Values of *mg* are closely comparable for the anthophyllite-hornblende pair of the Mallard Lake metagabbro, but are contrasted in the cummingtonite-hornblende pair described from Finland.

As has been emphasized by Eskola it will be useful to have further amphibole parageneses quantitatively investigated, for their chemical variation may well prove sensitive indicators of the conditions under which these metamorphic assemblages have crystallized.

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PREPARATION OF PETROGRAPHIC SECTIONS WITH BONDED DIAMOND WHEELS

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Introduction

The preparation of thin sections of rocks and minerals for petrographic examination was ably presented in 1953 by Read and Mergner (1) who summarized the development of thin-sectioning techniques together with a detailed description of the established practice of the U. S. Geological Survey. In recent years, the methods of petrography have become increasingly useful in ceramics and other non-metallic and refractory technology. Recently Insley and Frechette (2) have published a comprehensive work in this field of industrial petrography. In many instances standard methods for preparing thin sections may be applied to ceramic microscopy, but there is an increasing number of articles or materials to which they can be applied with only partial effectiveness or not at all. Included among these are grinding wheels, other abrasive articles, super refractories of silicon carbide and other compounds, and ceramic articles such as sintered alumina products.

Bonded diamond wheels were introduced into industry about twenty years ago, specifically for grinding and dressing sintered carbide tool points. For a number of years before bonded diamond wheels were available, the Research and Development Laboratory of the Carborundum Company at Niagara Falls, N. Y., had repeatedly attempted unsuccessfully to make thin sections of vitrified bonded silicon carbide grinding wheels. It was suggested that diamond wheels be tried for this purpose, and after a number of trial runs using laps of different grits, and grade designation, a method of making such sections was successfully developed. Bonded diamond wheels were at first made only with resinoid bonds and consequently wheel life was short and the use of the wheels proved to be costly. As new and better types of bonded diamond wheels were produced, the process of sectioning bonded abrasives, loose abrasive grain, and special refractories has become routine procedure in the petrographic laboratories of several manufacturers of abrasive and special refractory products. The metal bonded diamond wheels are now effectively and economically employed and resinoid wheels used little or not at all. Vitrified diamond wheels may also be used, and although they have good grinding efficiency, they are slower cutting than the metal wheels.

Equipment and Wheel Specifications

The equipment generally employed for preparing thin-sections with loose silicon carbide grain uses large iron disks of the order of twelve inches in diameter for lapping. In the use of bonded diamond wheels we have found wheels of six inch diameter to be most economical. For further economy and also for convenience in mounting we have a one inch diameter recess countersink in the center, the center itself is a $\frac{1}{4}$ drill hole through which is placed the bolt for mounting.

While commercially available polishing equipment such as is widely used in metallography may be adapted to the preparation of thin sections, we, like many other petrographic laboratories, have built our own lapping machines. Fig. 1 is a close-up view of thin sectioning equipment in the mineralogical laboratories of the Research Laboratory of the Carborundum Company in Niagara Falls, N. Y. It is possible to make sections successfully with a single machine because wheels may be changed rapidly, and there is no danger that a loose coarse grain from an early stage will be retained to contaminate and ruin the section in a later stage. The apparatus shown is provided with a means of varying the speed between 500 and 1500 RPM. In preparing thin sections the higher speed is used, but the equipment is adaptable to other methods of specimen preparation such as polishing, where slower speeds are required.

Technique of Preparing Sections

In preparing thin sections with bonded diamond wheels the same principles apply as when loose grain is used. A slice of the order of $\frac{1}{16}$ to $\frac{1}{8}$ inch thick is cut from the sample. In our laboratory, we use a Felker

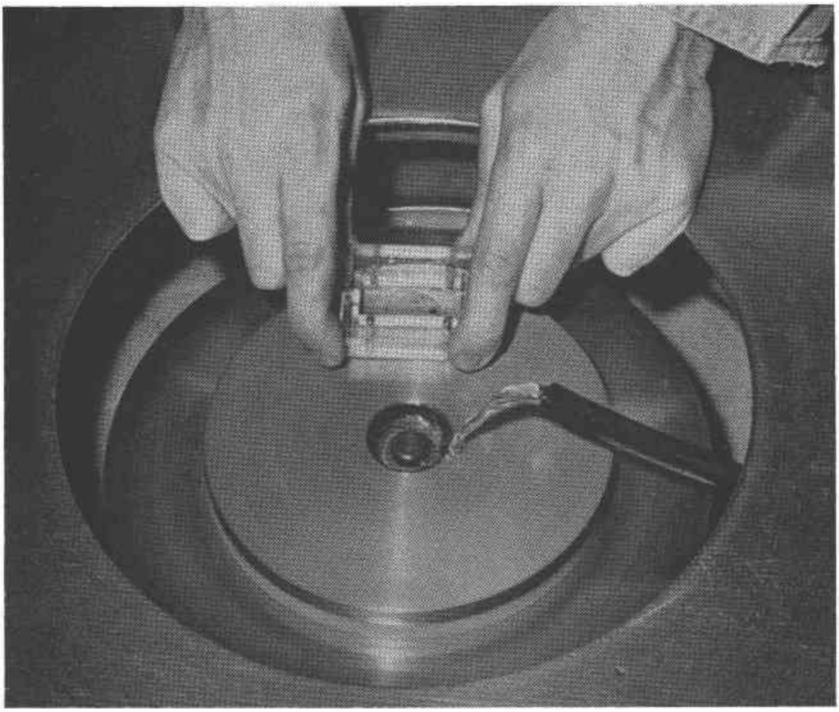

Fig. 1. Close-up of bonded diamond wheel in use. Note the special slide holder, and the freely flowing stream of water.

Manufacturing Company Model 11R cutting-off machine equipped with a rotary table and vise, and on which a Carborundum Co. MI8695H-8 $\times 0.45 \times \frac{5}{8}$ inch metal bonded diamond cutting-off wheel is mounted.

The slice is placed on a glass object slide with Canada balsam, after first polishing one face for the final mount. Many petrographers develop their own methods for mounting sections, and a particular procedure for abrasive articles is described by the author in the section on Abrasive

Microscopy in the Insley and Frechette manual for the Microscopy of Ceramics and Cements (2). This mounted section is then ground to its proper thickness in stages using the following order of wheels, first 100 grit, then 240 and finally a 400 grit lap. At times a 600 grit wheel is used, especially for a polished face (3). During the operation of grinding the section a full stream of warm water should be used in order to keep the specimen and mounting medium from spalling and also to minimize loading of the wheel, but the water should not be so warm that the balsam would soften. The wheel is occasionally dressed with lump pumice, chiefly to keep the wheel from loading with the mounting medium. Occasionally, it may be dressed with a vitrified bonded stone such as is provided by diamond wheel manufacturers for dressing wheels used in grinding sintered carbide tools. In handling the mounted specimen, it should be moved radially in such a manner as to minimize dishing of the surface. Figure 1 shows the manner in which the specimen should be held.

We have attempted unsuccessfully up until now to use bonded silicon carbide laps for making thin sections of materials on the order of hardness of quartz. The abrasive action of rolling loose grain is quite different from that of bonded abrasives with fixed abrasives points. The success of bonded diamond lap is the great hardness of diamonds compared with all other crystalline materials. Wooddell (4) has shown by his method of hardness rating that on a scale on which quartz is 7 and corundum is 9 (the ordinary Mohs' scale values), various types of diamond would be on of the order of 40 and silicon carbide would be 14. The bonded diamond grit cuts right through the crystals of the section without undercutting any of the softer bond or included structures.

While the subject method was designed primarily for the preparation of hard materials in the field of abrasives, refractories and ceramics, we have also found it economically applicable to the sectioning of the rocks and minerals. It has also been useful in preparing special materials; for example, thin sections of teeth and bone for biological studies. Thin sections of water soluble or water reactive materials such as calcium carbide have been successfully made using a layer of kerosene or some light oil on the surface as a coolant and lubricant instead of a stream of water. The chief disadvantage of this method is the first cost, but if properly bonded diamond laps are carefully used they should be economical, provided that the volume of work is sufficient.

The advantages of the preparation of thin sections with bonded diamond wheels are: (1) obtaining thin sections of material not otherwise possible to section, (2) cleaner sections since there is no loose grit to embed, (3) speed of the operation, (4) ease of learning the technique,

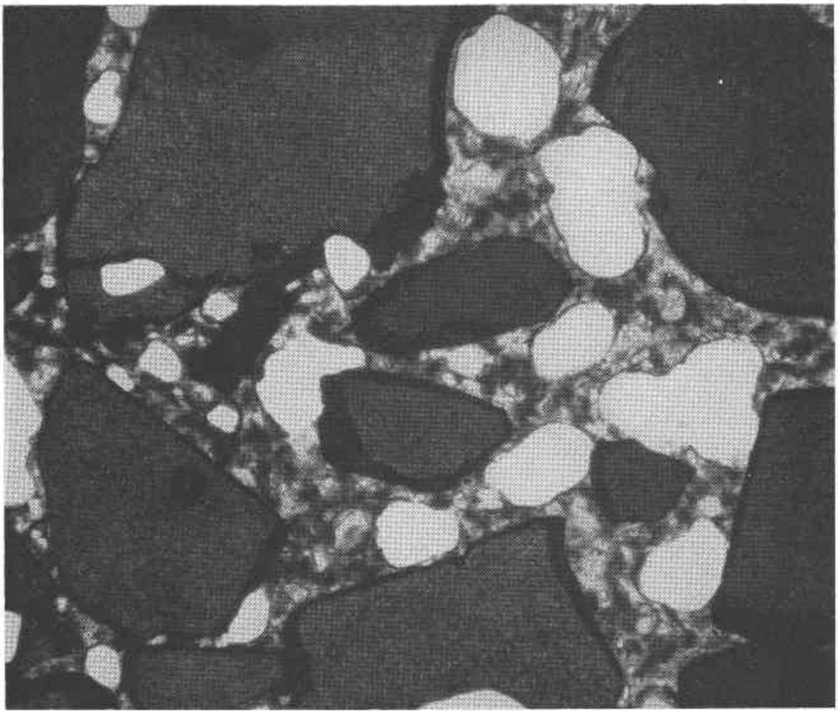

FIG. 2. Photomicrograph of a thin section of a vitrified bonded silicon carbide grinding wheel made with a bonded diamond wheel. ×71, transmitted light.

(5) no undercutting of sections containing soft components such as the soft, porous bonds in some vitrified abrasive wheels.

Figure 2 is a photomicrograph of a section of a vitrified silicon carbide grinding wheel that can only be made with diamond abrasives.

The structure of the abrasive grain, the adhesion and other properties of the ceramic bond, and the shape and size of the pores can be observed.

Figure 3 is a photomicrograph of a thin section of a calcareous sandstone made by this method.

That the principles of petrography have been applied only in a limited way to the technology of ceramic products may be in part due to the difficulty of quickly obtaining thin sections. We have overcome this condition by the use of the equipment and procedures described above, and consequently petrography has become a regular technique for research, development and technical control in the abrasive and refractory industry.

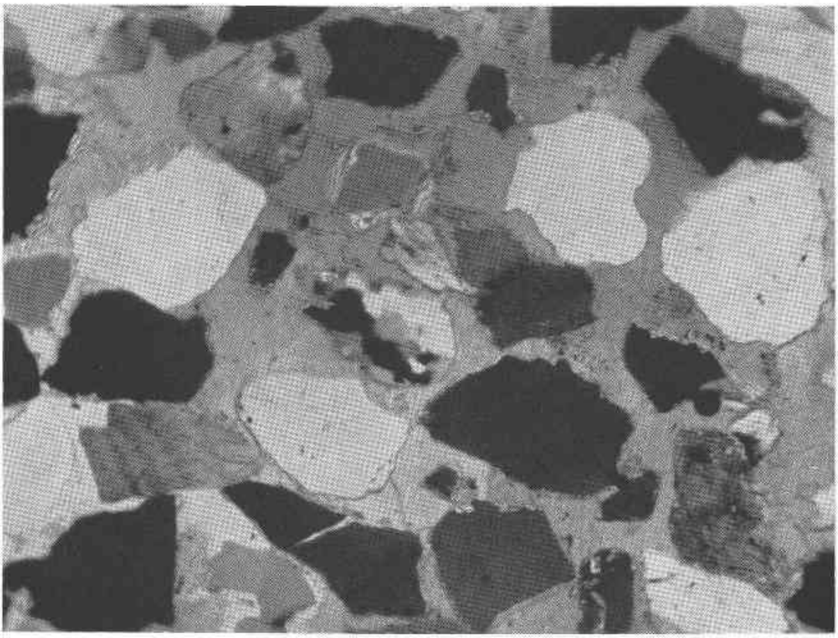

FIG. 3. Thin section of a calcareous sandstone made with a bonded diamond wheel. ×57. Crossed nicols.

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3. The Carborundum Company designations for this series of metal bonded diamond wheels are:

   61106C—$6\times\frac{3}{4}\times\frac{5}{16}$—D100-M50—M$\frac{1}{16}$
   61106C—$6\times\frac{3}{4}\times\frac{5}{16}$—D240-M50—M$\frac{1}{16}$.
   61106C—$6\times\frac{3}{4}\times\frac{5}{16}$—D400-M50—M$\frac{1}{16}$.
   61106C—$6\times\frac{3}{4}\times\frac{5}{16}$—D600-M50—M$\frac{1}{16}$.

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