Liberation of accessory minerals from various rock types by electric-pulse disintegration—method and application

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Synopsis

Electric-pulse disintegration is a mineral separation technique that liberates all mineral grains from any igneous or metamorphic rock irrespective of its lithology or grain-size distribution. The normal mechanical crushing of whole-rock samples is replaced by the rending effect of an explosion, 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 explosion, which occurs 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.

The electric-pulse disintegration method has wide potential application in geoscience and industry. Examples are given of the liberation and concentration of economically and scientifically important accessory minerals from different rock types. The examples considered are the recovery of diamonds from two types of non-kimberlitic host rock and of platinum-group minerals associated with chromitites and sulphides from mafic intrusions.

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-tellurides and platinum-group minerals (PGM), or industrially important minerals, such as diamonds and gold, or they may carry rare-earth and/or radioactive elements. Accessory minerals provide much information on their host rock—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 orebody, 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 present contribution describes the principles and application of electric-pulse disintegration, a technique of mineral liberation that quickly releases all mineral grains in their natural size distributions and preserves their original shapes. Further concentration of different grain-size fractions after such treatment can be achieved by gravitational, electromagnetic, flotational or other methods. Electric-pulse disintegration can be used to split individual mineral phases or aggregates and provides an opportunity for detailed study of their morphology and shape, crystal structure, physical and textural features and chemical composition.

The use of electrical energy for rock breakage is not new[1,2] and interest in the use of pulsed-power technology for rock disintegration has increased greatly in recent years.[3,4,5] The significantly lower energy consumption and the much higher efficiency of the electric-pulse technique than of mechanical crushing have been demonstrated by Andres and Bialecki[2] and Touryan and co-workers.[5]

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Technical description of electric-pulse disintegration apparatus

In the method described here the compressive force of normal mechanical crushing is replaced by the tension that is caused by the rending effect of an explosion.[2,6] The tension is created by the direct application of an electric current to the rock sample.

A generalized circuit diagram (Fig. 1) 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 instrument at the Mechanobr-Analyt Center for Chemical and Physical Research in St. Petersburg, Russia, which was used in the present study, contains ten 0.1- to 0.2-μF capacitors.

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 trigger, 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 water bath 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 a 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.[2,6–9] The discharge moves through the rock along grain boundaries because they present a better conducting path. The product consists of unbroken, indi-

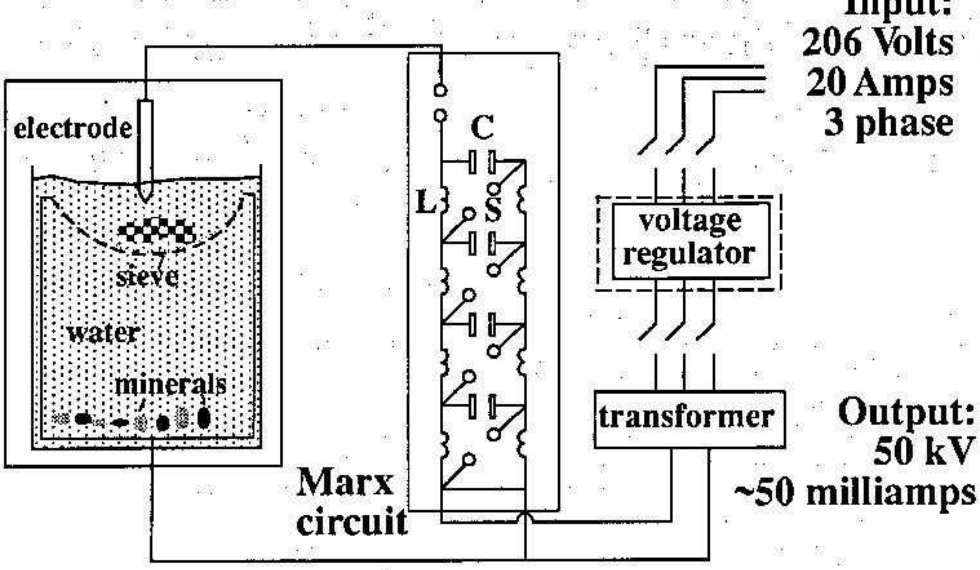


Fig. 1 Generalized circuit diagram of electric-pulse disintegration apparatus showing basic components. Capacitors, *C*, are charged in parallel and discharged in series. Other electrical components: *L*, inductance coil; *S*, spark gap. Sieve size (in water bath, *left*) is varied according to grain size of sample

vidual mineral grains in their original shape and form, regardless of grain size.

Use of the method may cause secondary contamination. Melted electrode material (i.e. from the steel, copper or aluminium used as the electrodes) can be found in the finest grain-size fraction. Less commonly, remelted accessory minerals from the sample may appear in the finest fraction, although they are easily identified in scanning-electron microscope (SEM) or electron-microprobe images. Particularly careful attention should be given to this phenomenon when natural mineral parageneses are reconstructed.

Examples of application

Diamondiferous rocks from meteorite impact crater and metamorphic deposit, Kazakhstan

The method was used on samples of diamond-bearing rocks from the Popigai meteor crater and from the Kumdykol deposit in Kazakhstan, both of which are of non-kimberlitic origin. The diamonds occur as accessory grains of very fine size (<0.25 mm and less) and are unevenly distributed in the rocks. The host rock of the impact diamonds is a graphitized biotite–garnet gneiss from the zuvite zone in the southeastern part of the Popigai meteorite crater.[10] The sample from the Kumdykol deposit was of metamorphic origin and contained very fine-grained (20–80 μm) accessory diamonds.

After electric-pulse disintegration of a 90-g sample of the gneiss from Popigai most of the diamonds were found to be concentrated in the fine fractions, with 26 grains in the 0.18- to 0.06-mm fraction and more than 100 grains in the <0.06-mm fraction. A single grain was detected in the coarsest fraction (2–0.5 mm), seven grains in the 0.5- to 0.25-mm fraction and 17 grains in the 0.25- to 0.18-mm fraction.

A very similar result was obtained with a 48-kg sample from the Kumdykol deposit. The finest fraction (<0.08 mm) contained five times more diamond grains than all the coarser fractions combined.

Morphological investigation of the impact diamonds from the Popigai sample revealed the presence of two varieties: black, opaque tabular diamonds of hexagonal symmetry (Fig. 2(*a*)); and light-coloured, translucent, white to grey cape diamonds of irregular shape. The diamond grains from the metamorphic sample were, likewise, divisible into two types: cubic crystals (Fig. 2(*b*)); and tabular, platy crystals.

All extracted diamond grains are perfectly preserved, even when the grains show some fractures (Fig. 2(*a*)); moreover, very fine textures are observable on the crystal faces (Fig. 2(*b*)).

PGM-bearing chromitites from Kondjor intrusion, Russia

Total platinum-group element (PGE) contents in chromitites are commonly in the range 1–3 ppm, are sometimes less than 1 ppm and only rarely exceed 3 ppm. To study the mode of occurrence of the PGE it is, of course, necessary to investigate the mineralogy of the PGM. This can be a time-consuming task; several tens of polished sections are often required, and even then finding sufficient PGM grains for detailed mineralogical and genetic investigation can be a matter of luck. The same applies to low-grade (<2 ppm total PGE) PGE–sulphide mineralization in mafic–ultramafic layered intrusions (as shown in the third example, below). Electric-pulse disintegration provides a rapid solution to the problem by extracting almost all the PGM grains contained in a rock sample.

A 6-kg sample of chromitite from a massive chromitite pod enveloped in dunite that forms the core of the Kondjor intrusion, Russia,[11] containing about 3 ppm Pt was broken up by the electric-pulse disintegration method. The PGM were significantly concentrated (several hundred grains) in the two finest fractions (<0.15 mm); a total of only five PGM were detected in the coarser fractions. The results are summarized in Table 1, along with the Pt and Pd contents of the different fractions. The PGM in the fine fractions are dominated by crystals of isoferroplatinum, which may be cubic (Fig. 3(*a*)), cuboctahedral (Fig. 3(*b*)), octahedral (Fig. 3(*b*) and (*c*)) or, less commonly, rhombic dodecahedral in shape. Subordinate PGM are sperrylite and some composite PGM phases. The PGM grains are perfectly preserved, allowing textural details such as fine growth zones to be distinguished even in irregularly shaped grains (Fig. 3(*c*) and (*d*)).

The separated grains were embedded in epoxy resin and polished for more detailed mineralogical investigation. The

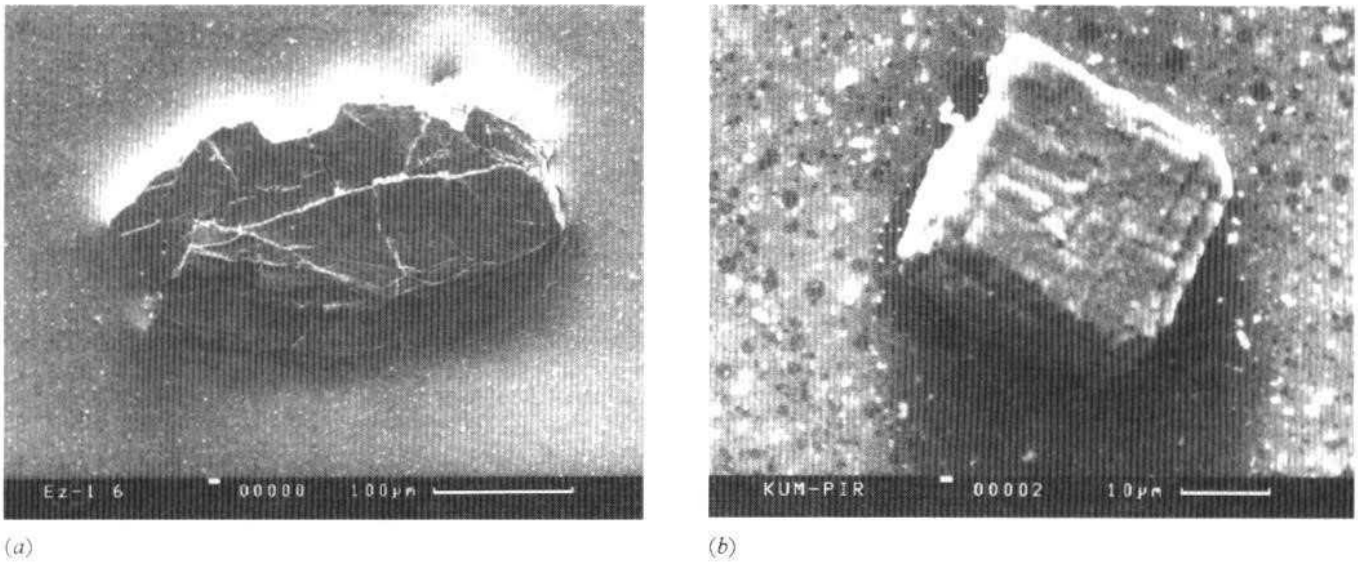


Fig. 2 SEM micrographs of diamonds recovered after electric-pulse disintegration of host samples. (*a*) Black, opaque tabular diamond grain from Popigai meteor crater showing preservation of fine fractures. (*b*) Cubic diamond grain from Kumdykol deposit, Kazakhstan, showing cubic crystal shape; note also fine textures on crystal face

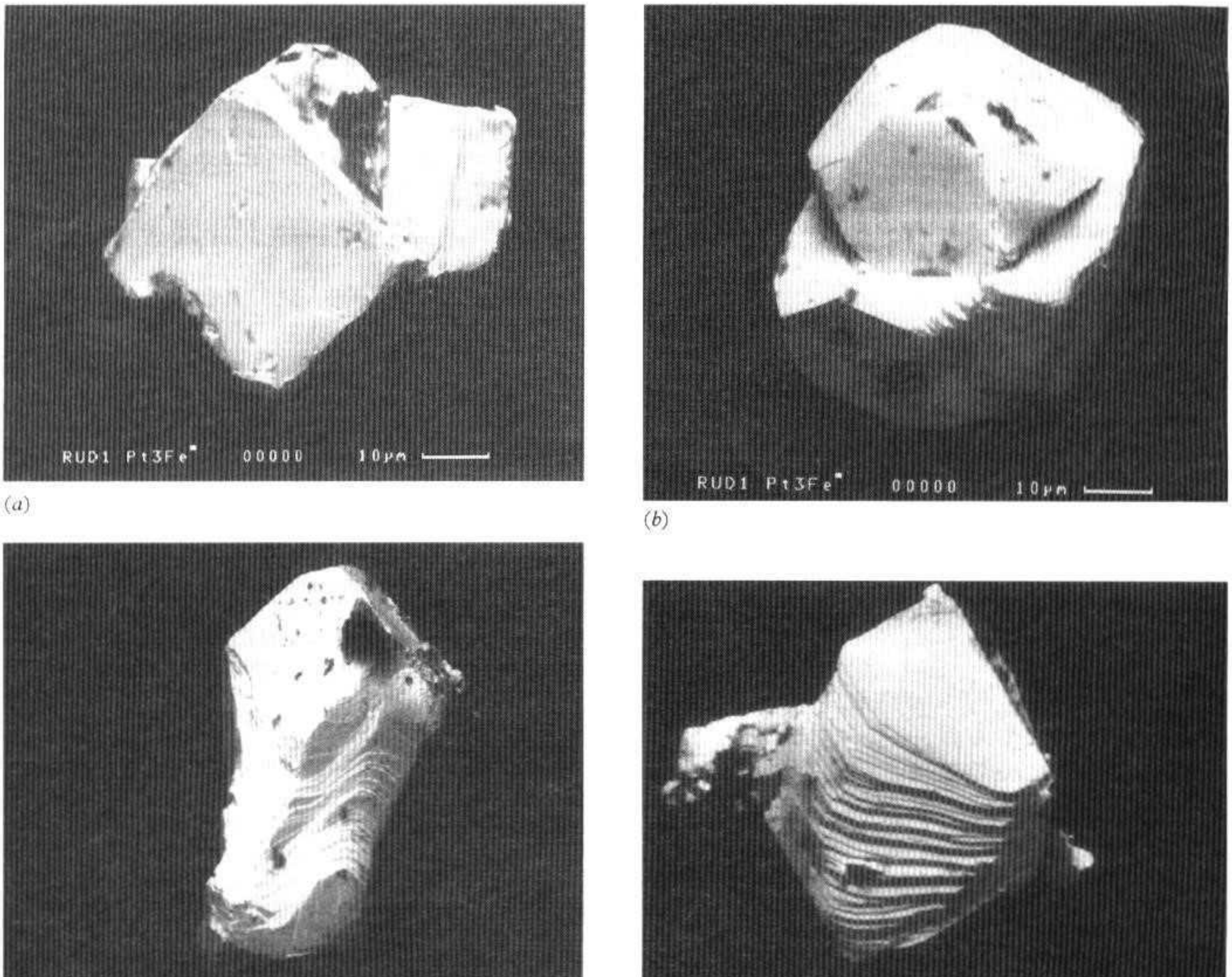
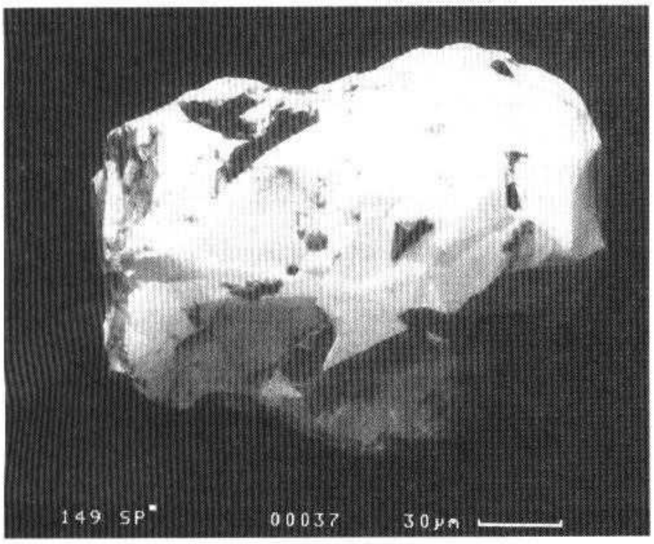


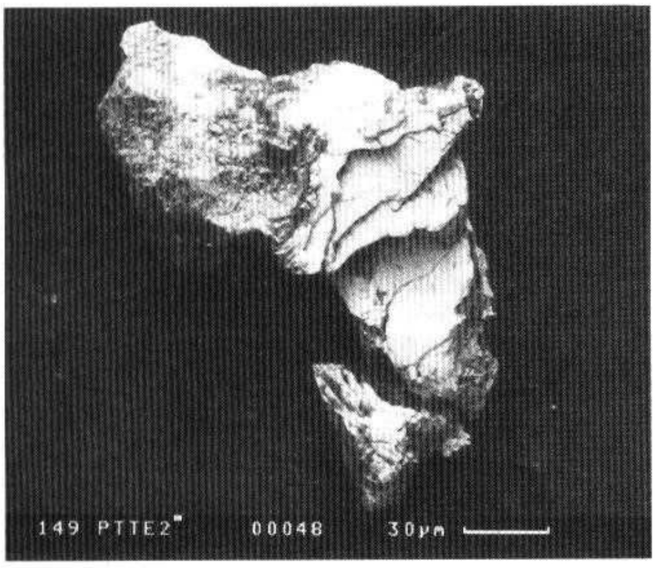
Fig. 3 SEM micrographs of isoferroplatinum grains recovered after electric-pulse disintegration of chromitite sample from Kondjor intrusion, Russia. (*a*) Cubic form. (*b*) Cuboctahedral form. (*c*) Octahedral form. (*d*) Crystal showing perfectly preserved growth zones

Table 1 Grain-size analysis of chromitite sample from Kondjor intrusion, Russia, after electric-pulse disintegration. Pt and Pd contents of different grain-size fractions also given

Fraction, mm	Mass, g	Pt, ppm	Pd, ppm
1.0–0.5	2600	3.1	0.03
0.5–0.34	1350	3.7	0.03
0.34–0.25	418	2.9	0.03
0.25–0.15	880	3.5	0.03
0.15–0.08	434	6.5	0.04
<0.08	234	18.0	0.08



(*a*)



(*b*)

Fig. 4 SEM micrographs of PGM grains recovered after electric-pulse disintegration of sample of sulphide-rich pegmatoidal gabbronorite from Lukkulaisvaara layered intrusion, Kola Peninsula, Russia. Grains are perfectly preserved and display all morphological details. (*a*) Sperrylite ($PtAs_2$) grain. (*b*) Moncheite ($PtTe_2$) grain

dominant PGM are isoferroplatinum, followed by hollingworthite, irarsite, sperrylite, erlichmanite, iridosmine and tulameenite. Rare PGM phases are laurite, platarsite, geversite, native osmium, Sn–Sb-tulameenite, Sb–Sn-hongshiite and unnamed mineral phases—for example, $(Pd,Pt,Cu)_3(Bi,Sb)$ and $Pt(Cu,Sb,Ni)_3$. Other phases identified were bismuthite, aggregates of native tin and lead, stistaite and Zn-bearing copper.

It is beyond the scope of the present contribution to go into a detailed genetic interpretation of this PGM association. However, in illustration of the utility of the electric-pulse disintegration method brief mention should be made of the fact that this mineral association is typical for alkaline–ultrabasic intrusions (for details see Rudashevsky and co-workers[12]). These mineral phases were found and identified through use of the electric-pulse disintegration technique, and it should be emphasized that conventional microscopic examination of polished sections of chromitite samples from the Kondjor intrusion would not have permitted the observations detailed above and described elsewhere.[12]

PGE-bearing sulphide mineralization in two layered intrusions of Kola Peninsula, Russia

Low levels of PGE are associated with disseminated sulphides—mainly pyrrhotite, chalcopyrite, pentlandite, pyrite and violarite—that occur in certain thin (tens of centimetres) horizons in the layered series of the Lukkulaisvaara and Kivakka intrusions of the Oulanka Group on the Kola Peninsula, Russia. Particularly in the Lukkulaisvaara intrusion the mineralized horizons are associated with pegmatoidal gabbronorites that lie in close proximity to unusually uniformly fine-grained, lens-like gabbronorites.[13,14] Platinum-group minerals, silver and gold occur as fine grains (<0.1 mm), most commonly along sulphide grain boundaries and less abundantly as inclusions in silicates and sulphides.

A 12-kg sample of disseminated sulphide-rich pegmatoidal gabbronorite from the Lukkulaisvaara intrusion was treated by electric-pulse disintegration. More than 300 grains of PGM and gold were extracted by heavy-mineral separation from the finest fraction (<0.06 mm). The shapes of the grains are perfectly preserved (Fig. 4(*a*) and (*b*)). Polished grain mounts were made and the PGM assemblage was studied. Sperrylite and pelargpalite are the dominant PGM, followed by moncheite, kotulskite and tulameenite. Rare PGM are represented by zvyagintsevite, sopcheite, stillwaterite, isomertieite, taimyrite, braggite, hongshiite, electrum and some unnamed Pd–Pt–Ag-tellurides.

One 3-kg sample of disseminated sulphide ore from the Kivakka intrusion containing 3.5 ppm Pd, 0.6 ppm Pt, 1.0 ppm Ag and 0.2 ppm Au was treated by electric-pulse disintegration. Table 2 summarizes the results, which again show that about 70% of the Pd and more than a third of the Pt, Ag and Au are concentrated in the finest grain-size fractions (<0.25 mm).

Table 2 Grain-size analysis of sample of low-sulphide ore from Kivakka intrusion, Kola Peninsula, Russia, after electric-pulse disintegration. Pd, Pt, Au and Ag contents of different grain-size fractions also given

Fraction, mm	Mass, g	Pd, ppm	Pt, ppm	Au, ppm	Ag, ppm
2.0–1.0	1432	2.9	0.56	0.17	0.9
1.0–0.5	918	3.4	0.66	0.20	1.1
0.5–0.25	323	5.4	0.80	0.23	1.5
0.25–0.18	140	8.1	0.76	0.22	1.5
<0.18	234	17.8	1.30	0.36	2.0

Conclusions

(1) The electric-pulse disintegration method is an efficient technique for the disaggregation to constituent grains of rock samples of various sizes. The physical basis of the method has been theoretically understood since the early part of the twentieth century. The cohesive forces between grains are overcome by the application of an electric current to whole-rock samples. The rock breaks along the grain boundaries of its constituent minerals, particularly when the minerals have different electrical conductivities.

(2) The technique has the special advantage that it rapidly liberates mineral grains independently of their size while preserving their original shape. Complex morphologies (even of grains only a few micrometres across), such as crystal faces, growth banding, twinning, intimate intergrowth of compositionally slightly differing mineral phases, etc., are preserved and can be examined by SEM.

(3) The electric-pulse disintegration technique has the potential for a wide variety of applications (see Andres and Bialecki[2] and Touryan and co-workers[5]): in industry the method could offer an alternative to conventional, time-consuming crushing methods in the liberation of mineral components of economic interest from various rock types; in geoscience electric-pulse disintegration can be used in isotope geochemistry and to obtain concentrates of accessory minerals, including precious metal-containing mineral phases that have a significant bearing on the genesis of the host rock, as has been illustrated here.

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