PREPARATION OF ROCK THIN SECTIONS*

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ABSTRACT

A firm rock or mineral of which a thin section is to be made must first be sawed to obtain a slice approximately $\frac{1}{8}$ in. thick. This is then cemented to a numbered glass slide with Canada balsam, pressing the slice at an oblique angle against the glass slide to eliminate bubbles. The slice is then ground on a rotating lap using 1F silicon carbide and finally on a similar lap using #600 silicon carbide until the standard thickness of 0.03 mm is obtained, when the cover glass is cemented firmly to the section.

Friable rocks such as sandstones, clays, and shales must first be impregnated with Canada balsam or some other medium before sawing and grinding. Coals are treated with a mixture of two parts of Canada balsam and one part of marine glue. Kollolith and glycol phthalate are also used to cement the rock slice to the glass slide. Very friable rocks are impregnated with Bakelite varnish.

INTRODUCTION

The U. S. Geological Survey is occasionally requested to furnish information concerning the techniques employed in the preparation of rock thin sections. To make such information readily available, this paper

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describes the procedures involved in making thin sections of ordinary, firm, non-friable materials as well as clays, coals, gypsum, water-soluble minerals, and minerals decomposed by water.

The preparation of thin sections, which was described by Sorby (1882), was well developed by 1860. A clear presentation of the techniques involved was published by Vogelsang (1867). Vogelsang's paper contains the fundamentals of methods for preparing thin sections. The history of the development of thin section technique is treated by Holmes (1923) and Johannsen (1918). In recent years the methods of preparing standard thin sections have been described by Milner and Part (1916), by Head (1929), and by Rogers and Kerr (1942). A paper by Mary G. Keyes (1925) describes in part the techniques developed in the Geological Survey laboratories. The following treatment gives the methods in use in the Geological Survey laboratory in greater detail and includes the developments of the past quarter of a century.

Equipment

Grinding motors and laps

Thin sections require several stages of grinding on steel laps driven by $1\frac{1}{2}$-hp. vertical motors (Fig. 1). There are three such laps in the Geological Survey laboratory used for rough, medium, and fine grinding. The motors are driven at a speed of 1150 rpm. Each motor rests on a cast-iron stand 2 ft. 11 in. high. The laps on which the grinding is done are made of milled forged steel. They are 13 in. in diameter and 1 in. thick when new. The hub is 2 in. long and the outer diameter $2\frac{1}{4}$ in. The laps become concave with use and should be resurfaced as soon as a straightedge shows a slight concavity. This is especially necessary for the fine-grinding lap, for if this lap becomes too concave the preparation of a uniform thin section is impossible. Lead-lined boxes for catching and holding the abrasive as it flies from the rotating lap rest on top of cast iron stands. A framed glass case, with one end open to permit the entrance of the hands during grinding, rests on the lead-lined box. This aids further in minimizing the amount of abrasive that flies from the box and serves as a safety measure so that the operator will not inhale too much abrasive. The abrasive used for the three stages of grinding is #120 silicon carbide for rough-grinding, #1F silicon carbide for medium-grinding, and #600 silicon carbide for fine-grinding.

In connection with the description of the grinding motors and laps, mention must be made of hand-grinding on plate glass. A piece of plate glass about 8 in. square and $\frac{1}{4}$ in. thick is a very convenient size for this operation. No. 600 optical alundum is used for this grinding.

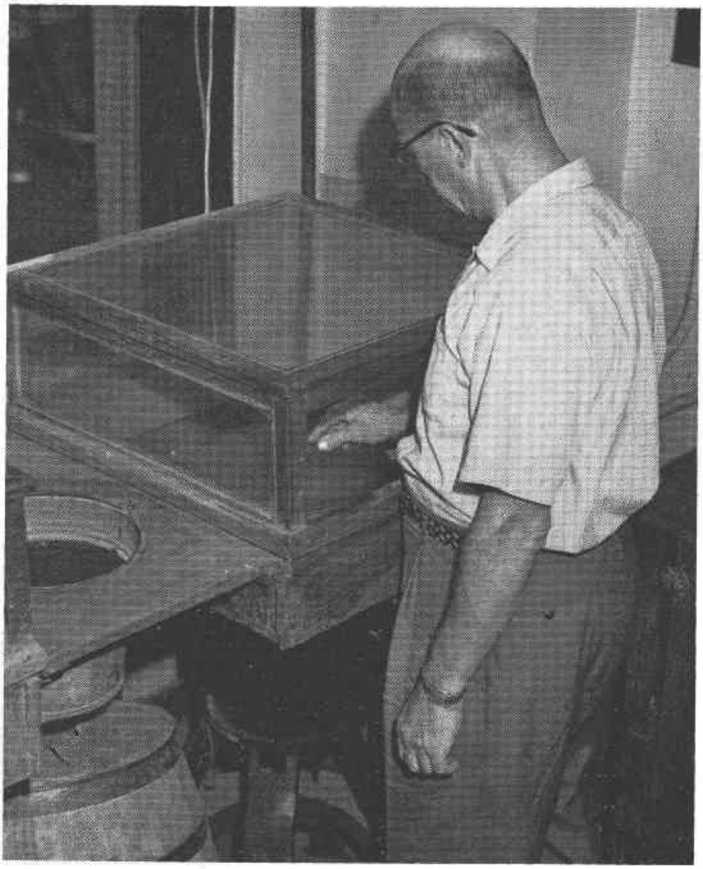

FIG. 1. Grinding unit with horizontal steel lap.

Diamond saw

A rotary diamond saw is a most helpful and necessary piece of equipment for the thin-section laboratory. A rock slice of uniform thickness can be cut very rapidly and much time saved thereby as contrasted with the slower method of breaking small chips from the hand specimen with a square sharp-edged trimming hammer. A blade 8 in. in diameter has proved to be the most practical for general use in the laboratory.

The first blades used were made of copper. However, contamination of copper was occasionally detected in the thin section being studied under the petrographic microscope. This led to the adoption of a steel blade. Surprisingly, the blade proved most efficient, cutting much faster and binding very much less than the copper blade when it neared the point when the diamond abrasive was about gone. This sawing machine is

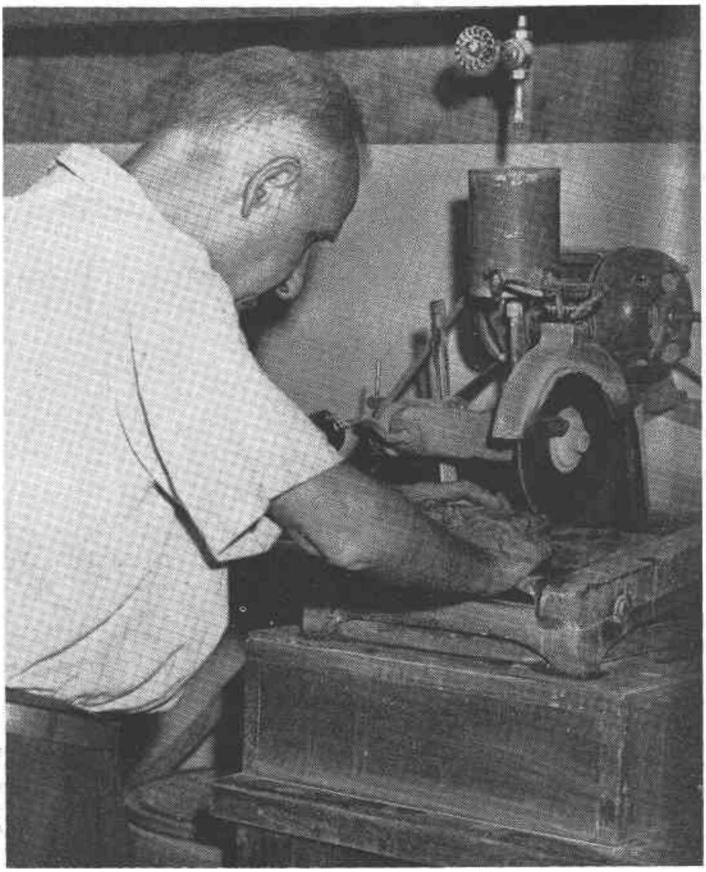

FIG. 2. Use of diamond saw.

driven by a $\frac{1}{2}$-hp motor at a speed of 1425 to 1475 rpm. Water or kerosene can be used as a lubricant. In the Survey laboratory, a soapy-water solution has been found to be a very satisfactory lubricant for sawing. Use of the diamond saw is illustrated in Figure 2.

Mounting table

The table on which the rock slices are mounted to the glass slides is brass $18\times5\frac{1}{4}\times\frac{1}{4}$ in. and supported on four legs 8 in. long (Fig. 3). The table holds 20 rock slices and their corresponding numbered slides. It is heated to a temperature of approximately 100° C. by a Bunsen burner. Reference numbers are cut on the glass slides with a diamond point mounted in a holder $5\frac{1}{2}$ in. long and $\frac{5}{16}$ in. in diameter. Canada balsam is used for cementing the rock slices to the glass slides. A mounting rod

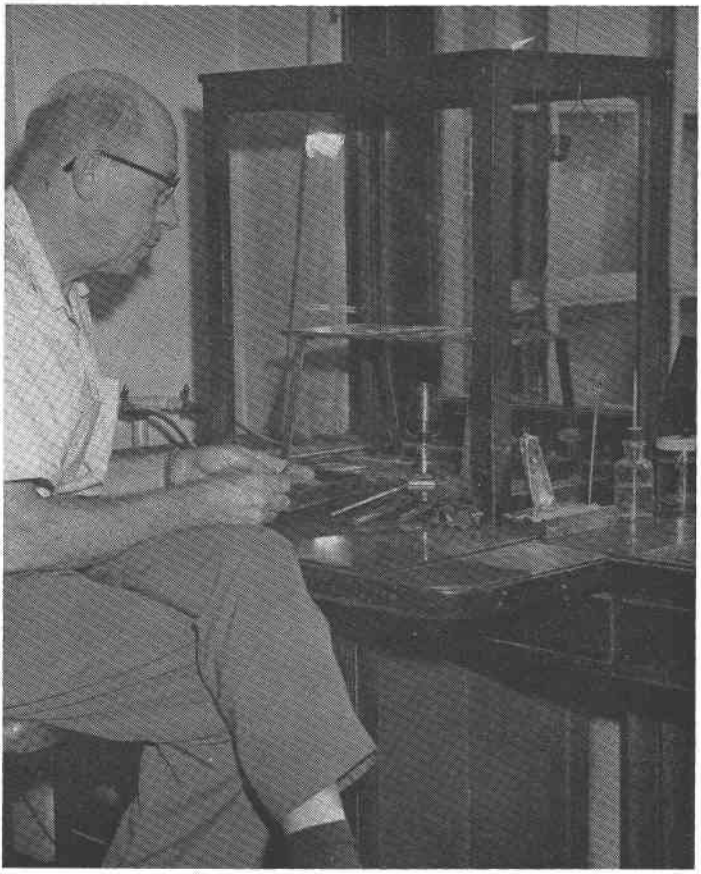

FIG. 3. Brass mounting table heated by a Bunsen burner.

8 in. long and $\frac{1}{8}$ in. in diameter has one end bluntly pointed, and this end is heated sufficiently so that it can be pushed into a lump of hard-cooked balsam. When cool the lump of balsam is held firmly.

Band saw

An ordinary wood-cutting band saw with few modifications is made serviceable for stone cutting (Fig. 4). The rock specimen to be sawed is clamped to a sliding platform that is guided by two tracks. There are a sufficient number of threaded bore holes cut into the platform so that specimens of various sizes and shapes may be clamped. Five or six iron rods threaded at both ends and ranging from 6 in. to 12 in. in length, a channeled crossbar, and iron weights or wooden blocks comprise the equipment for clamping the rock to the platform. A glass container is filled with #120 silicon carbide abrasive. The flow of abrasive is controlled

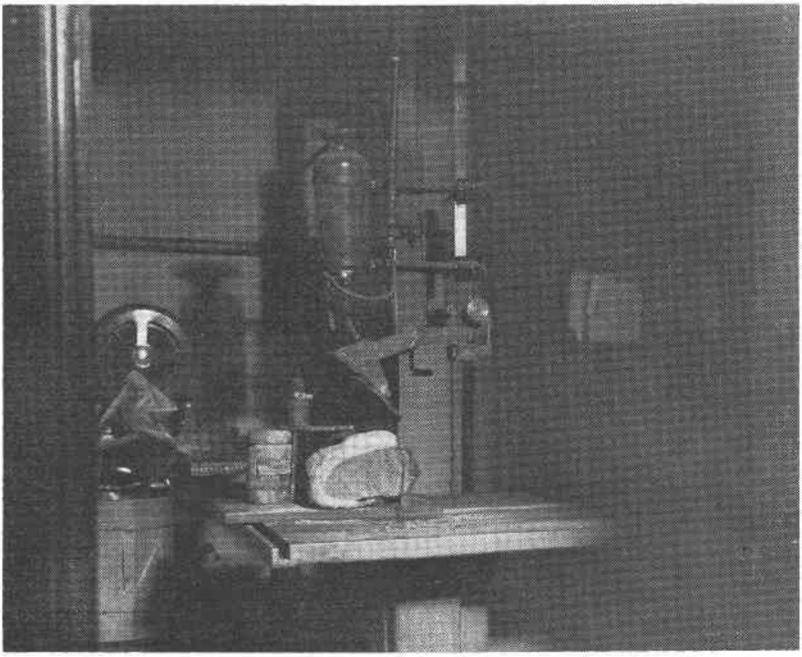

FIG. 4. Band saw modified for cutting rocks.

by a petcock cemented at the bottom of the container. The abrasive drops into a metal box and is flushed onto the saw with water. A piece of leather belting that ends in a point is attached to the metal box with rubber bands to direct the flow of the abrasive onto the edge of the saw. The upper wheel of the saw has an attachment for moving the band against or away from the rock. Obviously, the band must come into contact with the rock specimen. The wheels are set so as to provide pressure of the band against the specimen.

When a rock specimen has been securely clamped to the platform, the silicon carbide and water are turned on, adjusted to the proper flow, and the motor started. The specimen is slowly and carefully pushed to the edge of the saw band to allow the band gradually to cut its way into the rock. As the sawing progresses the platform is moved forward, about half an inch at a time, to keep the saw and rock in contact. A slow speed is best for this type of sawing. The motor is geared for a band speed of about 150 feet per minute.

STANDARD ROCK THIN SECTIONS

For the ordinary firm rock thin section, a slice approximately $\frac{1}{8}$ in. thick is cut from the specimen with the diamond saw. This slice is first ground on the rough-grinding lap. Very little grinding is needed to remove saw marks, but a uniform thickness should be maintained to facilitate the elimination of air bubbles when the chip is cemented to the glass slide.

The rock chip, after having been "roughed down," is transferred to the fine-grinding lap and one of the faces given a smooth, flat, scratch-free surface. Any convexity of this surface must be avoided. The chip should be held firmly and evenly against the lap during grinding and not be permitted to "rock," and the fine-grinding lap must be free from concavity. The tendency of the laps to become concave can be lessened by grinding the chip with a circular motion from the center of the lap to the edge and back again to the center. Also, in fine-grinding the surface of the rock chip, a flat surface is best obtained if, when the chip is ground nearly flat, it is held firmly in one place near the center of the lap for approximately the last half minute of grinding.

After the rock slice has been rough- and fine-ground, it is ready for cementing to the glass slide with Canada balsam. Both chip and numbered slide are placed on the mounting table and heated until the hardened balsam applied with the mounting rod spreads easily when applied to the slide and chip, both of which are to be coated with balsam. The slide is taken up with the fingers and pressed down on the chip, beginning at one side of the chip and pressing down at an oblique angle toward the opposite side, to eliminate air bubbles. After the slide is firmly pressed onto the chip, excess balsam and air bubbles, if any remain, are removed by moving the slide in a circular motion while exerting pressure from the mounting rod.

The mounted chip is then ground on the lap with No. 1F silicon carbide, which is the most suitable abrasive for this first grinding of the mounted chip. It allows grinding down to a point where the section becomes sufficiently translucent to transmit light with a minimum of strain and scratching of the slide. The section is then ground on the fine lap. Here #600 silicon carbide is used, and the rock section is ground down until it reaches the standard thickness (0.03 mm.). Most of the thin sections made from ordinary firm rock material can be finished on the rotating lap. Some thin sections show signs of fraying at the edges; and then it is necessary to continue the grinding by hand on a piece of plate glass with #600 optical alundum.

The ability to decide when the thin section has been ground to the proper thickness is a matter of experience. The thickness of a thin section may be very accurately judged by means of the birefringence exhibited by certain standard minerals, as shown under the petrographic microscope. The following suggestions should, however, prove helpful to beginners. Quartz and feldspar are common minerals in most igneous rocks, and their birefringences are similar. As a consequence of this phenomenon, grains in a position of maximum birefringence may be safely used as indicators of the proper thickness of a section. The birefringence of these minerals is given in the following table:

Table of birefringence

Quartz	0.009
Orthoclase	0.006
Microcline	0.007
Plagioclase	0.007–0.012

Charts relating birefringence to thickness for crystalline substances are contained as colored plates in many books on optical mineralogy or petrography (Iddings, 1911; Rogers and Kerr, 1942).

By consulting such charts it is possible to determine under crossed nicols the proper interference color that the grains should exhibit when the thin section is ground to the proper thickness, namely, 0.03 mm. Thus, for quartz, orthoclase, and some of the plagioclases the maximum color shown by any grains of these minerals is pure white; and for the very calcic plagioclases, the proper color may be pale yellow. Some of the other common rock-forming minerals, such as the amphiboles, pyroxenes, and olivine, show a considerable variation in birefringence with crystallographic orientation and require more knowledge on their use as indicators than do the minerals referred to above. The experienced worker, by noting the interference colors of these minerals when associated with the standard minerals, should be able to use them as guides in such rocks as dunites, pyroxenites, and amphibolites, in which the light-colored minerals are commonly absent.

Most sedimentary and metamorphic rocks carry some of the minerals listed above, and in addition they frequently contain calcite or dolomite. The interference colors of calcite in a thin section of standard thickness are referred to as "whites of high order." Actually, when the calcite is examined closely in polarized light, and under crossed nicols, this "white" is seen to be made up of an intricate pattern of tiny pale-colored areas that blend to give the impression of white light. An altered igneous rock that has been ground to the proper thickness as judged by the standard minerals and that contains calcite serves well as a reference for the carbonates.

The next operation is the mounting of the cover glass. The balsam still clinging to the slide is chipped away with a small sharp steel knife to within $\frac{1}{16}$ in. around the edge of the entire section. Then the slide is gently washed with a fine camel's-hair brush dipped in turpentine. This washing removes any particles of silicon carbide that may have become embedded in the balsam surrounding the section or in holes or cracks in the section itself. Turpentine is used because it has a slight solvent action on the balsam. The film of turpentine remaining on the slide is blotted off with newspaper or paper hand towel, and the lint from the paper that clings to the slide is removed by gently rubbing the slide over the palm of the hand. Most thin sections of common rocks are sufficiently coherent so that they will not tend to part along grain boundaries during the mounting of the cover glass. A small amount of uncooked Canada balsam is now placed on the thin section, the amount sufficient to cover the area of the section. It is very important to have the mounting table just barely warm when the thin section is placed upon it for cover-glass mounting. If it is too hot, bubbles form immediately. The gas burner is then turned up enough to heat the mounting table to about 90° C. The thin section with its fresh coating of uncooked Canada balsam should be heated long enough so that the balsam will be hard but not brittle when cool. If the balsam is too brittle, the cover glass tends to work loose from the slide before long. Sufficient cooking is tested by removing a small globule of balsam from the thin section with a mounting needle and pressing it lightly against the finger nail. If it does not stick to the finger nail, the balsam has been sufficiently hardened and the thin section is ready for the cover glass to be placed upon it. The cover glass is held in a pair of forceps and slightly heated in the flame of the Bunsen burner, then placed at one side of the slide and drawn at an oblique angle slowly over the thin section to the opposite side. This procedure helps to eliminate air bubbles. Excess balsam is pressed from between the slide and cover glass with the mounting needle. The contact between the cover glass and the thin section must be as close and even as possible to permit petrographic examination under the highest-power objectives. All excess balsam around the edges of the cover glass is cut away with a hot knife. This knife is an ordinary bread knife squared by cutting off the rounded end. The remaining thin film of balsam on the slide is washed off with alcohol and the slide immersed in a pan of water to prevent the alcohol from eating under the edges of the cover glass. If the rock is so friable that there is danger of its parting along grain boundaries, the surface should be given a thin coating of collodion before the cover glass is applied. The collodion, which is applied with a fine camel's-hair brush, is colorless and does not affect the relations between the indices of refraction of the minerals and the mounting balsam.

Mounting and Impregnating Media

Canada balsam

Canada balsam is the most satisfactory mounting medium for most common rocks except coal. For coal the combination of two parts Canada balsam and one part marine glue is better than Canada balsam alone. The index of refraction of Canada balsam (1.54) approximates the index of quartz, thus making it very useful in the microscopic determination of the minerals in thin sections. The balsam is easy to prepare and serves to cement both the ground chip to the glass slide and the cover glass to the thin section. It remains workable long enough to eliminate bubbles. Furthermore, less heat is required than for other media. The hard-cooked balsam used for cementing the ground chips to the slides is prepared by pouring the desired amount into a procelain dish and cooking slowly on an electric hot plate until a globule of it on the end of the mounting needle will not stick when pressed against the thumbnail. Care must be taken to guard against overcooking, which causes the balsam to become brittle. Should this happen, serious difficulty will be encountered in the final stages of grinding the thin section. When the section is approaching the proper thinness, the brittle balsam will break away from the slide and pull portions of the section with it.

Canada balsam also serves very well as an impregnating medium for friable rocks. The friable chip is placed in a container with some lumps of the hard-cooked balsam and allowed to cook slowly on an electric hot plate for about 10 minutes or until all the pores of the chip are thoroughly impregnated. After this impregnation the chip can be sawed or rough-ground. Large chips may have to be impregnated twice.

Kollolith

The compound Kollolith is similar to Canada balsam as a medium for cementing rock slices to slides and the mounting of cover glasses. When obtainable it can be had in tubes in both the liquid and the hardened state. It differs from Canada balsam in having a slightly lower index of refraction. Long-continued heating of friable rocks impregnated with it does not cause appreciable darkening of the material.

Glycol phthalate

Glycol phthalate is a hard and tough compound that is not satisfactory for most types of thin-section work, but it has the special advantage of adhering to the glass slide with much greater tenacity than balsam. It requires a much higher temperature than balsam for melting, and this high temperature causes bubbles to develop in great numbers; also the material hardens so quickly that difficulty is experienced in trying to squeeze out the bubbles. Owing to the high viscosity at lower temperatures, greater pressure is required to squeeze out the bubbles; and this pressure tends to cause the thin section to separate along crystal boundaries. It is used most effectively in making polished thin sections, which require no cover glasses. The technique of the preparation of polished thin sections has been worked out in this laboratory and has been described by Kennedy (1945).

Bakelite varnish

The greatest usefulness of bakelite is in the impregnation of particularly friable materials preparatory to making thin or polished sections (see section on impregnation). Overnight heating in the electric oven, with a temperature of 70° C. is required to harden it sufficiently. For the preparation of thin sections of small grains or fragments bakelite varnish is desirable.

In preparing thin sections of rock fragments or grains, first cut a piece of glass about $\frac{3}{4}$ in. square from a slide, then spread a thin layer of grains over the entire area or as many of the small rock fragments as it will hold. Next dilute the bakelite varnish with acetone until it is of the consistency of thin syrup. Then drop the thinned bakelite on the grains or fragments until they are completely covered. After an hour or so the excess of acetone will have evaporated; place the glass slide holding the grains or fragments in the electric drying oven overnight at a temperature of 70° C. By morning the bakelite varnish will have been cured, i.e., polymerized. The grains or fragments thus cemented to the glass are ground on the fine lap until a smooth scratch-free surface has been obtained. From here on the method for making the thin section follows the same procedure as that of the ordinary rock thin section. The bakelite has a high index of refraction (1.63) and a pale amber color, which may be objectionable. The one who is to use the thin section should be told that bakelite has been used if he himself has not suggested its use.

Method of Applying the Abrasive

The abrasive, a silicon carbide and water mixture, is scooped from a container with the fingers onto the rotating lap for the rough-grinding of the chip. The lap must be sufficiently charged with the abrasive during the grinding. For the final grinding of both the unmounted and the mounted chip the abrasive is applied in the same manner as in the preceding grindings. The abrasive should be of such consistency that, when applied to the lap, it will not be thrown off too fast because of its wetness or not be so thick as to impede its spreading over the lap evenly. Some practice will be necessary, however, before the technician learns how much and how often to apply the different abrasives to the laps in the several stages of grinding.

Repairing Damaged Thin Sections

If a thin section is dropped, it may be shattered beyond repair, but more commonly the damage is a sprung cover glass or a broken corner. Sometimes the thin section clings to the cover glass instead of to the slide. A sprung cover glass may show only slight strains in the Canada balsam and exhibit an iridescent effect. Also, if a thin section gets too hot, as, for example, if it is left near a window in direct sunlight, it may develop bubbles.

When the damage is slight, such as a few strained areas in the balsam appearing between the cover glass and the slide, repair is simple. If the slide is held in a pair of forceps and passed gently through the flame of a Bunsen burner several times, the balsam will soften enough to eliminate the strained areas. Caution should be exercised to avoid overheating, because this may produce bubbles. If this happens, the cover glass must be removed and the thin section remounted. The same treatment is used for a cover glass that has completely sprung from the slide or for one held only by a small area of balsam. When numerous bubbles have formed between the cover glass and the slide, from overheating in the attempt to remove strains, the cover glass is removed by holding the slide in the forceps and passing it through the flame until the cover glass can be moved rather freely with the mounting needle. Then it is pushed to one end of the slide and removed with the fingers. If the balsam begins to stiffen before the cover glass has been pushed out to a little beyond the end of the slide, reheating is necessary.

A cover glass held only by a small area of balsam can be pried loose by inserting the edge of a razor blade between it and the slide and giving it a quick flip. The balsam still adhering to the slide need not be washed away if it has not become discolored or too hard. The chief trouble encountered when balsam has hardened too much because of age is that the thin section cannot be moved about on the slide for the removal of bubbles, should they be present between thin section and slide. Under these circumstances, the thin section is transferred to another slide. The slide is heated on the mounting table until the thin section can be gently pushed from the old slide onto the new one. This same method is used also when the thin section clings to the cover glass. Where there is no discoloration or extra hardness in the balsam, a small amount of uncooked Canada balsam is deposited on the thin section as in the procedure described in the section on standard rock thin sections. Occasionally, however, balsam becomes so tough that it is risky to heat the slide with the intention of transferring the thin section to a new slide. When this happens, the thin section slide is immersed in a suitable receptacle containing turpentine. The balsam dissolves overnight. If the receptacle has not been disturbed, the thin section will be found to be resting on the slide. The slide is carefully removed from the container with forceps and the thin section gently pushed onto the new slide, upon which has been deposited a small amount of uncooked Canada balsam. Then an additional amount of balsam is applied to the thin section, and the previously described standard procedure followed. Such transfers are successful only if the material of the thin section is very coherent. If it has been previously coated with collodion, however, the chances are that it will withstand transfer. Transfer of a thin section from a broken slide to a new one is comparatively simple if the thin section is sound. All that has to be done is to remove the cover glass, heat the slide over the Bunsen burner until the balsam is soft, and, with the aid of the mounting needle, gently push the thin section onto the new slide.

Materials Requiring Special Treatment

At one time petrographic studies were confined largely to crystalline rocks and a few sedimentary rocks, such as sandstones and limestones. More recently geologists have become increasingly interested in the more friable rocks, including shales, bentonites, poorly consolidated volcanic materials, slightly indurated sands or gravels, bauxites, coals, ceramic materials, and a large variety of clays and soils. To prepare usable thin sections of this variety of materials necessitated the devising of new mounting media and section-making techniques that were not necessary in the old days. However, the materials and textures range over such wide limits that procedures can not be standardized. Each lot of specimens must be evaluated individually and the most suitable method devised.

Ross (1926) was the first to suggest a suitable method. Ahrens and Weyland (1928) and later Schaffer and Hurst (1938) have also described satisfactory methods for the preparation of thin sections of friable rocks. The methods given here are essentially those of Ross. Some of these materials have to be ground without the use of water; heating to the lowest possible temperature when mounting chips on the glass slides is another requisite in the process of making thin sections of friable material.

The preparation of coal thin sections has been studied by Thiessen and associates (1938).

Clays

For clays, a slice is cut from the sample with a fine-toothed hacksaw or, if available, a jewelers hacksaw. If the sample is comparatively free from quartz, a motor-driven circular carborundum saw permits one to cut a slice from the sample quickly with less danger of breakage than if the sample is held by the fingers and cut with the hacksaw. No water is used with the carborundum saw. The equivalent of rough-grinding on the sawed clay slice is done on a 12-in. flat "bastard" file. The chip is rubbed forward and backward over the file to eliminate saw marks. Deep scratches must be avoided, for they cause a distortion of the clay chip that results in birefringent striae in the thin section. If such scratches are formed an appreciable thickness of the clay material underlying the scratch must be removed. This can be done on the same file or, if preferred, a 12-in. flat "smooth" file may be used. With a little practice, the proper feel or touch is developed. Samples of nearly pure clay materials, or shales or related material containing mineral grains with a diameter less than the thickness of the finished thin section, present a minimum of difficulties. If coarser grains are present, impregnation permitting wet grinding is commonly advisable. Some samples become checked after the moisture dries out, others become friable, so that impregnation is necessary before they can be sawed and rubbed on the file. Kollolith or Canada balsam is used. After a reasonably smooth surface has been obtained by rubbing on the file, further grinding is continued on plate glass with mineral oil and #600 optical alundum. Liquid petrolatum (light) mineral oil is recommended for the mixture because this does not rapidly dissolve the balsam. The chip is rubbed firmly and gently over the plate glass until the remaining fine traces of the file marks are removed. If there are quartz grains present, some will break loose, and they will gouge deep lines into the clay slice. Impregnation with balsam or Kollolith helps to overcome this obstacle if the clay is not too compact. By impregnating the slice, penetration is deep enough to hold the quartz grains. On the other hand, when the specimen is very compact and impregnation is more or less ineffective, a fair result is obtained by gently rubbing the clay slice on the plate glass in a thick paste of alundum and oil. When mounting the clay slice on the slide, care must be exercised to avoid too rapid heating and overheating. If this should happen, the ground surface becomes checkered with numerous cracks, preventing good mounting. In most cases, however, only a few cracks develop in the clay slices during mounting. After the clay slice has been cemented to the slide with Canada balsam, it is ground or rubbed down on the file until it becomes translucent. The final grinding of the section to the proper thickness is completed on the plate glass. Number 600 optical alundum and the mineral oil serve for this grinding. Despite the fine, even-grained texture of this grade of alundum, some fine scratches will be found in the thin section. In thin sections they are quite numerous and rather coarse, if fine grains of quartz break loose. Further grinding on the plate glass to reduce them is useless. Dipping the forefinger into some of the oil and alundum, and then rubbing rather firmly forward and backward over the thin section helps to reduce the number of scratches and to decrease their coarseness.

The mounting of the cover glass follows the procedure for other friable rock thin sections. However, care must be exercised to avoid washing away the clay when the old balsam is removed with turpentine. The technique of reducing scratches by rubbing with the forefinger is effective also with such soft waxlike minerals as talc, gypsum, alunite, and serpentine.

Water-soluble minerals and minerals decomposed by water

The following methods have been used successfully on shortite, halite, sylvite, and polyhalite.

A piece is cut from the sample with a hack saw having 14 teeth to the inch. The chip is roughed down on the flat "bastard" file on both sides until it is as close to 3 mm. thick as possible. The use of water is not permissible in any of the grinding operations. Instead of proceeding with the fine-grinding on the plate glass with oil and optical alundum, grinding of the chip surface is resumed on the fine rotating lap charged with a mixture of #600 silicon carbide and alcohol, to provide a finished surface for mounting on the glass slide. Ordinarily, a suitably fine-ground surface can be obtained on the rotating lap. If not, the finishing touches are applied by grinding on plate glass with #600 optical alundum and alcohol. The silicon carbide that clings about the edges of the chip is washed away with a stiff-bristled hand brush and alcohol. Chips of these minerals are mounted in the same way as those of the ordinary rock thin sections with the exception of minerals that lose water readily when heated. Here the least possible amount of heat must be used.

After the chips have been mounted on the glass slides, grinding is resumed on the file until the chips are cut down to the balsam or farther, if they will stand it, which saves time in the final preparation. After the section has been ground down on the file, final grinding to the proper thickness is done by hand on the plate glass with # 600 optical alundum and oil. Oil is substituted here for alcohol, which would dissolve the balsam holding the thin section to the slide. Except for minerals decomposed by heat, the cover glasses are mounted in the same manner as those for friable rock thin sections. For minerals decomposed by heat, however, a somewhat different method of cover-glass mounting is employed. The thin section of a mineral that is broken down by heating should have its cover-glass mounted with xylol-balsam, a cold mount, following the procedure for friable rock thin sections. By handling carefully, a thin section so mounted can be examined under the microscope without getting either the hands or the microscope sticky. However, the thin section can be dried in an electrical oven overnight at a temperature not above 40° C. With a little experience one can learn to mount with just enough xylol-balsam so that the balsam flows to the edges of the cover glass and no farther. Also, with practice, one can learn to place the cover glass on the section so as to prevent the forming of bubbles altogether.

Gypsum

The procedure employed in cutting thin sections of gypsum follows the same general pattern as that of ordinary rock thin sections, but the softness of the mineral and the low temperature at which it tends to undergo a transition to the hemihydrate present unusual difficulties.

A slice is cut from the hand specimen or drill core on the diamond saw. With this soft mineral grinding on the rough lap is not necessary. The first grinding takes place on the medium lap with #1F silicon carbide to remove saw marks and to cut the slice down uniformly to about $\frac{1}{8}$ in. in thickness. If $\frac{1}{8}$ in. can be achieved, very little grinding on the medium lap is necessary to remove saw marks. Soft minerals like gypsum require special care in getting a fine-ground surface prior to mounting on the glass slide. This operation is thus a critical one in the procedure. Number 600 silicon carbide serves as the grinding abrasive on the fine-grinding lap. Grinding on the fine lap is continued until further grinding does not improve the smoothness. Scratches and also a finely pitted surface develop during this grinding. To remove them, grinding is resumed on the plate glass with #600 optical alundum. The key to producing a smooth, scratch-free surface is the pasty consistency of the mixture of the alundum and water. If the mixture is too watery, the grains of alundum flow too freely and form scratches even though this abrasive is very fine and of even texture. By a gentle, steady rubbing forward and backward on the glass plate, a smooth, scratch-free surface is obtained. A little practice is necessary to get the best results.

The gypsum slice is next mounted on the glass slide with Canada balsam. As gypsum loses part of its water of crystallization and water absorbed between cleavage planes at a low temperature, bubbles are readily formed and must be guarded against. Therefore chips are not heated but are allowed to dry overnight at room temperature before being cemented to slides.

For mounting, the slide and chip are heated on the brass mounting table just enough so that the hard-cooked Canada balsam will flow fairly easily and allow pressing the slide down on the chip and squeezing out excess balsam. Keeping the temperature low prevents the formation of bubbles (as mentioned above). But difficulty will be experienced in getting a good mount the first time because the balsam, while flowing fairly easily, is not as fluid as it would be at a higher temperature. Generally the operation has to be repeated several times before all bubbles are removed. After the chip is cemented to the glass slide, grinding is resumed on the medium lap. Number 1F silicon carbide serves as the abrasive for this grinding. For good results the gypsum chip is ground down no thinner than $\frac{1}{32}$ in. The next and final grinding on the revolving lap follows the usual procedure in the preparation of ordinary rock thin sections. Here it is well to grind down the section until the gypsum shows a bright-yellow interference color under crossed nicols. An attempt to secure a thinner section might result in the complete grinding away of the section. Final grinding is done on plate glass with # 600 optical alundum until the required thinness is obtained. It may not always be possible to cut the section down to a thinness to permit gray to show under the crossed nicols because of a tendency for the section to fray at the edges. Usually gypsum sections show pale yellow under crossed nicols by the time fraying begins. Once fraying begins, it progresses rather rapidly, and therefore grinding must be stopped before the section becomes very small or is lost entirely. A pasty mixture of water and alundum is necessary to prevent scratches when a fine surface is to be ground on the mounted gypsum chip.

The cover glass is mounted after the various stages of grinding are completed. This proceeds partly along the same lines as in the preparation of ordinary rock thin sections. As mentioned before, the use of minimum heat is an important factor. To avoid any danger of overheating, the cover glass is mounted by cold mounting, as described above. The slide is placed in the electric oven at 50° C. and allowed to remain overnight, so that the balsam becomes hardened about the edges of the cover glass. The excess balsam around the edges is removed with a knife, just hot enough to permit the scraping away of the balsam. If too hot, it causes sufficient melting of the balsam to form bubbles under the cover glass. It is necessary, after the first scraping, to place the slide in the oven again overnight at the same temperature to allow the balsam under the cover glass to harden to a greater depth from the edges inward. On removing the slide from the oven this second time, a little more balsam will be found to have oozed from under the cover glass. This is also scraped away with a hot knife. In most cases the balsam under the cover glass has had sufficient volatile matter driven off so that it is hard enough to permit washing off of the remaining film of balsam adhering to the slide. Only experience enables one to determine how far this procedure should be carried. The slide is washed in alcohol with a hand brush and quickly immersed in water to prevent the alcohol from eating under the edges of the cover glass, after which it is dried with a soft cloth. As a safeguard against the possibility that the balsam is not sufficiently hard and to prevent stickiness about the edges of the cover glass, it is a good plan to place the slide back in the oven for another night.

Coal

Thin sections of coal are more difficult to prepare than any material previously described. Some of the difficulties are due to friability, the danger of burning and checking of the fine-ground surface with the application of too much heat, and the fact that the thin sections of coal must be thinner than other thin sections. The sample of coal from which the thin section is to be cut is impregnated with paraffin overnight in the electric oven at a temperature of 70° C. The sample is placed in a white enameled pan with enough paraffin when melted to cover it. In this way it is made strong enough to permit the sawing off of a piece for a thin section. Also, a lower temperature can be used than would be possible if Canada balsam or some other impregnating medium were used. Next morning the sample is taken from the oven and placed on a mat of paper hand towels or newspapers so that excess paraffin drains off. When cool a piece is cut from the sample with the diamond saw, or, as a second choice, with a hack saw. During mounting to the slide, which requires a moderate amount of heat, the impregnated coal has a tendency to warp. This may be prevented by cutting a rather thick slice—5 mm. or more, depending on the soundness of the sample. The first grinding takes place on the medium lap with #1F silicon carbide, for the removal of saw marks, after which grinding continues on the fine lap with #600 silicon carbide. This is followed by hand grinding with #600 optical alundum on the plate glass until a smooth, scratch-free surface is obtained. Coal sections differ from most other sections in that a polished surface is necessary. Before mounting on the glass slide, the smoothly ground surface is polished on a cloth-covered 6-in. rotating lap with tin oxide or chromic oxide until all traces of scratches and pits are removed. The cloth used in covering the lap should not be coarse, but a fine-grade cotton material. The chromic oxide or tin oxide is placed in a container with water and applied to the revolving lap with a camel's-hair brush. Manipulation by the fingers of the coal slice in a circular movement from the center of the lap to the edge prevents furrows from developing.

The Canada balsam used in mounting the polished coal slice on the slide should be cooked only to the degree of hardness that will permit pressing the fingernail into it with slight effort. It is then soft enough to give a cushioning effect to the chip during the grinding of the slide. If a very slight fluidity of the mounting medium is not objectionable, a mixture of one-third by volume of marine glue and two-thirds uncooked Canada balsam answers very well. This mixture is prepared by cooking the balsam and the marine glue to a consistency that, when cool, can be dented easily with the fingernail. The cushioned effect created by the marine glue mixture or the not-too-hard cooked balsam aids considerably by preventing the thin section of coal from fraying away at the edges. By allowing the chip to dry thoroughly overnight, the tendency to form bubbles is reduced. The chip is mounted on the slide in the same way as a chip of gypsum. However, after the coal chip has been firmly mounted on the slide and all bubbles eliminated, it is a good plan to maintain pressure on the slide with the mounting rod until the balsam has set.

Grinding is resumed on the medium rotating lap with #1F silicon carbide until the coal section is approximately 0.25 mm. thick, and then continued on the fine lap with #600 silicon carbide. This grinding is continued until the section becomes slightly translucent at the edges. Commonly the section starts to fray a little at the edges before it shows any sign of translucency. When this happens, it is time to discontinue the lap grinding. Grinding is continued by hand on the plate glass with #600 optical alundum, but a close watch is kept for signs of fraying at the edge of the section. A slight fraying away is not dangerous and happens with most coal sections. The last operation, in which the coal thin section is ground down to the proper thinness, is done on a 6-in. cloth-covered lap with #600 optical alundum. The cloth used here is of the same type as that for polishing the surface of the unmounted chip. Alundum and water are applied to the rotating lap with the fingers. The lap must be kept moist to prevent scorching of the section. The slide is moved slowly with the fingers in complete circles from the center of the lap toward the edge and back until the section is thin enough. Throughout this polishing the slide should be held firmly against the lap and not be permitted to rock from one side to the other. This ensures uniform thinness. Sometimes further polishing and grinding, using the forefinger, is necessary to finish the section. By applying a pasty mixture of water and alundum to the section of coal and rubbing it with a firm forward and backward motion with the forefinger, the proper thickness can be attained. If there are several coal sections to be ground, the forefinger may become sore and tender. A cork big enough to cover the thin section and worked in the same manner as the forefinger can be substituted. The probable advantage of the forefinger is that a sense of feel is present. This operation, whether performed with the forefinger or the cork, is somewhat tedious, but with care and patience excellent results can be obtained.

The cover glass is mounted as for thin sections of gypsum. However, one may risk mounting of the cover glass by the procedure for standard friable sections. If heating is carefully controlled, very little scorching will develop. The cleansing of the slide proceeds in the manner described for both the cold and the hot mountings.

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