains with gangue. Figures 12 and 13 show that chlorargyrite and iodargyrite were forming later than quartz and simultaneously with jarosite, barite and goethite which prove that these euhedral Ag-minerals crystals have been ideally recovered by EPD.

Bauxites of West Australia

The EPD products of bauxites (West Australia) and their HS concentrates was studied by different analytical methods (XRD, chemical assays, mass-spectroscopy and SEM with EDX analysis) in order to optimize the criteria for the recovery of Al-minerals. This resulted in understanding that these particular gibbsite type bauxites have a high quantity of quartz (~20%) together with a relatively large grain size (60-200 μm) in Figure 14. The EPD product of these bauxites is represented by soft fine-grained Al-minerals, thus hard quartz preserves its primary coarse grain size. The highest quality bauxite concentrate (<40 μm grain size, Al_2O_3 46.9 %, SiO_2 3.98 %, and Fe_2O_3 20.4 %, with 41 % recovery) was obtained by sieving of this EPD product.

Additionally, the study of HS concentrates (Fig. 15) produced from bauxites and their processing tailings ("red mud") provided data on the minor elements contained in the following minerals: ilmenite and pseudorutile (Ti, Mn, V, Nb, Ta); muscovite (K, Li, Be); zircon (Zr and Hf); Fe-minerals (goethite and hematite) – Sc; monazite and xenotime – REE (Ce- and Y-groups), and the radioactive elements Th and U.

Zircons from ancient ultramafic igneous rocks of SW Greenland

The EPD and HS results was used for mineralogical investigations of the sample of ancient ultramafic igneous rocks in South West Greenland, with the aim of recovery, separation and

identification of possible primary phases for isotopic (U-Pb, 40Ar-39Ar) measurements. The sample was selected from ultramafic rafts within gneisses. Primary main mineral of this rock is olivine; accessory minerals are chromite, ilmenite and sulphides (pentlandite, pyrrhotite sometimes chalcopyrite, polydymite) and secondary minerals are chlorite and biotite.

After hydroseparation (Hydroseparator HS-02M) the monolayer polished sections were prepared from half of each heavy mineral HS concentrate. These polished sections (and one polished section of the primary rock) were investigated under SEM with EDX. Twenty-one zircon crystals were hand-picked and placed on adhesive tape from the heavy mineral HS concentrates. Additionally, 10 crystals were extracted from the surface of polished sections after SEM studies.

We should underline the ideal safe recovery of zircon crystals from the EPD product and identification of the olivine inclusion in one of the zircon crystals (Fig. 16), which proves their synchronous formation. These results made it possible to provide useful samples for dating of typically "mute" ultramafic rocks.

CONCLUSIONS

The EPD method has been shown to be very efficient at processing very hard rock and liberating delicate minerals (e.g., gemstones) or very soft minerals (e.g., Ag halides, native gold and bismuth) from very hard matrix without breaking, smearing, while retaining their original shapes.

It has been demonstrated that EPD crushing followed by HS concentration on several very different types of rocks or ores is a protocol that produces valuable data that is not be possible using conventional methodology. The use of EPD and HS together with monolayer polished sections provides representative information on many different sample types, even in the case of a soft ore such as bauxite. Subsequent analyses of such polished sections by quantitative SEM-based image analysers would follow naturally from this methodology.

The CNT Spark-2 EPD is used in a commercial setting, producing at a rate of 200kg of gem material from a 20 hour shift. Latest developments of EPD and HS techniques include the HS-21 hydroseparator (50 kg/hr) and the Spark-21 EPD (5 t/hr), which will enable use of both techniques for prospecting and mineral processing of industrial size samples of certain ores.

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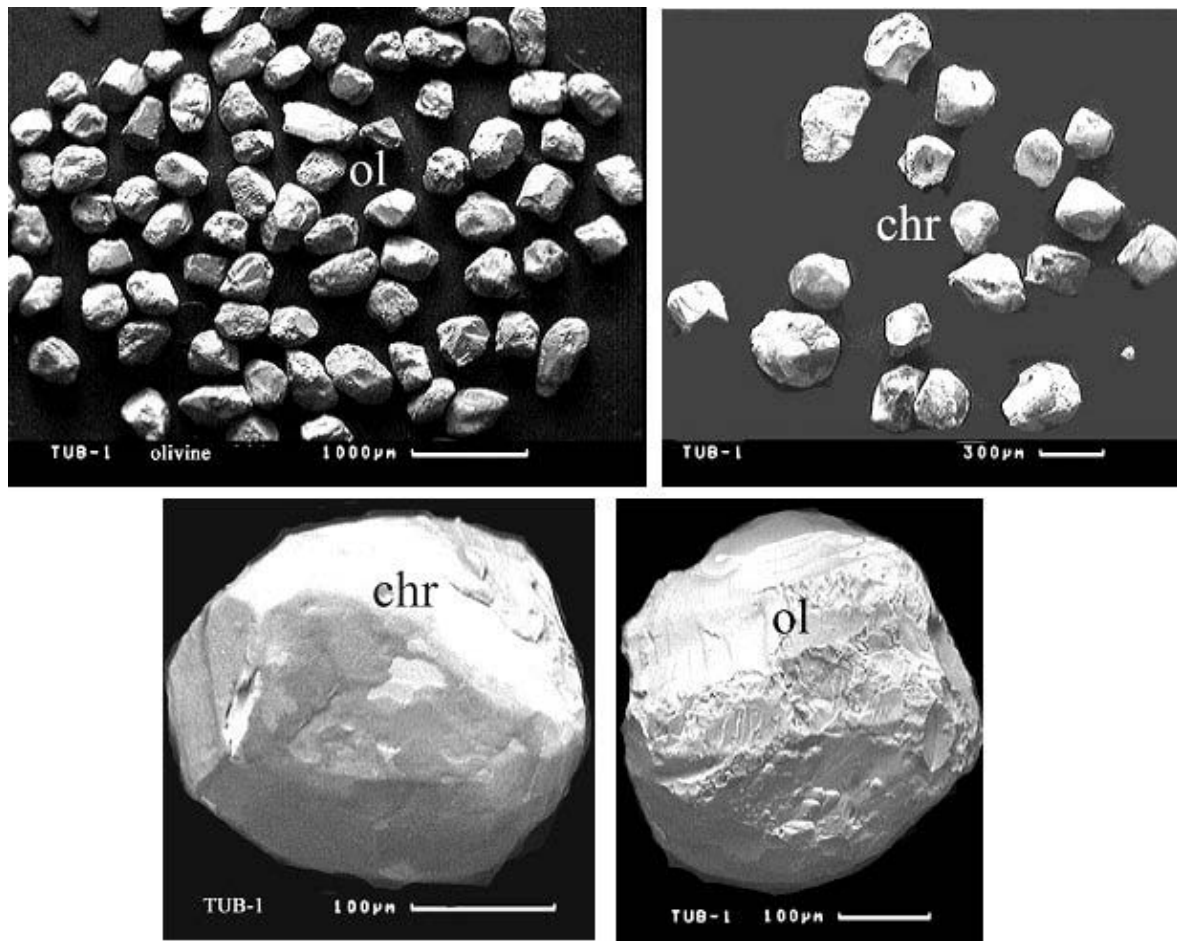
APPENDIX

Figure 7: SEM BSE Images Of Handpicked Olivine (Ol) And Chromite (Chr) Obtained From Epd Crushing
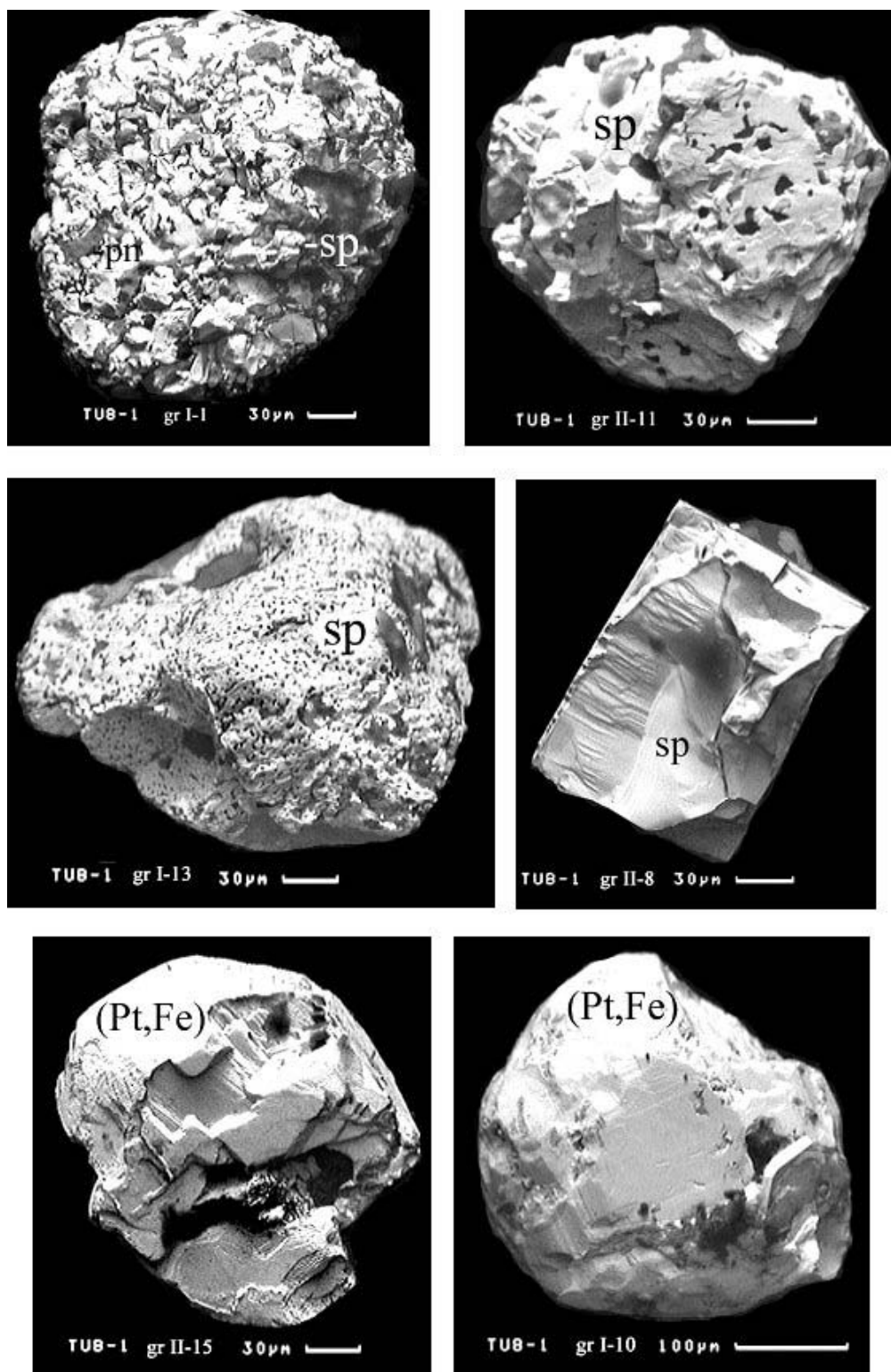
Figure 8: SEM BSE Images Of Sperrylite And Pt-Fe Alloy From The HS Concentrates After EPD Crushing. Sp = sperrylite, (Pt,Fe) = Pt-Fe alloy, pn = pentlandite
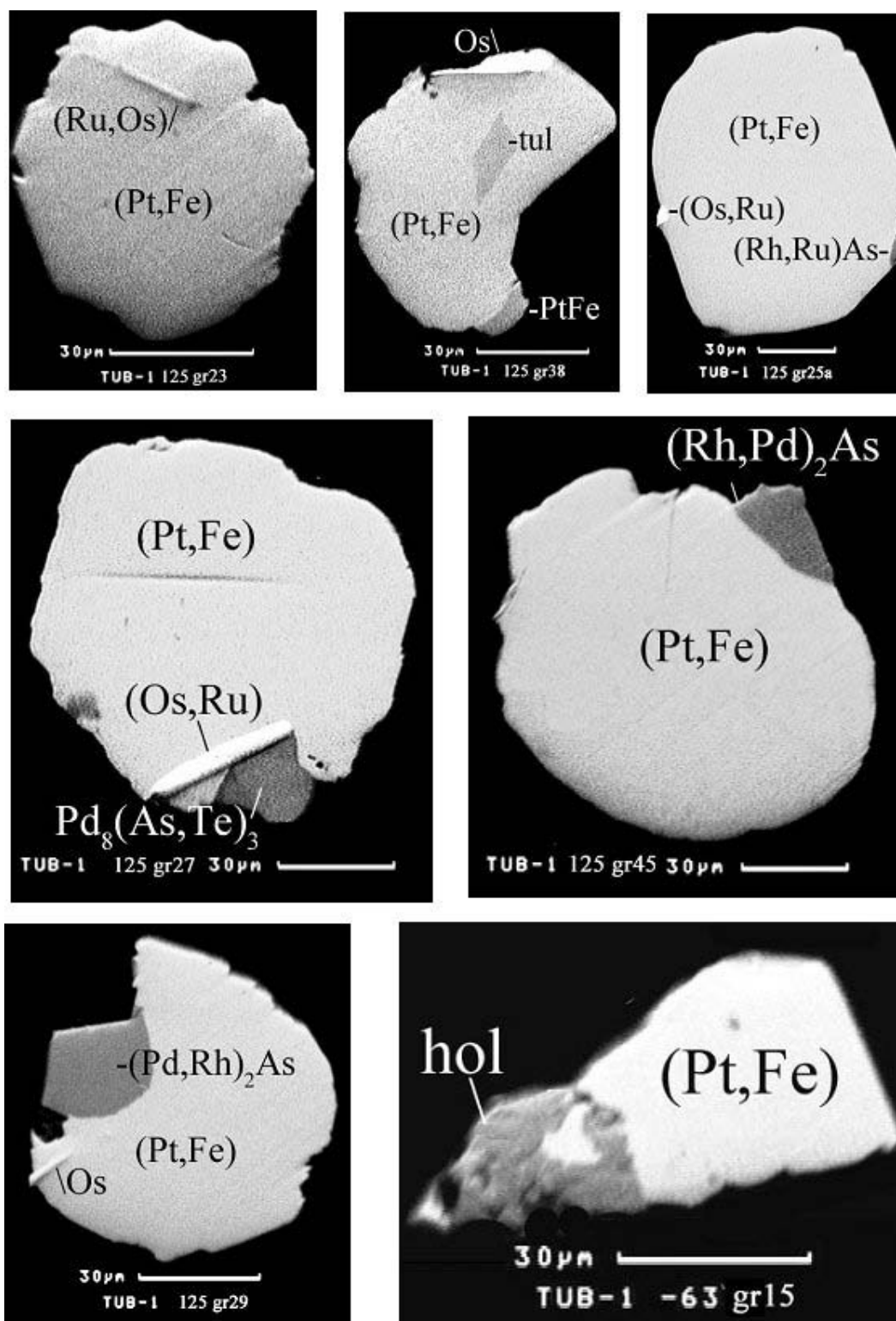
Figure 9. SEM BSE Images Of HS Concentrates After EPD Showing Pt-Fe Alloy (Pt,Fe), Tetraferroplatinum (Ptfe), Hollingworthite (Hol), Cherepanovite (Rh,Pd)As, Arsenopalladinite/Stillwaterite $Pd_8(As,Te)_3$, Rhodarsenide $(Rh,Pd)_2As$, And Palladodymite $(Pd,Rh)_2As$
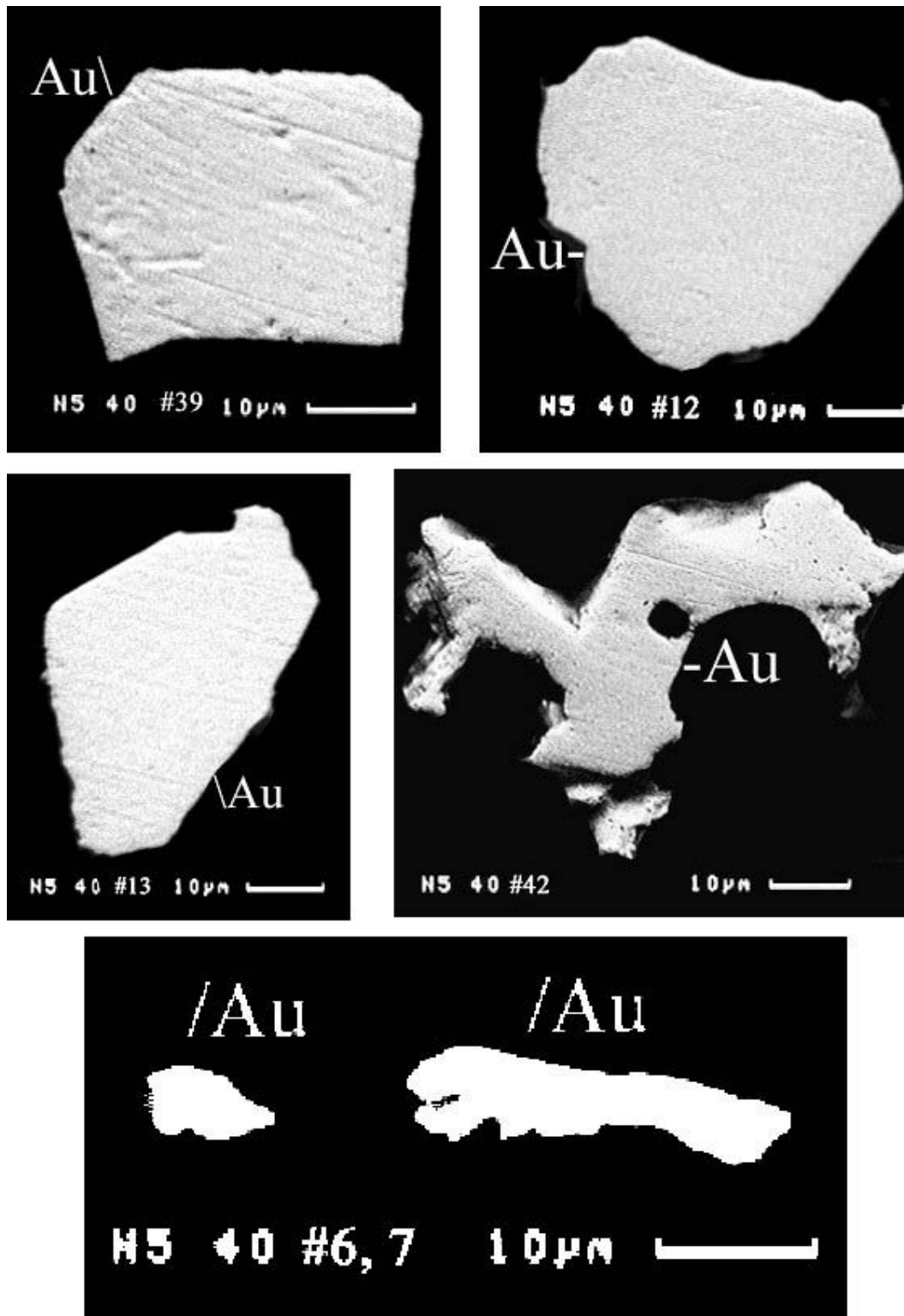
Figure 10: SEM BSE Images Of Free Particles Of Native Gold In HS Concentrates After EPD Crushing Showing Some Original Undamaged Crystal Faces
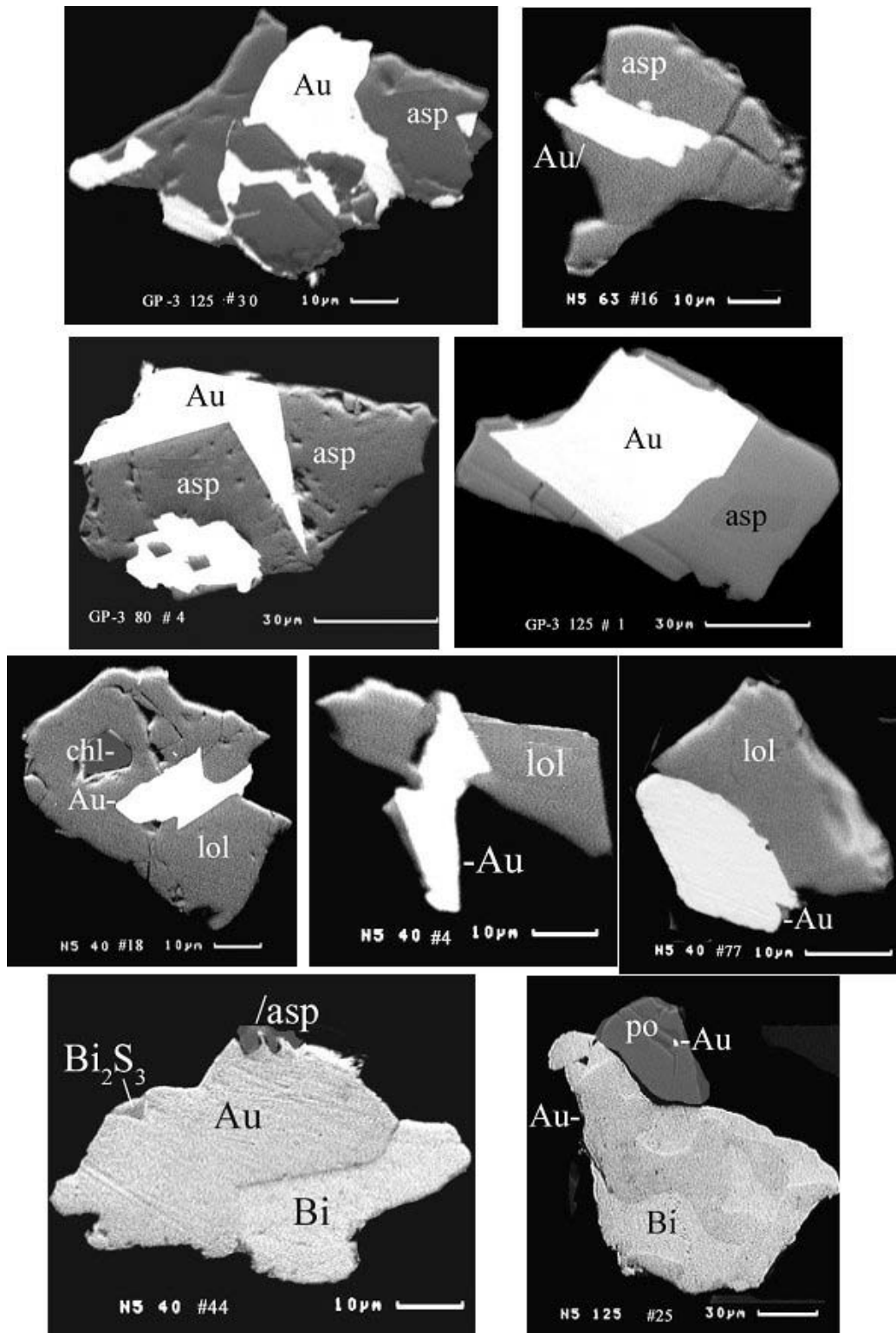
Figure 11: SEM BSE Images Showing Association Of Gold With Arsenopyrite (asp) Löllingite (lol) And Native Bismuth (Bi), As Well As Chlorite (chl).
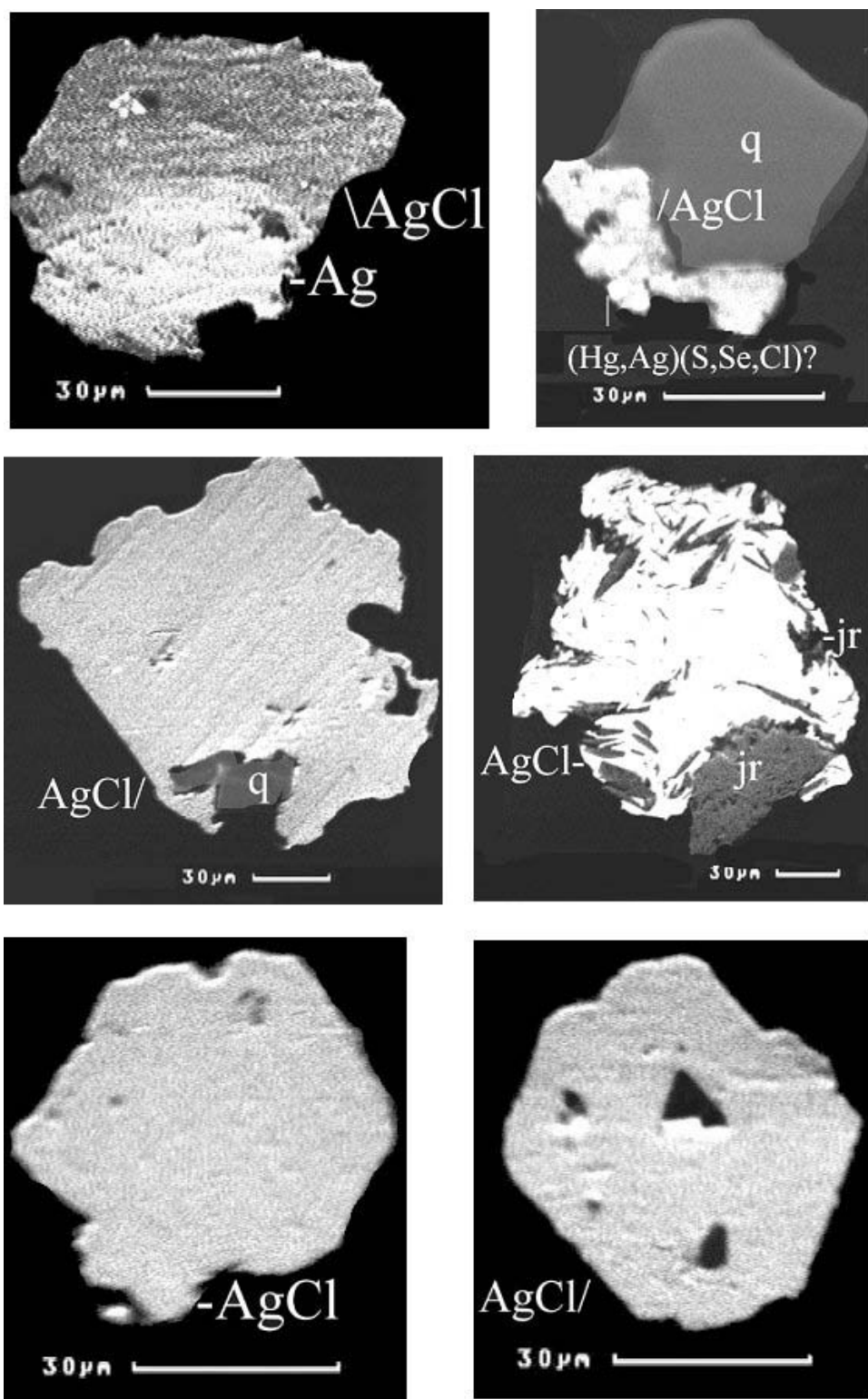
Figure 12: SEM BSE Images Showing Free And Exposed Particles Of Chlorargyrite In HS Concentrates After Crushing By EPD. Quartz = q, jarosite = jr.
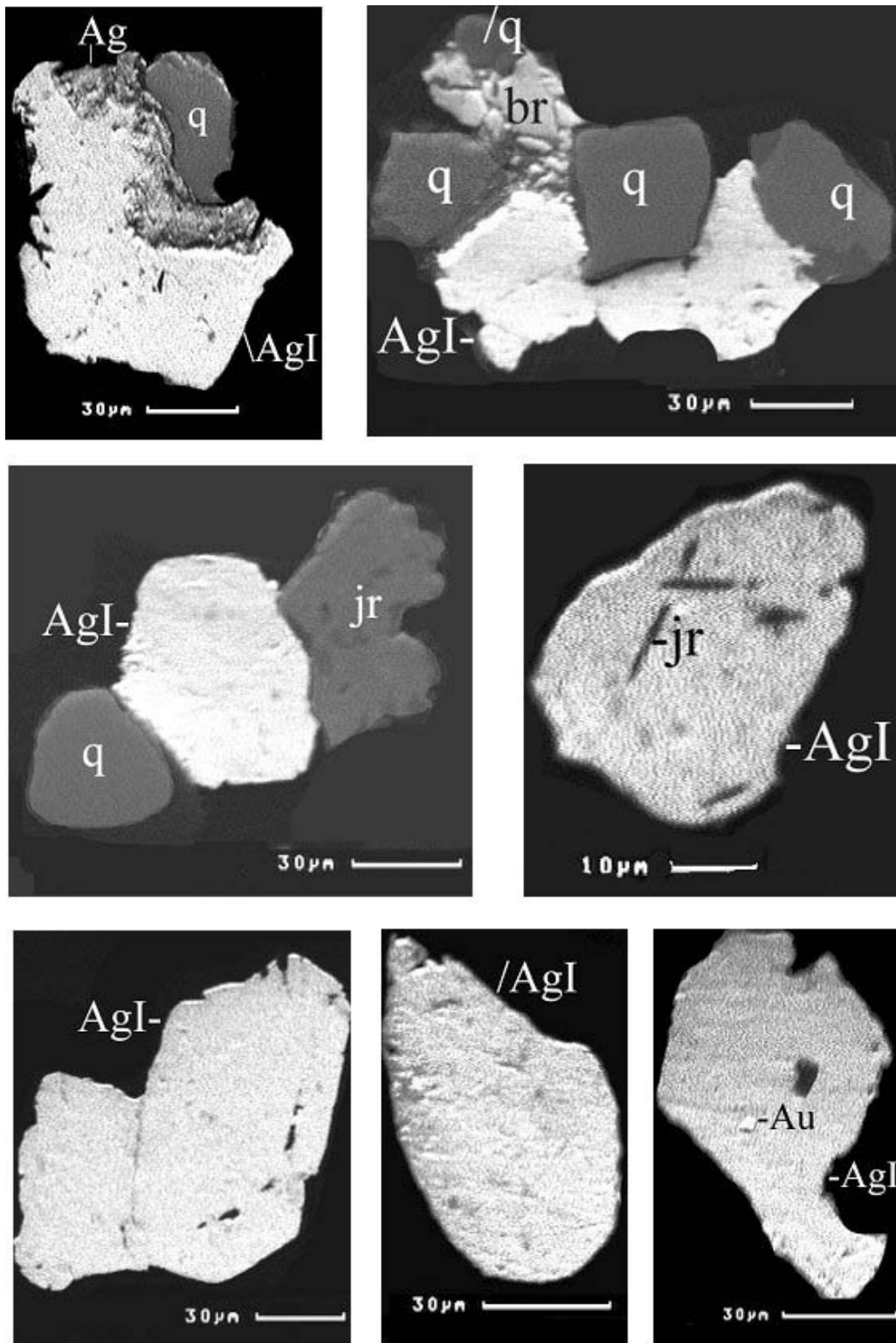
Figure 13: SEM BSE Images Showing Free And Exposed Particles Of Iodargyrite In HS Concentrates After Crushing By EPD. Quartz = q, jarosite = jr.
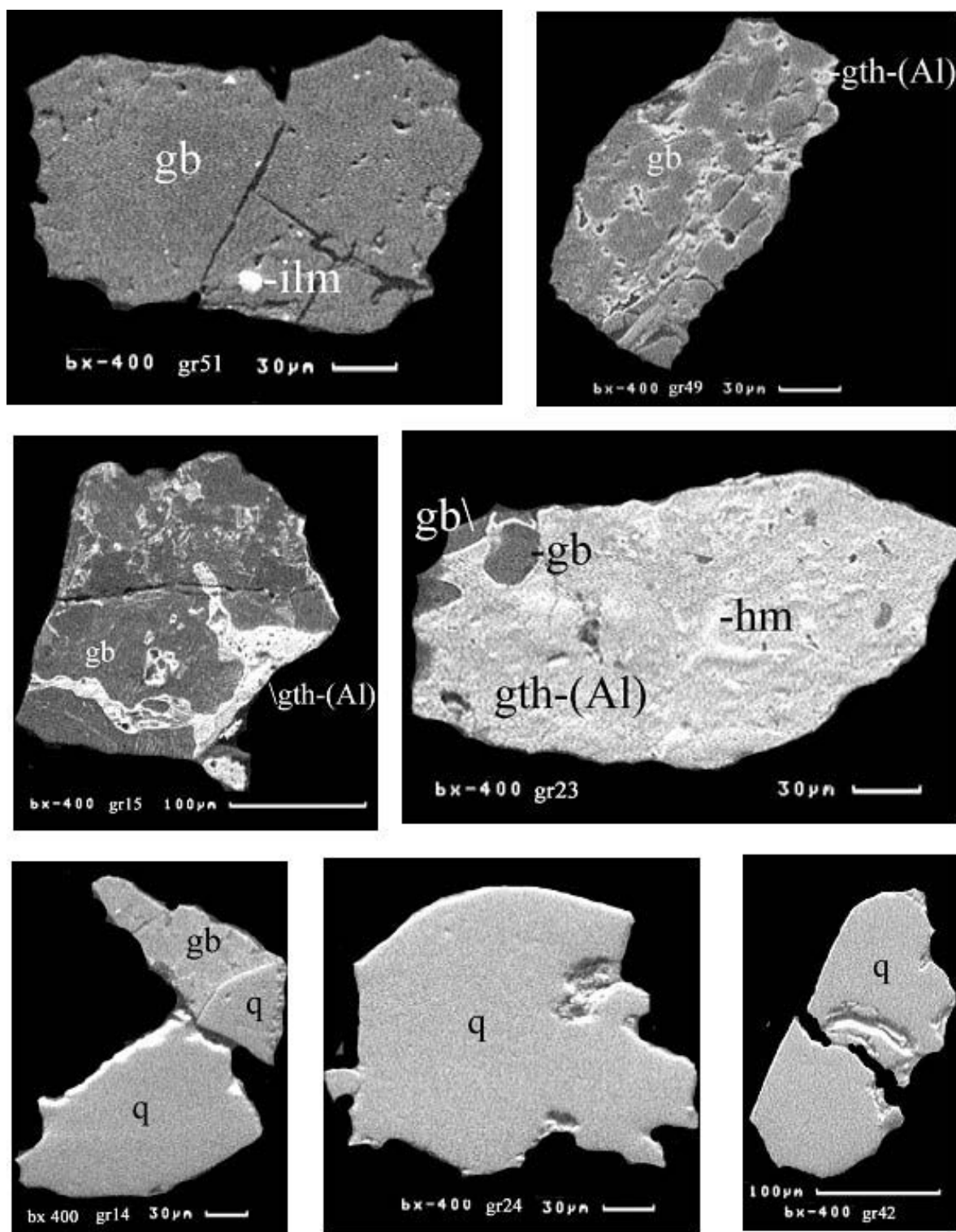
**Figure 14: SEM BSE Images From EPD Crushing Of Bauxite Ore And HS
Concentration Of The 200-400 μM Fraction. Gibbsite = gb, Al-bearing goethite
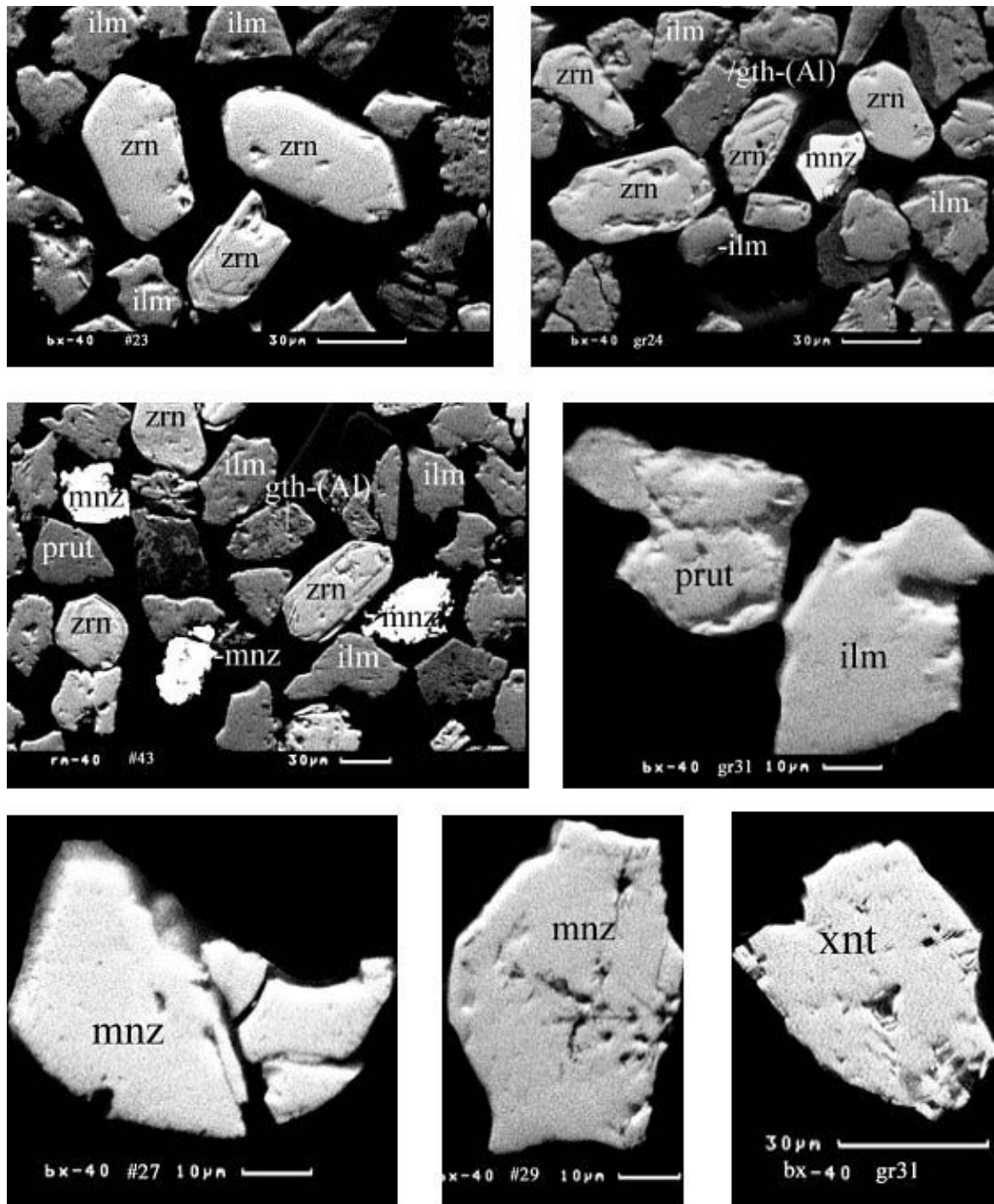= gth-(Al), hematite = hm, ilm = ilmenite, quartz = q.**

Figure 15: SEM BSE Images Of HS Concentrates From Bauxite. Ilmenite = ilm, pseudorutile = prut, zircon = zrn, monazite = mnz, and xenotime = xnt.
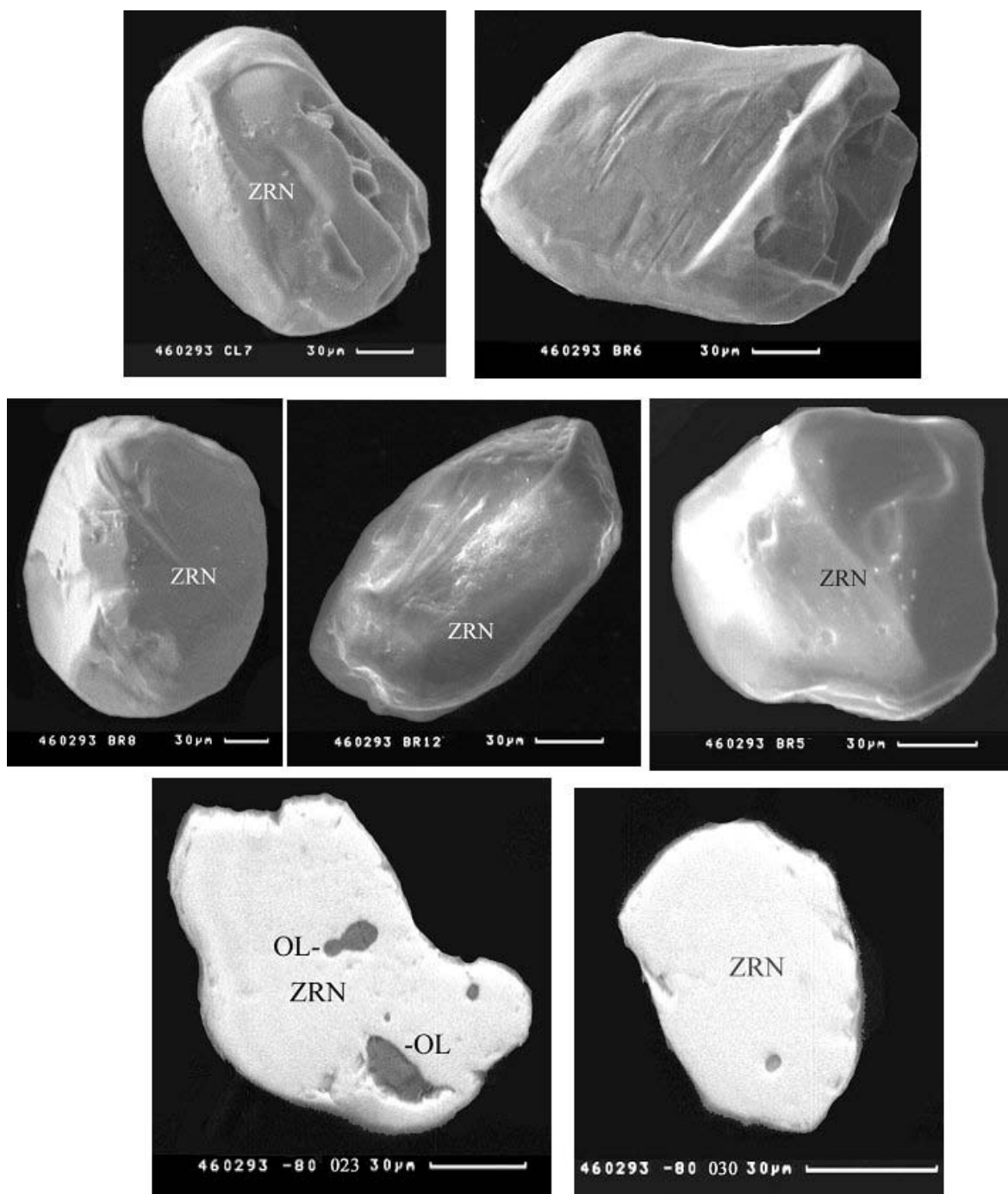
Figure 16: SEM BSE Images Of HS Concentrates After EPD Crushing Of Ancient Ultramafic Rocks From SW Greenland. Zircon = zrn, olivine = ol.