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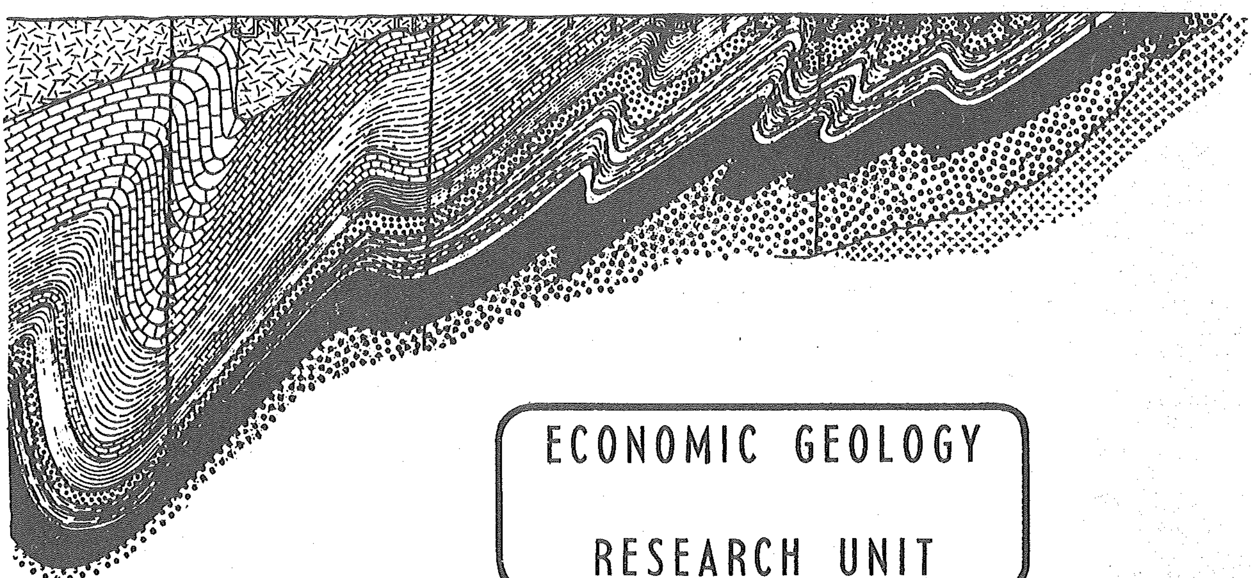

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# NEW TECHNIQUES FOR POLISHING ORE MINERALS

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# NEW TECHNIQUES FOR POLISHING ORE MINERALS

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# NEW TECHNIQUES FOR POLISHING ORE MINERALS


## ABSTRACT

New, easier, and more efficient, polishing techniques for the Graton-Vanderwilt and Rehwald-Depiereux polishing machines are presented, and are compared with a 'quick technique' used at the Petrological and Mineralogical Department of the Federal Institute of Technology in Zürich, and the 'orthodox technique' described by Schneiderhöhn. Different embedding and impregnation methods are discussed and the advantages and disadvantages of these methods are enumerated. Mistakes in polishing, as well as a number of simple techniques for obtaining a good polished surface on difficult material, are discussed. Finally the preparation of polished slabs for micro-textural studies is briefly explained.


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# NEW TECHNIQUES FOR POLISHING ORE MINERALS

## CONTENTS



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# NEW TECHNIQUES FOR POLISHING ORE MINERALS

## INTRODUCTION

"There is no such thing as an universal technique for polishing ore minerals, therefore, each mineral and each paragenesis has to be treated in a different way".

Davy and Farnham (1920).

"Es kann ein schlechter Schliff wegen der Selbsttäuschung gefährlicher sein als gar keiner". (A bad polished section may be more misleading than no polished section at all).

Ramdohr (1960).

Although some polished sections can be very easily described the above two quotations illustrate clearly that, even after more than forty years of extensive research in ore-polishing, it is still no easy process to obtain a good polished section. At the beginning of this century the early workers in ore-polishing followed the known metallurgical methods closely, but it was soon found that vigorous grinding and polishing resulted, in deep disturbance and twin movement, particularly with soft ores. Dry techniques were, therefore, abandoned and wet techniques were introduced. Koenigsberger (1908 and 1909) used a slurry of chromic acid in water, as an abrasive, for the first time and invented the first polishing machine. Whitehead (1917) recommended fine and medium emery on a motor-driven cast-iron lap for grinding, and used black magnetic 'rouge' and aluminium oxide, together with water as a wetting agent, for polishing. Schneiderhöhn (1920) found that magnesium oxide was an extremely successful polishing medium, so much so, that it is still today, probably the most widely employed, inexpensive abrasive used for ore-polishing. After 1922, Ramdohr carried out extensive studies in microscopical techniques and introduced several polishing methods for difficult minerals, using laps of pitch and linden wood. All these methods are described in the textbook 'Lehrbuch der Erzmikroskopie' (Schneiderhöhn and Ramdohr, 1934). With the advent of this very important publication the pioneering period of ore-polishing and microscopy came to its end.

A further major step forward was the introduction of the Graton-Vanderwilt polishing machine — (Vanderwilt, 1928) — the first really successful machine which gave a polished surface with reasonably low relief. Short (1940), explained in detail the technique of the Graton-Vanderwilt machine and presented further new hand-polishing techniques. (Hand-polishing techniques are those whereby the sample surface is pressed by hand on to the polishing base, which can be either a glass plate or a motor-driven lap). Since then, many different polishing methods, using motor-driven laps or polishing machines, have been developed, and it is impossible to cover all of them in this paper. It must be mentioned, however, that in recent years the search for speedier grinding and polishing techniques has led to the extensive use of diamond abrasives, and recently there have also been suggestions that chemico-mechanical techniques be employed for polishing ore-minerals (Cameron and van Rensburg, 1965). However, the most important breakthrough in polishing techniques was achieved with the introduction of the Rehwald polishing machine (Ramdohr and Rehwald, 1954) which yielded almost perfect sections with a minimum of surface deformation and very little relief, irrespective of the mineral paragenesis. During recent investigations, involving the making and studying of almost 200 polished sections of the Basal Reef of the Free State Geduld Mine, Orange Free State, it was found necessary to develop a new polishing technique for the Graton-Vanderwilt machine, because the old method used was very slow and did not yield satisfactory polished surfaces. This new technique, together with a more efficient technique for the Rehwald polishing machine — developed during the past few years for investigating Norwegian sulphide ore-bodies, Saager, (1966; 1967) — is compared with the 'orthodox' hand method described by Schneiderhöhn (1952) and the 'quick technique' used at the Petrological and Mineralogical Department of the Federal Institute of Technology in Zürich.

# THE PRODUCTION OF POLISHED SECTIONS

As stated previously, every ore presents something of a special problem, and the production of a good polished surface can be considered an art, which can be acquired only by experience. The production of a polished section involves three processes. These are: the preparation of the specimens, the grinding, and the polishing.

## A. THE PREPARATION OF THE SPECIMENS

### (a) General

A specimen is usually cut with a diamond saw. A hammer should never be used on a sample as it could cause serious destruction of its inner-structure, leading inevitably to outbreaks of sample-material from the polished section. It should also be noted that a small surface is polished faster than a large surface, and it has been found more advantageous always to make two or three small specimens rather than one large specimen. A convenient specimen size is a square with 15 mm sides. If the specimen is of low porosity and is hard, it does not require impregnating and can be taken directly to the grinding stage, if polished by a hand technique. Soft, porous, or fractured samples must, however, first be impregnated. Transparent varnishes and nail polish are frequently used as impregnating fluids. These must dry at low temperatures and should not be soluble in benzine. Epoxide plastic 2255 together with hardener ZZL0822 (manufactured by Union Carbide) can also be recommended.

A few drops of the impregnating fluid are placed on the area to be impregnated and the fluid is then spread as evenly as possible into the pores, and the excess liquid is wiped away with a tissue. The specimen is ready for grinding as soon as the fluid has hardened. When larger specimens are being impregnated, the whole sample is placed into 'Araldit' resin (manufactured by CIBA, Basle, Switzerland, and is available in South Africa under the name Araldit) and left under vacuum for 30 to 60 minutes. This process is described later, when the mounting technique for specimens to be polished with the Rehwald machine is discussed.

### (b) Graton-Vanderwilt Mounting Technique

For the Graton-Vanderwilt polishing machine the specimens are embedded either in bakelite or in perspex. Both these materials are hot-setting and must be cast between 115°C and 120°C. They are moulded under a pressure of 5 to 10 tons per square inch for 10 to 12 minutes. These hot-setting materials have several disadvantages. Firstly, mounting in perspex and bakelite is very time-consuming; one specimen taking between 30 and 45 minutes to embed. Secondly, many samples cast in perspex begin to crack after four to six months storage and cannot be repolished. The reason for this cracking is not known at present but it appears as if it has something to do with the cooling of the embedded specimens. Thirdly, the high temperature and pressure used can disadvantageously affect certain materials. For example, chalcocite becomes unstable below the embedding temperature of 120°C, and pyrrhotite, a very brittle mineral, may fracture under the applied pressure.

Recently a water-cooled mounting press, developed by Struer (distributed by Protea Holdings, South Africa) has become available. This press enables rounded perspex-mounted samples to be made within eight minutes.

(c) Rehwald Mounting Technique

For the Rehwald polishing machine, the specimens are embedded in bakelite rings with 'Araldit' liquid resin, which, of all the substances tested, has proved to be the most satisfactory. It is cold-setting, shrinks less than 0.5 per cent when solidified under 30°C, and is fully transparent. This makes it possible to mark the specimens permanently on their undersides. Porous specimens need not be impregnated before embedding, as impregnation takes place at the same time as the embedding. After being cut, the specimens are cleaned carefully with benzine, dried, and then placed into the centre of the bakelite ring, which, for casting, is pressed on to a greased lead washer in the mould to prevent the resin from flowing out. The ring is only partly filled to about 2 mm with 'Araldit' and then put into a vacuum desiccator. A strong vacuum is applied until the resin starts to foam — a sign that the air in the pores of the sample is being forced out. After 20 minutes the vacuum is released and the same process repeated twice. After the specimens have been taken out of the desiccator, the rings are filled completely with resin and put aside to harden. This step takes between 14 and 16 hours. The samples are not heated or subjected to pressure. A special impregnation is unnecessary, and the method is reasonably fast. Up to 30 specimens can be prepared in an afternoon.

(d) New Mounting Technique Developed for the Graton-Vanderwilt Polishing Machine

Because of all the advantages available on the Rehwald polishing machine a similar technique for the Graton-Vanderwilt polishing machine has been developed. For this purpose a brass mould, with six 1.5-inch by 1.1-inch openings was constructed. Before casting of the specimens begins the openings are carefully greased and then the entire mould is placed on a greased glass plate to prevent the resin from flowing out. Casting of the specimens is then continued as described for the Rehwald polishing machine. If bakelite forms of the size required for the Graton-Vanderwilt specimen holder are available, this embedding method could be as fast and simple as it is for the Rehwald polishing machine.

## B. THE GRINDING PROCESS

(a) General

In all grinding and polishing work, cleanliness is essential. Because these processes are a progression from coarser to finer abrasives, a single unwanted grain can ruin the whole polishing surface. It is, therefore, important that polishing cloths, laps, and brushes are cleaned before use. After grinding and after each polishing stage, the specimens are cleaned firstly, with a handbrush, liquid soap, and warm water, and then secondly, with benzine and a stiff paint brush. Finally, the specimens are wiped dry with tissues. For each stage, separate brushes must be used, which are stored separately in airtight plastic bags. As a rule, one should never grind and polish simultaneously in the same room with different abrasives. It is best, where possible, to have two separate rooms for grinding and polishing.

(b) Graton-Vanderwilt, Rehwald and 'Quick Technique' Grinding Procedure

For the Graton-Vanderwilt and Rehwald machine techniques, as well as the 'quick technique', the grinding processes are identical. Firstly, a surface of the prepared sample is ground flat, with corundum 400 and sufficient water as a wetting-agent, on a rather slowly turning cast-iron lap, until the whole surface is exposed and is completely flat. It is then cleaned and polished by hand with corundum 600 and water, on a clean glass plate for about three to five minutes until the specimen starts to adhere to the plate. After renewed washing, the sample is ground in the same way with corundum 1200 and 1600, each on a different glass plate. At this stage the embedding material begins to shine, and all scratches from the very coarse corundum should have disappeared. Fine-grinding is then done on a glass plate with the 'green' polishing paste (manufactured by Dürener Maschinenfabrik und Eisengiesserei H. Depiereux, Düren, Germany) of the Rehwald polishing machine. The paste has a grain size of 6 to 4 microns and the wetting-agent is 1/3 petroleum and 2/3 paraffin-oil. After a maximum of two minutes fine-grinding, the embedding material should appear polished over the entire surface (Plate 1, Figures 1 and 2). If this is not the case, the specimen must be reground from the corundum-1200 stage. It is most important that the sections are never rotated during grinding on the glass plate, but are ground in straight movements and turned every 20 seconds. This will avoid polishing in one direction. Rotation of the specimen would cause a convex surface, which later, would make polishing over the entire surface impossible.

### (c) 'Orthodox Technique' Grinding Procedure

For the 'orthodox technique', the sample, after being ground flat, is ground still further on a motor-driven, cast-iron lap with corundum 600 and water, until the surface starts to shine and adhere to the lap. Fine-grinding is then carried out on a linen-covered lap with corundum 1200, and water as lubricant. This stage is completed after four to fifteen minutes. The surface should begin to shine, and only a few pores, especially in the harder minerals, should be visible under the microscope. There will, however, still be many fine scratches resulting from the coarse corundum used earlier.

## C. THE POLISHING PROCESS

### (a) General

The polishing procedure on the Graton-Vanderwilt and Rehwald polishing machines is comparatively slow and needs constant supervision of the machines, specimen, and abrasives. The most critical factor, however, is the maintenance of a thin polishing film on the surface of the lap. Insufficient abrasive or lubricant may completely ruin the surface of the specimen and the lap, and excessive abrasive causes strong relief and considerably lengthens the polishing time.

### (b) Graton-Vanderwilt Polishing Procedure

On the Graton-Vanderwilt polishing machine, pre-polishing is done with diamond paste (manufactured by Boart and Hard Metal Products, Johannesburg; using paste 12 to 6 microns and 3 to 0 microns). Diamond paste (12 to 6 microns) the size of a pea is placed on the 'coarse' lead lap together with three to five drops of Redex lubrication oil, and with the fingertips is evenly distributed over the whole lap. The abrasive is then strongly pressed into the lap with a glass rod, and the load on the spindles is maintained at 450 grams. The specimens are then placed on the machine in succession, and every five to seven minutes a small amount of diamond paste, or a few drops of oil, must be added. The lap should never be allowed to run dry, as this causes severe scratching of the surface.

After about 30 minutes with the coarse diamond paste the finer diamond paste (3 to 0 microns) is added, and in about another 10 to 39 minutes it should be evident that polishing is beginning over the entire surface and not just in the centre or on the periphery. At this stage, hard minerals such as pyrite or arsenopyrite begin to shine. Under the microscope the surface must be almost free of larger pores, though there will still be many scratches visible (Plate 1, Figures 3 and 4). If, after 60 minutes, only the centre or the edge of the surface shows these characteristics, the surface is either convex or concave and has to be reground from the corundum-1200 stage. Pre-polishing is thus a most important stage, and only samples that are perfectly pre-ground will eventually acquire a good polished surface.

Polishing is done on a different lead lap with medium sized Metallurgical Media (manufactured by Vickers Ltd., York, England) — a slurry of aluminium oxide in water with a grain-size of 2 microns. Approximately 10 drops of this abrasive are placed on the lap, together with three to five drops of Redex oil. A steel blank is allowed to run for about five minutes to distribute the abrasive evenly. The spindles are loaded with a weight of 800 grams and after about 10 minutes a small amount of abrasive is again added. In about 30 minutes the surface should be polished. Under the microscope, practically all pores and scratches will have disappeared (Plate 2, Figure 5). Too long a polish results in a high relief and smear marks (Plate 2, Figure 6). For this reason the sample must be checked regularly towards the end of this polishing stage.

If, for special investigations or photomicrographs, a relief-free surface is desired, the specimen can be fine-polished with the 'black' aluminium oxide paste (grain-size 0.5 microns) on the Rehwald polishing machine. Half a match-head amount of paste is placed on the very carefully cleaned lap and is evenly distributed with very little oil. The spindles are loaded with 800 grams for soft minerals and 1000 grams for hard minerals. The lap and the specimens have to be checked during the first 60 minutes at five-minute intervals, and the abrasive must be added in very small portions. It is also extremely important to check the temperature of the lap. Should it reach more than 60°C to 80°C, the machine must be stopped and the lap allowed to cool down, otherwise the surface of the specimen becomes tarnished by the excessive heat. In addition, the heat causes surface disturbance that is too deep and certain minerals (e.g. chalcocite) may become unstable. If the polishing film is maintained properly, the overheating of the lap can easily be controlled. Fine-polishing is completed after two to five hours (Plate 2, Figure 7). Scratches in the lead lap can be levelled out by pressing a clean glass rod firmly over the lap and rounding the sharp edges of the scratches. Pits and deep scratches in the sample surface must be impregnated in the manner described above. It has been found that very soft minerals and some soft native metals give the best results when polished with comparatively 'dry' Metallurgical Media on the 'medium' lap. No third polishing stage is necessary (Plate 2, Figure 8; Plate 3, Figures 9 and 10).

(c) Rehwald Polishing Procedure

On the Rehwald polishing machine, pre-polishing is done with the 'yellow' paste (grain-size 0 to 2 microns) using lap No. 3. This lap is cleaned carefully, and then sufficient paste and oil (1/3 petroleum and 2/3 paraffin-oil) are added with the finger-tips. To distribute the abrasive, two empty rings are polished for five minutes. More paste and oil are then added until the lap appears wet. The specimens are now placed on the lap with a spindle load of 1800 grams. During working, the sound of polishing must be heard distinctly. The surface of the specimen should be almost covered with abrasive, otherwise some oil or paste must be added or removed. Pre-polishing starts on the edge of the surface and moves towards the centre. As soon as the centre is reached (after 5 to 7 minutes), the specimen must be taken from the lap. The maximum pre-polishing time is 15 minutes. A longer pre-polishing would cause a convex surface, and the sample would never become completely polished (Plate 3, Figure 11).

For the polishing stage, lap No. 4 is treated in exactly the same way as lap No. 3; only much less oil and paste are used because the lap should not appear wet. The loading weight on the spindles is 2800 grams, and the water-cooling of the laps must be switched on. To maintain the right polishing film, the sample must be checked every 3 to 5 minutes. If there is exactly the right amount of abrasive on the lap, it is distributed in a fern-like pattern over the specimen surface, and a faint polishing sound should be heard. Every 3 to 5 minutes oil or paste should be added to the rotating lap with a tissue. If there is too much abrasive on the lap the polishing sound becomes too loud, and if there is too little, the bakelite rings start to rattle. The Newton's colours that often occur on the surface of the sample are caused by the very thin polishing film and are a further sign that the correct amount of polishing material has been added. Tarnishing, caused by overheating, never occurs, because the lap is water-cooled and the speed of rotation is low. The polishing time is between 2 and 8 hours, depending on the hardness of the minerals (Plate 3, Figure 12; Plate 4, Figures 13 and 14). Fine-polishing with the 'white' magnesium oxide paste is generally not necessary, but can be done in exactly the same way as the polishing. Fine-polishing is completed after about an hour (Plate 4, Figure 15).

Difficult minerals, such as needles of stibnite in quartz, or molybdenite flakes, or valleriite, have to be pre-polished by hand with 'yellow' paste on aluminium foil, and polished for 1 to 2 minutes with chromic oxide on a perspex plate or on linden wood. After this, the sample can be transferred to the polishing machine, and polishing is continued with the 'black' paste as above.

### (d) 'Quick Technique' Polishing Procedure

For the 'quick technique', the specimens are pre-polished with 1-micron diamond paste (distributed by Winter A.G., Hamburg, Germany) on a perspex plate for one or two minutes. Polishing is then done with 1/4-micron diamond paste. Hard minerals are polished on a rotating 'Winter' polishing cloth at a speed of about 450 revolutions per minute, and soft minerals on a 'Winter' Pellon disc at a speed of about 300 revolutions per minute. Depending on the hardness of the minerals, the polishing time ranges from between two to four minutes (Plate 4, Figure 16). It is important to note that, in general, hard minerals should be polished on a soft lap at high speed, and soft minerals on a hard lap at low speed. Fine-polishing is generally necessary only for soft minerals. This is done by hand on a perspex plate covered with Crêpe-de-Chine, and the abrasive used is an extremely fine suspension of aluminium oxide in water.

### (e) 'Orthodox Technique' Polishing Procedure

For the pre-polishing stage of the 'orthodox technique', chromic oxide is used as the abrasive. It is applied in sufficient quantities, together with water, on a cast-iron lap covered with a rough billiard-cloth. It is very important that the lap should never become dry and the sample is not pressed too strongly on to the lap. The sample must also be moved in a figure of eight against the direction of rotation of the lap to avoid making the lap surface uneven. This pre-polishing is completed in 3 to 15 minutes, depending on the hardness of the material. Polishing is done on fine billiard-cloth with magnesium oxide, which is applied dry on to the previously moistened polishing cloth. Less magnesium oxide is placed on the lap for soft minerals than for hard minerals. The speed of the lap has also to be adjusted for the mineral hardness as mentioned above. It is very important that magnesium oxide is kept in a sealed bottle because it tends to absorb carbon dioxide from the air, and thus forms magnesium carbonate, which, being coarser-grained, will scratch the specimen surface. Cameron (1961), recommends that magnesium oxide, when received, should be divided into small portions that will be stored, each in an air-tight glass tube, until needed.

Because of the formation of carbonates, the billiard-cloth used for polishing must be washed carefully before, and after, each use, and stored in plastic bags. Hard minerals are polished with magnesium oxide and should be completed in about 30 minutes, whereas, softer minerals may need only 30 seconds (Plate 5, Figures 17 and 18). After being polished with magnesium oxide the specimens must be carefully cleaned with benzine to avoid tarnishing of the surface by the alkaline magnesium oxide. Very soft and troublesome minerals, such as chalcocite, graphite, hessite, argentite, and native metals, are best polished on a very slowly turning steel lap covered with Crêpe-de-Chine. In this case, a slurry of aluminium oxide in water is used as an abrasive. If the surface still becomes scratched, it must be polished by hand on a non-rotating lap or a glass plate covered with aluminium foil, aluminium oxide again being used as the polishing medium.

## THE PREPARATION OF POLISHED SLABS

Polished slabs are very important and helpful when ore-bodies have to be investigated, particularly for the study of microtextural relations and transporting and depositional phenomena of the various components. A suitable size for such a specimen is a slab with a surface of 5 inches by $3\frac{1}{2}$ inches. Such a slab is cut with a diamond saw, and all edges should be carefully rounded. Care should also be taken for the cut to be clean and straight so that the surface is as flat as possible, as the flat-grinding of large surfaces takes an extremely long time. The slab is first ground with corundum 400 and 800 on a fairly fast-rotating cast-iron lap with water as the wetting-agent. Fine-grinding is done with corundum 1200 on a lap covered with linen. Finally, the slab is polished on a flannel-covered lap with a slurry of chromic oxide in water.

To get the best flatness on the surface, laps with diameters of about 30 inches are most useful. On smaller laps the slab surface covers also the centre portion of the lap where, due to the low rotation speed, polishing is extremely slow, and causes an uneven and imperfectly polished surface. For photographing, the slabs can be sprayed with varnish after the polishing (Plate 5, Figures 19 and 20). This helps to close many of the remaining pores and it also helps to avoid a rapid alteration of the surface. This procedure is very important when minerals that tarnish easily (e.g. pyrrhotite) are present. Polishing a slab until it can be used under the microscope cannot be recommended, as the large surface would need an extremely long time for polishing to the required degree of perfection.

## SUMMARY OF POLISHING TECHNIQUES

The polishing process is comprised of a large number of operations and for this reason it was found convenient to summarize the various stages of the polishing technique. This has been done in the following two tables. Table I is a summary of hand-polishing techniques employed after the preparation of the specimens, and Table II is a summary of the machine-polishing techniques applied, once again, after the preparation of the specimens.

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## Key to Plates

### PLATE 1

Figure 1 : Ground surface (Graton-Vanderwilt, Rehwald, 'quick technique'). Pyrite pebbles (bright) in gangue (dark). Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 140).

Figure 2 : Ground surface (Graton-Vanderwilt, Rehwald, 'quick technique'). Buckshot pyrite (bright) with inclusions of chloritoid flakes (dark). Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 180).

Figure 3 : Pre-polished surface (Graton-Vanderwilt). Buckshot pyrite (bright) with inclusions of chloritoid flakes (dark). There are too many, as well as too large a sized pores in the pyrite, a sign that the pre-polishing is imperfect. Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 180).

Figure 4 : Pre-polished surface (Graton-Vanderwilt). Buckshot pyrite. Note the much smaller pores than in Figure 3; the pre-polishing is perfect. Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 180).

### PLATE 2

Figure 5 : Polished surface (Graton-Vanderwilt). Porous buckshot pyrite (bright) with inclusions of chloritoid flakes and gangue (dark). Scratches and pores have almost completely disappeared; the polishing is perfect. Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 45).

Figure 6 : Polished surface (Graton-Vanderwilt). Bornite (grey) intergrown with chalcopyrite (white). The surface has been over-polished, which caused smear marks (especially in the chalcopyrite.) Messina Mine, Transvaal. Ordinary light (X 100).

Figure 7 : Fine-polished surface (Graton-Vanderwilt). Myrmekitic gold (white) and pyrrhotite (dark grey) in a skutterudite pebble (grey). Other inclusions in the skutterudite are tetrahedrite (grey). Relief between gold and skutterudite, and tetrahedrite and skutterudite, is remarkably low. Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 600).

Figure 8 : Polished surface (Graton-Vanderwilt). Gold (white), pyrite (grey), chalcopyrite (slightly darker than pyrite), and thucolite (dark grey). The extremely good polishing of gold was obtained using almost 'dry' Metallurgical Media. Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 180).

## PLATE 3

Figure 9 : Fine-polished surface (Graton-Vanderwilt). Chalcopyrite (grey) with inclusions of skutterudite (dark grey) in gold (white, scratched). Basal Reef, Free State Geduld Mine, O.F.S. Ordinary light (X 500).

Figure 10 : Same specimen as Figure 9 after repolishing with almost 'dry' Metallurgical Media. Note the better polish of the gold. Basal Reef, Free State Geduld Mine, O.F.S. Oil immersion (X 500).

Figure 11 : Pre-polished surface (Rehwald). Chalcopyrite (grey) intergrown with sphalerite (dark grey). Surface still shows many scratches but is almost completely free of pores. Bleikvassli Grube, Helgeland, Norway. Ordinary light (X 180).

Figure 12 : Polished surface (Rehwald). Supergenic alteration of pyrrhotite (grey) to 'Zwischenprodukt' (dark grey) and marcasite (white). Such a well polished surface is extremely difficult to obtain on this alteration product. Sølvberg Grube, Mo-i-Rana, Norway. Ordinary light (X 180).

## PLATE 4

Figure 13 : Polished surface (Rehwald). Arsenopyrite porphyroblast (white) in chalcopyrite (grey), together with sphalerite (dark grey) and mica (black). Note the reasonably low relief between the different minerals which cover quite a wide hardness range. Sølvberg Grube, Mo-i-Rana, Norway. Ordinary light (X 180).

Figure 14 : Polished surface (Rehwald). Fractured quartz pebble (black) with galena (white) and pyrrhotite (grey) as fracture fillings. Very low relief between galena and pyrrhotite. Umskaret, Mo-i-Rana, Norway. Ordinary light (X 180).

Figure 15 : Fine-polished surface (Rehwald). Pyrite porphyroblast (white) in altered pyrrhotite (grey) and gangue (black) and goethite (dark grey). Mofjell Grube, Mo-i-Rana, Norway. Ordinary light (X 180).

Figure 16 : Polished surface ('quick technique'). Pyrite (white) intergrown with sphalerite (grey) and galena (intense white, imperfectly polished). Note the smear marks on all minerals and the pores in the soft galena. Mofjell Grube, Mo-i-Rana, Norway. Ordinary light (X 180).

## PLATE 5

Figure 17 : Polished surface ('orthodox' method). Pyrite (white), galena (white, scratched) and sphalerite (grey). Strong relief between galena and pyrite and irritating pores and scratches in the imperfectly polished galena. Lej Grevasalvas, Switzerland. Ordinary light (X 180).

Figure 18 : Polished surface ('orthodox' method). Pyrite (white) strongly replaced by chalcopyrite (grey). Strong relief and smear marks caused by too lengthy a polishing on too soft a base. Lej Grevasalvas, Switzerland. Ordinary light (X 180).

Figure 19 : Polished slab of typical, strongly 'durchbewegt' chalcopyrite and pyrrhotite ore from Mofjell Grube, Norway. Scale on photograph in mms.

Figure 20 : Polished slab of typical, fine-grained breccious ore from Umskaret, Norway. Ore is mainly sphalerite and pyrrhotite. Rounded pebbles consist of quartz. Scale on photograph in mms.

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PLATE 1

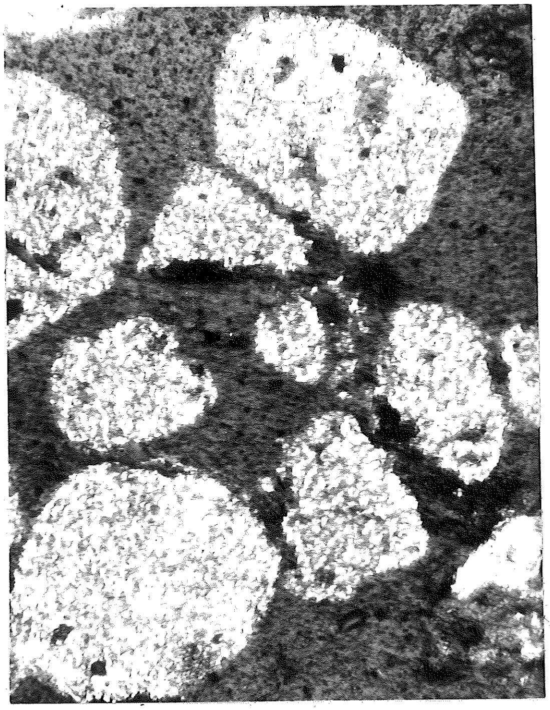


Fig. 1

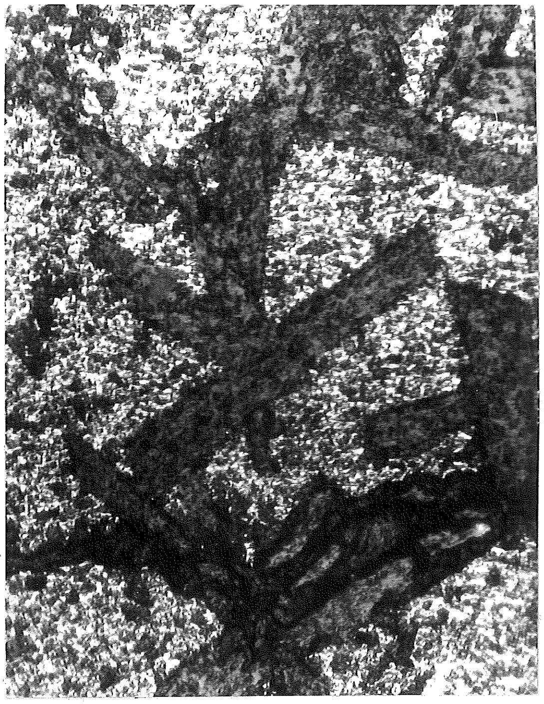


Fig. 2

Fig. 3

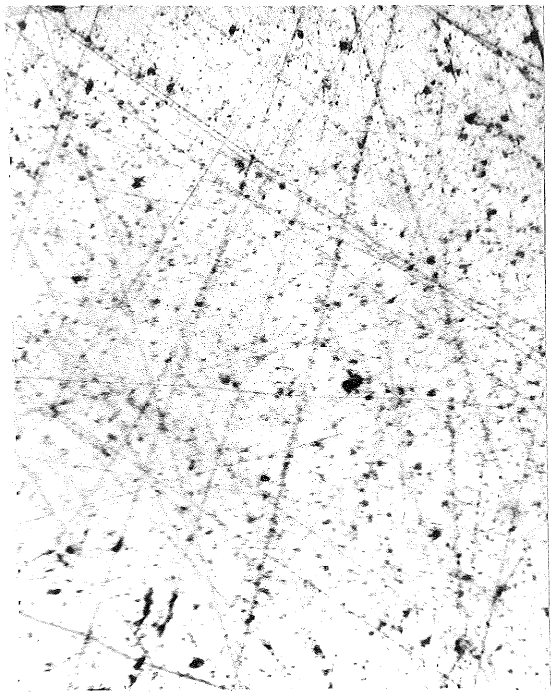
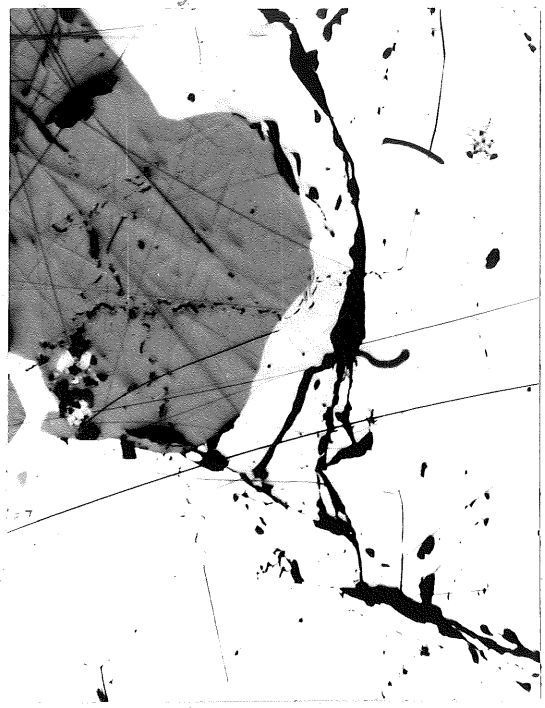


Fig. 4

PLATE 2

Fig. 5



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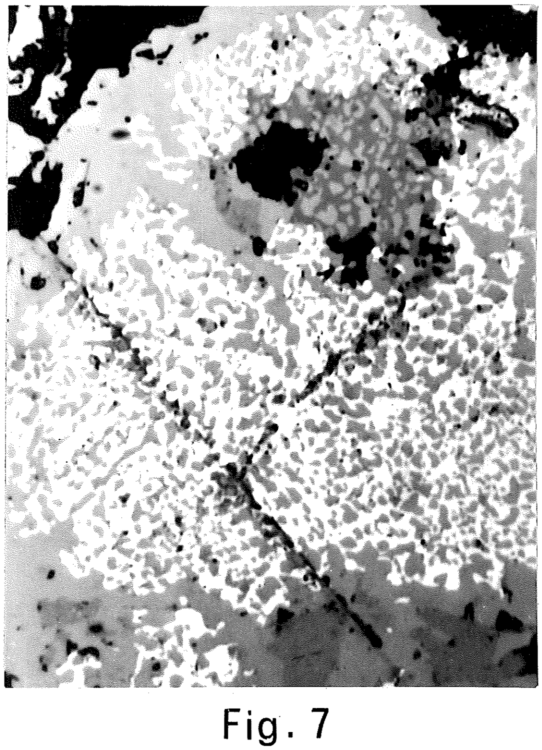

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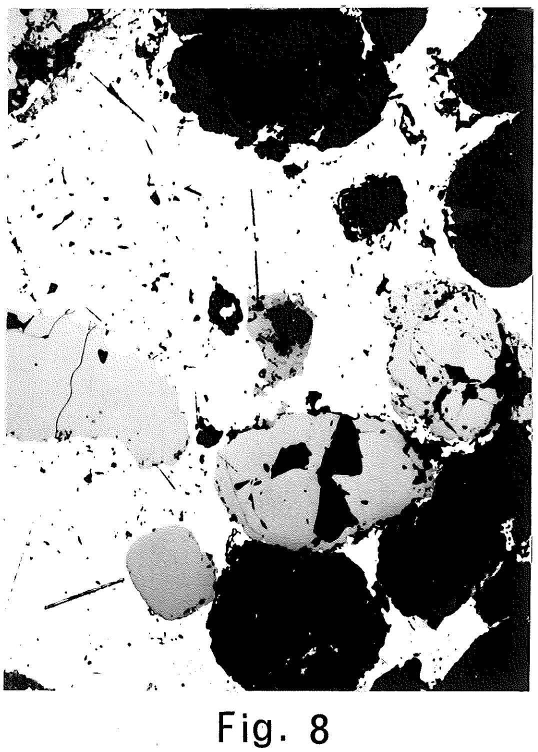

Fig. 8

# PLATE 3

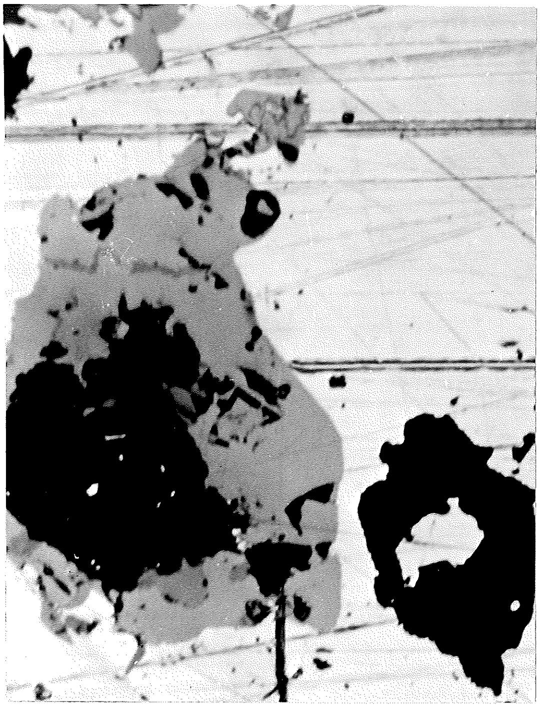

Fig. 9

Fig. 10

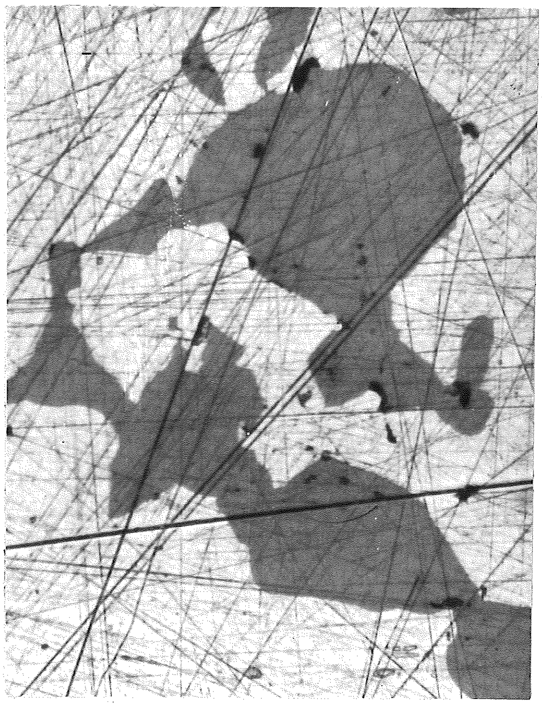

Fig. 11

Fig. 12

# PLATE 4

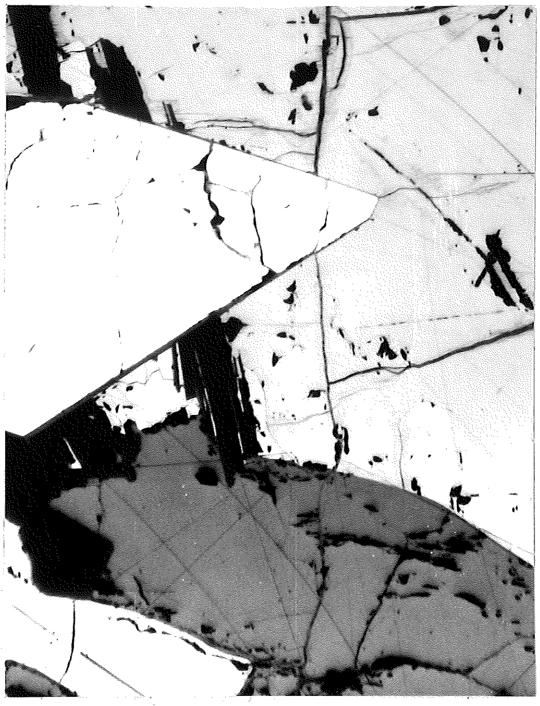

Fig. 13

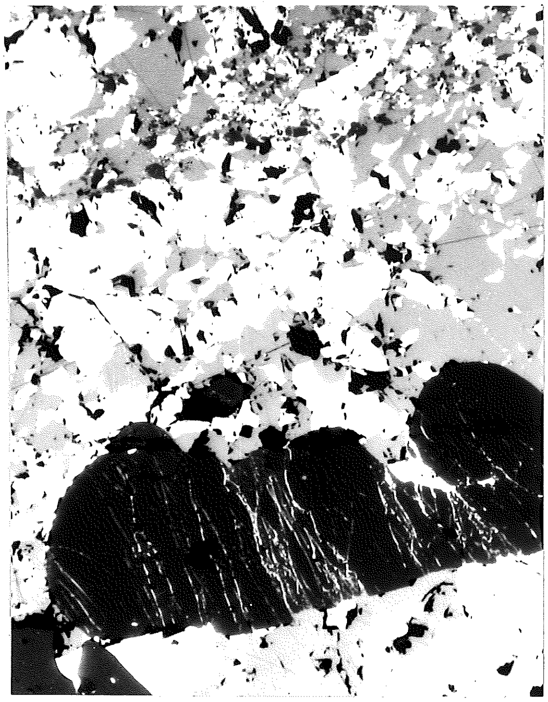

Fig. 14

Fig. 15

Fig. 16

# PLATE 5

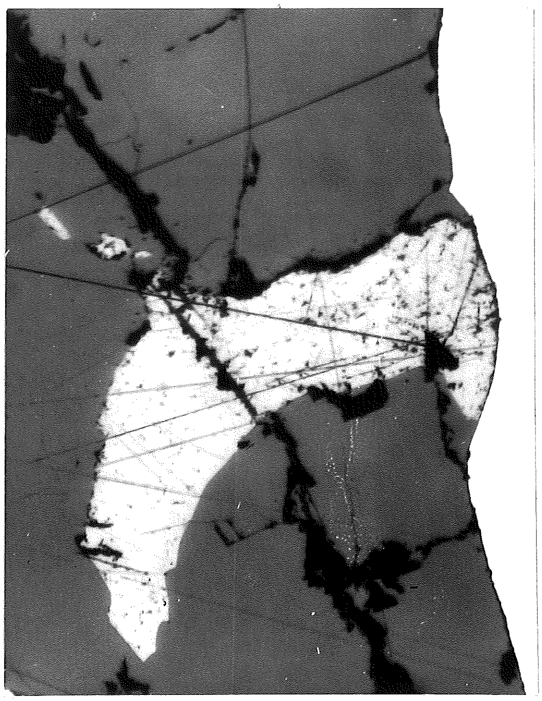

Fig. 17

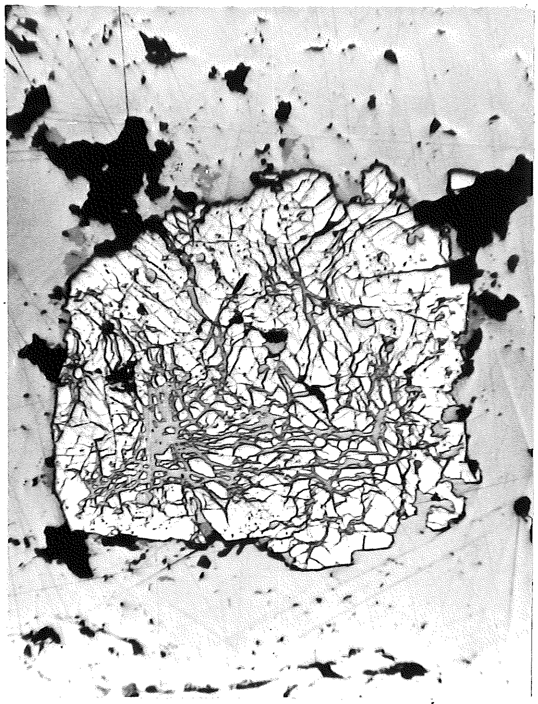

Fig. 18

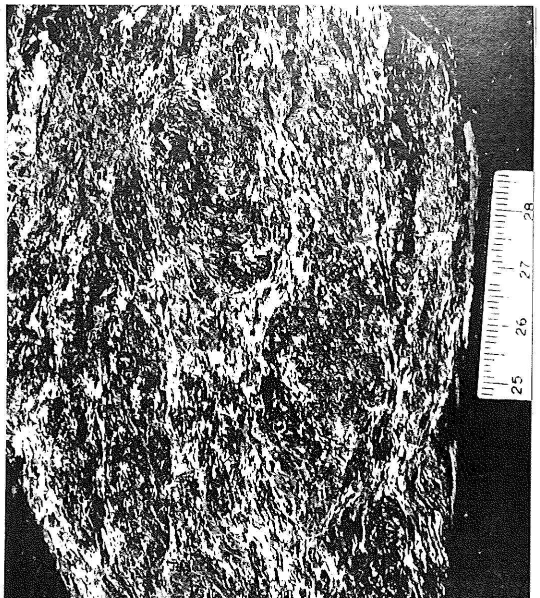


Fig. 19

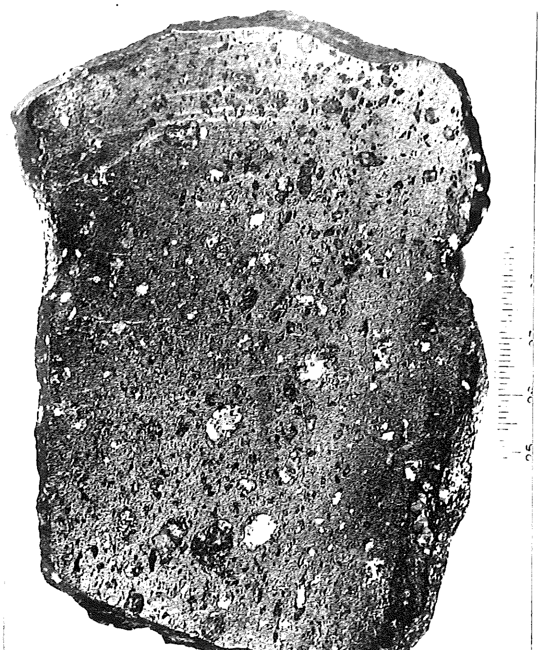

Fig. 20