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PREPARATION OF TRANSPARENT SECTIONS OF ROCKS AND MINERALS.

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IT is generally stated that Mr. Witham was the first to introduce the method of preparing thin sections of stony material for use with the Microscope. He published many years ago a work on the Microscopical structure of fossil wood, but I think it is very much open to doubt whether he was the man who invented that method.

A good many years ago I had the pleasure of making the acquaintance of Mr. Nichol, of Edinburgh, well known as the inventor of "Nichol's Prism." He was about seventy years of age, and was a very fine man indeed for that age. He had an exceedingly interesting collection of sections of wood and minerals, and he told me that it was he who originated the method of preparing thin sections of fossil wood for the use of the Microscope, and that Mr. Witham did not write that book. It was written for him, and the author had special instructions given to him never to allude to Mr. Nichol. He is now dead, however, and I suspect that all who knew about the circumstances are also dead, but I am inclined to believe that Mr. Witham bought his sections of fossil wood from Mr. Nichol, and had the book written for him, and he thus got the credit of being the first to introduce the method.

Of course we have not now the opportunity of ascertaining what was Mr. Witham's view upon the matter; but in any case there can be no doubt that Mr. Witham's book was the first account of the method by means of which sections of fossil wood could be prepared so as to be examined as transparent objects with the Microscope.

Sometime after that a similar method was adopted by Professor

Owen, and Mr. Nasmyth, a celebrated dentist in London, in studying the structure of recent teeth. And then I believe that Dr. Carpenter was the first to introduce the method as applied to the study of the structure of recent shells.

Very little else was done for some time, and, as far as I am able to ascertain, nothing whatever had been done in applying the method to the study of sections of rocks for geological purposes.

Curiously enough, up to some years after I introduced that method, the old plan of studying the structure of rocks was still adopted, namely, crushing portions of the rock and examining the powder.

I was aware of the application of the Microscope to fossil wood and teeth, and it occurred to me, about thirty-three years ago, that a very great deal of light might be thrown on the structure of rocks by preparing thin sections of them, and, as I daresay many of you are well aware, that suggestion has borne a wonderful amount of valuable fruit.

I believe that the first sections I prepared were some very imperfect ones from the Carboniferous Limestone of Derbyshire. I have not seen them for years, and the only interest attaching to them would be that they were the first that were prepared.

But a short time after that I established myself at Malvern, to study the Geology of the Malvern Hills; and it was with specimens obtained here that I first began making sections of any kind of value for use with the Microscope, and I thought it would be interesting to the Members of this Society if I brought down for inspection one of the very first sections that were prepared for this purpose. And here I may say a word or two with regard to this form of glass. I find that glasses about $1\frac{6}{10}$ inch square are much better for my kind of work than the ordinary form, because you can have a larger piece of rock, and you can work them more evenly in every direction, than if you have a long narrow glass. As an illustration of how subjects like these are developed in a manner which appears amusing when looked at afterwards, I will describe how I was led to adopt the form and size of these objects. Not very long after I had begun the examination of the structure of rocks I grounded myself well in the optical properties of crystals, and made for myself a rather complicated polariscope. This was made out of brass tubes of various sizes, and ultimately there was a tolerably large top portion to enable me to put crystals underneath, and I had to leave a square piece at the top into which the glasses might fit, and then was made the right size for the tube I happened to use. Some of these earlier glasses were ground by myself and the gardener on a grinding stone used to sharpen the scythe.

The size then was determined by the accidental size of this

polariscope, and having prepared sections of calcite and other minerals, I had a box made to hold these, and when first preparing sections of rock the natural thing was to fasten the rocks on these pieces of glass. The result is that I have now a very large collection of sections of rock, all mounted on squares of glass of this size.

With these few preliminary remarks I will begin by giving an account of the method I have adopted in preparing sections of rock.

Of course everything had to be learnt, and there were then none of the facilities you have now.

The most obvious method now would be to use a slitting machine, but I commenced and afterwards continued to adopt a method which would not be used now, but which led to good results. I found that if you had specimens such as you would get out of a museum, it would be very desirable to saw thin portions off, but nearly all the specimens that I have studied have been collected *in situ*. Of course there are obviously great advantages in that, because you are then acquainted with the conditions under which the specimens are found, and you can break off thin portions. I always used to break them at right angles to the stratification, and in the case of rocks with slaty cleavage, one portion in the line of the dip and another in the line of the strike, reserving larger pieces for hand specimens.

Having then collected specimens in that manner, the next thing is to deal with them in such a way as ultimately to give you a thin section. A deal of the work I did myself, but afterwards I found it very convenient to get much done by glass cutters. I had them thus ground into portions such as the specimens I have here, say about one inch square and $\frac{1}{8}$ inch thick. Then, having got a portion of rock like this, the next point is to finish off one surface, so as to have it as perfect as possible. You can well understand that it should be absolutely flat,—a perfect plane,—because many sections of limestone must not be more than $\frac{1}{1000}''$ in thickness. If not quite flat in grinding them down, ultimately you are liable to grind one portion away whilst the other is too thick. The method adopted to obtain a perfectly plane surface on which to rub these sections was as follows: I had a sort of flagstone, about two feet square, fixed on a table in the yard,—it was a sawn flag, tolerably level; then I had two portions of little flags, about fourteen inches square, of good quality, such as you obtain in this neighbourhood; then the first consideration was to rub these two flags with emery backwards and forwards on the large flag till perfectly smooth. You might get them both a little convex, perhaps, but both alike. The next thing to do is to rub these two stones together, and the stones being of the same hardness and

the same curvature, when you come to rub them down they are worn evenly until they are perfectly flat, and you have really then got two small flagstones with a comparatively plane surface.

You require a number of different kinds of stones to work your specimens upon. I first used to apply sandstone with emery, but this was inconvenient and wore hollow; but I have found that a convenient method was to do the rough grinding on a plate of zinc about a foot square and hammered flat, rubbing the specimens down on this zinc first with fine ground emery and then finishing them off with finer still. I had two zinc plates, one worn somewhat hollow and the other as flat as possible, doing the rough work on the first and finishing it off on the more level with finer emery; but you cannot get a flat surface in that manner. The specimens always wear away more at the corners, and that is, perhaps, one of the greatest difficulties in the preparation of these objects, because it entails so much labour, but I do not see how it can be avoided.

Having got the specimens dressed up in that manner, the next point is to get the surface into a far better condition than it can be got by emery, and I used to employ two or three kinds of stone. It is not always easy to get pieces of a satisfactory character, but I used to employ a kind of stone called Congleton stone, and also Water-of-Ayr stone. This Congleton stone does not scratch, and it does not polish, but keeps a good cutting edge, so that you can rub down tolerably quickly. The specimens are finished off ultimately on the Water-of-Ayr stone, and for that purpose I used to have two portions, six inches square, one of a soft grain and the other a hard grain for finishing. These stones are rubbed flat on the little flags that I alluded to. Having got these Water-of-Ayr stones, you grind both of them first on one stone and then on the other, so as to thoroughly equalise any irregularity. Then these two were rubbed together, and by this means you get such a perfect plane that you can obtain far more accurate results than you require, but when you can get absolutely perfect results it is as well to do so. I find that if a drop of water was put on one stone and the other put upon it, it would float about as if on water, the perfection of the plane being such and the capillary attraction so powerful that the stones did not touch one another, but moved about quite readily.

The specimens of rock roughly ground on the zinc plates were ground down on these stones, and then finished off on the harder. When you come to reflect on the question you will see that to get a perfect section of some rocks it is absolutely requisite to use all this care.

As an illustration of the perfection to which this method may be brought I may say that very often Limestones contain sand, and there is not the slightest difficulty whatever in preparing a section

so that these grains of, perhaps, the $\frac{1}{500}''$ or $\frac{1}{400}''$ in diameter, shall be ground down and polished on both sides, and I could show specimens of slates in which sections of grains of sand not thicker than $\frac{1}{1000}$ of an inch are cut and ground down so as to be shown as transparent objects.

It is very important indeed in studying some kinds of rock to slice through the minerals in that manner, because otherwise you might be misled by false appearances.

In some cases a single grain of sand has a complete history of its own—there are fluid cavities and enclosed crystals—and possibly in the case of some volcanic rocks you have minute glass cavities, all of which can be distinctly seen in a grain of sand $\frac{1}{100}$ of an inch in diameter. Of course, to see these satisfactorily it is requisite that the preparation should be made in a satisfactory manner.

When you come to rub the pieces of rock down on these smoother stones, you find that the emery has ground them down so as to be a little convex. When you rub on the smoother stones you do not tear up portions from the specimen, but wear it down by a perfectly legitimate grinding of the constituents. For example, in the case of a limestone the emery pulls out the little grains of sand; it makes a flat surface, but it is not a mathematically true section of the rock, which, of course, is unsatisfactory. When you begin rubbing on the smoother stones you find that these grains of sand are worn down on a level, and the first result is that you begin to polish the surface of these grains in the centre of the specimen, and gradually by continuing the grinding it is ground flatter and flatter, until you get close up to the corners. The process must be continued till you feel persuaded that the harder portions are not only polished but that they are worn down to the level of the softer portions, and then made as smooth as they can be got.

I have never used polishing material in preparing sections of rock, because it penetrates into the rock and makes you see things which are not naturally there, and so may deceive you.

Having got your portion of rock dressed off as described, the next point is to fix it down on a piece of glass with Canada balsam. I have a little tripod stand, under which I can have a jet of gas, and on the top of this a piece of brass so that it will keep the glass in the proper place in the centre. You heat this sufficiently, and put a portion of Canada balsam on to it, and an important point is to get rid of all the bubbles,—they rise to the top, and with a little manœuvring you may get them to the centre and with a pin draw them all out. Then you carefully stir it, keeping it hot until you have got the balsam sufficiently hard. I have found the best indication of that was to take a portion out with a large pin, and when the balsam has got so hard that when cold it

will just break to powder between your fingers it is satisfactory. If it is not hard enough you will perhaps find subsequently that portions of this solution will break away; whilst if it is too hard and brittle portions break off from the opposite fault. If you maintain the heat sufficiently long to make the balsam so hard that when a portion is taken up with a pin you give it a bit of a squeeze with your fingers and it just breaks to powder, it is, I take it, in the state of a happy medium between the two objectionable extremes. Then you have your portions of rock hot; you put it on the tripod stand with the finished side upwards, and keep it sufficiently hot so as to be ready to mount it. But you must not make it too hot; if so you might sometimes expel the fluid from the fluid cavities that occur in some minerals, which would spoil the whole object as far as certain questions are concerned. Then, having kept the rock moderately hot, and having got your Canada balsam sufficiently hard, the next object is to spread over the surface of the rock a portion of *hard* Canada balsam kept for the purpose. You then put this on and spread it so as to get the balsam to penetrate to a certain extent. Do not put the rock straight on the Canada balsam, but get it coated over, and then take off all you can,—stroke it off with a flat wire till you have got the surface just wetted with balsam,—the object being to prevent the formation of too many bubbles when you come to put the portion of rock on. Having done this, press it down with a pencil carefully till you squeeze out all the excess of balsam. It should not be pressed into absolute contact. A thin portion of Canada balsam should be left between the glass and the object, and then you may turn it upside down to see that you have no bubbles underneath it. You have now your portion of rock fastened down, but probably a considerable amount of balsam more than is necessary, which you take off with a large pin. This is the balsam that you keep for the purpose just mentioned, *i.e.*, to put on the surface of the rock when you are going to mount it down.

The next thing is to reduce the thickness of the portion of the rock thus fastened down.

The manner I adopted was to place them in the hands of a very intelligent glass cutter, and he used to grind them down till he left them about the thickness of a good stout card,—not thinner, for fear of portions being torn up and damaged.

If you can avoid it, it is as well not to scratch the corners of the glass, though it is of no very great importance. I found that the most satisfactory method was to cement at each corner a portion of thin sheet zinc, fastening it down with Canada balsam.

(To be continued.)

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(Concluded.)

WHEN you commence to grind down you can do it with your eyes shut and without any trouble; and you find it easy, if it touches at one part and not at another, to humour it until the specimen is ground down evenly and the zinc touches at all four corners.

Then comes the finishing off, which is really the troublesome point. You take off the zinc and must use more care. There is not so much difficulty in keeping it even, and now you see the advantage of having the glass made square. Instead of having to keep constantly looking you can tell at once by the feel whether the rock is uniformly thick. You have to rub down on the stones that I have described, and ultimately finish off on the very fine Water-of-Ayr stone, and leave the section of the thickness desired, a matter of course depending on the circumstances of the case. In some instances the section ought to be not more than the $\frac{1}{1000}$ of an inch in thickness, but in the case of other rocks you would not be able to learn what you wanted from a section of that thickness, you would have to leave it thicker. With very fine grained limestone or slate—a roofing slate, say—you must have the section exceedingly thin or you would learn nothing at all, because you require a power of 400 linear to explore such rocks, and unless the sections are exceedingly thin you would not be able to study the character of the individual constituents. There are no large fragments; all the material is finely divided, and you must have the section thin or one constituent hides another.

If you want to study a fine grained material make the section thin. On the contrary, if you want to study the optical characters of some of the larger fragments of minerals that occur here and

there, the section must be thicker. If I had to prepare my own again I should be disposed to make some of them thicker than they are.

But I found it very convenient to examine these sections as I went on, so as to learn what was the general character of the rock, as a guide to finishing it off and leaving it the best thickness for the study of its characters.

Having thus reduced the rock to the proper thickness, and being satisfied that all is right, the next point is of course to mount over the whole a portion of thin glass, and I found it very desirable not to do this at once, but to leave the preparation for some weeks so that the Canada balsam would get thoroughly hard, in order to prevent the section breaking up when you mount the thin glass over it with the balsam. Taking glass $\frac{1}{200}$ or $\frac{1}{100}$ of an inch thick (because when you have to mount a larger cover, if you have the finest glass it would all break to pieces) you melt a small portion of balsam on the cover glass, keeping it sufficiently soft to get rid of all the bubbles; then I found it very desirable to wet the section with turpentine and wipe it off. The effect of this is that when you put the thin section of rock down on the Canada balsam, the balsam spreads all over it without difficulty; if it were dry you would have a great number of bubbles formed.

The next thing is to press the thin glass down on to the object so as to get it as nearly as may be in contact, keeping the section warm so that the balsam may be fluid, but not so that the balsam which is employed to fasten down the object will melt, otherwise it might break up. You will now see the reason why the balsam should be allowed to get thoroughly hard. With a little dexterity you may mount the thin glass on and have the whole as perfect as you may desire.

I may make a few remarks on some of the difficulties you have to contend with in the case of some rocks.

When you see certain kinds of mica-schist in the field you would think it impossible to prepare a thin section perpendicular to the foliation. I never dreamed of being able to do such a thing at first. It is almost like making a thin section of the leaves of a book at right angles to the plane surfaces. Mica-schist is so friable in one direction that a very little thing causes it to break asunder. To think of making a section perpendicular to the foliation at first sight appears a very unlikely thing, but ultimately I found that it could be done. The plan that I adopted was this: I broke off a portion of fair thickness,—you cannot break them off thin, they fall to pieces directly, you must have one fairly thick, then you deal with it in the way I have described,—but having reduced it to a certain thickness, say about $\frac{1}{8}''$, you must contrive so as to get it hardened. Having got it into something like the proper shape, I wetted it

well with turpentine so that it might penetrate into the pores of the rock, and then covered it over with Canada balsam, and kept it hot inside the fender in the room.

The result was that the balsam penetrated into the loose material, and ultimately got hardened. The balsam thus supplied artificially what Nature had failed to supply, in not having hardened it sufficiently by infiltered quartz.

Then one could proceed to work. But when you have got some little distance down, it may be as well to repeat the process once or more.

This method is necessary for rocks of the softest description. It is necessarily tedious, but very important results come from the study of the rocks most difficult to deal with.

You have then the mica-schist not at all broken up, but the weak points and the planes of discontinuity filled with hard Canada balsam. It is, in fact, thoroughly hard throughout, and you can rub it down and leave the section of the thickness that you desire. You would hardly believe what awkward things some of these mica-schists are. They are not only foliated with alternations of mica and quartz, but you have what had been originally flat planes of foliation all crumpled up in the most complicated manner, and a vast number of joints; another set of planes of discontinuity crossing all the others, so that you have lines of weakness in every direction that you could *not* desire; but with a little care and management I succeeded in making sections of these rocks that left nothing to be desired; and I do not know that I was ever able to observe facts of more interest than in the study of some of these rocks.

One of them was the mica-schist in the neighbourhood of Dunkeld, and I was able to unravel a number of most interesting problems. I was enabled to ascertain that a considerable amount of the quartz was bona-fide grains of sand,—a most important point on the origin of mica-schist, for it is a most complete proof that they were originally rocks containing grains of sand, as well worn as you could get them in the Thames, over white quartz subsequently crystallised in perfect optical continuity.

There you have the history of the original material and the history of the chemical changes that took place, and after this crystallisation had occurred, you have the subsequent history of the crumpling up and the formation of the joints. All these points were made out by the study of this most unpromising rock.

I may say that in the case of some of these the trouble was thoroughly rewarded; but whether it would reward another student is a different matter, because when the whole field was before me and these facts had never before been observed, it did not signify what trouble I was at to establish facts of this kind. But having

been established it would be a questionable thing to make other sections of these rocks. But there is a vast amount to be learnt, and I would not hinder anyone from attacking such questions.

Then I found that you might take a somewhat similar method in preparing sections of very soft material indeed. The chalk on the Yorkshire coast is so very hard, and almost a limestone, that there is no difficulty in preparing thin sections; but the chalk of the South of England is exceedingly soft and friable, and you can brush it into fine material and study the minute foraminifera and coccoliths that constitute such a large proportion of it. But it was important to study the natural condition of the chalk,—not to wash it and study the débris, but to ascertain its condition when all the particles were *in sitû*, and I found no difficulty in doing that. I rubbed down a portion of the chalk into a convenient size, and then hardened it with balsam by soaking it in turpentine so as to get all the particles well wetted, and then putting on it a lot of Canada balsam and keeping it hot for some time. The balsam thus sinks into the chalk, and ultimately all the cavities are filled with hard balsam, and you can deal with it as though you were dealing with a rock. You rub it down and mount it on glass in the usual way, but you must take care that you have got the balsam very hard, and must take care not to make it very hot, because if you should it would all break to pieces. You can in this manner get sections of very soft chalk, and even of clay, if you desired to study the way in which the particles were associated in the material.

In the case of chalk, you may compare the soft chalks of the South of England with the hard ones of the Yorkshire coast. When you study the structure of the soft chalks you find that the cells of the foraminifera are empty, unless they may be filled with the soft chalk. Perhaps you might see a little crystal of calcite here and there, but as a rule the foraminifera and minute shells are wholly empty. In the case of the chalk of the Yorkshire coast, however, you find all the cavities filled with calcite. The Southern chalks are as they were deposited; there has been no introduction of soluble carbonate of lime to crystalise and fill the pores. But in the Yorkshire chalk carbonate of lime has been infiltrated and hardened the whole.

I remember making some experiments by ascertaining the increase in weight when thoroughly soaked in water, and calculating from the difference in the specific gravity the volume of water absorbed; and it was interesting to see what a large amount of empty space there was in the chalk of the South of England, but very little in the Yorkshire chalk—the whole having been consolidated by the introduction of carbonate of lime.

In preparing sections of mica-schist, notwithstanding all the

care that you may use, you sometimes cannot avoid cracking them. In spite of your care you see a discontinuity between the rock and the glass. When this is the case you must warm the preparation and allow the worked balsam to close up again; but that does not always succeed. Sometimes you must put Canada balsam over it and keep it hot for a considerable time. The balsam penetrates inside and the bubbles disappear.

Sometimes I have been unfortunate enough to break the glass, or found that I could not very well get rid of certain of the bubbles in the way I have mentioned, and it was occasionally desirable to remove the thin section from the glass and put it on another.

If you think it desirable thus to remove a thin slice of rock from one glass to another, you must clear away the Canada balsam all round up to the edge, cast plaster of Paris over it and allow it to harden, then make it hot and push the thin slice of rock completely off. A section can be moved completely off the glass, although it may be only the $\frac{1}{1000}$ of an inch in thickness. The plaster of Paris holds it firm, and you mount it as if it were bearing down a piece of the rock. You can get the plaster off and leave the section clean without any difficulty, and finally mount it in the usual way.

I also devoted a considerable amount of time to preparing sections of shells and corals. You can make very good sections of shells perpendicular to the structure, not by attempting to cut a thin portion of the shell, but by taking the whole shell—supposing it were a uni-valve, one of the Gasteropods—and rubbing it down, so that the shell itself holds the portion firm that you want to deal with. It would otherwise be impossible to make a thin transverse section of a shell perhaps only $\frac{1}{50}$ of an inch in thickness. With a thicker shell you deal as if it were a portion of rock. The surface must be polished with putty powder and all sections made very thin.

I must not conclude without saying a word or two with reference to the preparation of sections of minerals.

In the case of some minerals, when wanted for the study of the fluid cavities, you deal with them just as though you were preparing a section of rock, modifying the process according to the character of the mineral; but in some cases it is desirable to prepare much thicker sections, in order to study certain optical properties, especially to measure the index of refraction. It is very important that the two opposite surfaces that you polish shall be perfectly parallel with each other If you want to guide the sections in some very particular direction, as, for example, perpendicular to the axis, of course it requires a great amount of care, and you must make very careful observation of the angles of the crystal before you commence with it. You must do it by degrees, so as

to be sure that you are cutting perpendicular to the axis. But in the case of fluor spar, when there is no section of any particular interest you need not be so particular. You grind down one surface and polish it, grinding it very fine, and then you deal with the other; and the point that I am especially dwelling on now is the method by means of which you can ascertain that you have got the sides approximately parallel. When grinding it down look at a crossbar, say of a window, and turn the section about, looking partly through the crystal and partly through the glass. If it is at all wedge-shaped the crossbar will be as it were thrown down, and you can ascertain the direction in which it is not parallel. If on looking in this way, and having ascertained that you have done something wrong and have corrected the error, if you again look at the crossbar and, turning the crystal any direction you like, find that the crossbar looks the same and does not undergo any change, it proves that you have got your section cut sufficiently parallel for all ordinary purposes.

In cutting sections of minerals for the same purpose you must ascertain that you are looking in the particular direction that you want. If, for example, you are preparing a section of calcite so as to look right along the axis, you must take very great care to prepare a perfect rhombohedron to begin with, and then when roughly finished you must examine it to see that you are looking in the line of the axis.

You may often see certain things very well indeed through minerals that are imperfectly polished by putting them in benzole. Supposing you had a portion of calcite rubbed down roughly, and you wanted to ascertain if it were cutting it in a proper direction, you would get some glass and a thin cover, put some benzole between this and the section. The benzole having nearly the same index of refraction as the calcite makes the rough surface so transparent that you can ascertain then whether the section is cut in the proper direction or not.

This method was very useful when looking at different loose sands. By having them in benzole you can study the minute particulars of grains of sand, and ascertain the portion of the fluid cavities that are contained in them.

I am afraid I have given a very imperfect account of this subject. I have endeavoured to point out some of the principal difficulties, but I daresay I have left out a great many. For, when you have been for years practising an art, you do a great many things instinctively and do not know that they are difficult; it is only when you are beginning that you find them difficult. Especially in mechanical work you get by degrees not to realise points that perhaps might be difficult to others. But I hope that I have pointed out the principal facts and methods which I have employed.

I have not dwelt on the methods employed by others. If I had to begin again I should not adopt the plan I have done. I should economise my time by getting a deal of work done by others. But you must bear in mind that when I commenced this subject there were no people that could make these sections; such a thing was unknown. But I am very pleased to see that the method I had the pleasure to propose and first carry out has now become so universally adopted, not only in England but on the Continent, that there are many men who make a trade of preparing these sections.

Of course there are great advantages if you have the time and opportunity to work these things for yourself, because you can learn a great deal in preparing them that you otherwise could not learn. You give a specimen to the lapidary and he would not know the desired thickness; he would probably rub down everything to a uniform thickness, and you do not know yourself what thickness it should be; but if prepared in the way I have described you can learn something about it. You can learn that there are certain characters that it is very important to study more fully, and you perhaps find that the section has been rubbed down quite thin enough to show some important facts; but perhaps another operator who did not examine beforehand might think it was not anything like thin enough, and would rub it down and lose some of the most important characters.

There are two points to consider: first the structure of some of the constituent materials, and secondly the structure of the material existing between them. In the case of certain igneous rocks it is more important to be able to study the minute structure of some of the constituent materials, which you cannot do if they are very fine. Some of these contain scattered fluid cavities and enclosed crystals. If you leave the sections of sufficient thickness you can focus up and down with a proper object glass. You do not want a very thin section because the mineral is quite transparent. If you were to rub it down very fine you would let out the water from these fluid cavities by cutting them open.

But if you want to examine the minute structure of some of the fine grained material that exists between these structures, then you must make it very thin; and I should now be inclined to make two sections of each rock, so as to ascertain the constitution of each,—the larger and the finer grained material.

As to the fluid contents of cavities in crystals, I thought it desirable to ascertain what the fluid was when the crystal was of considerable size. I obtained a crystal of quartz, which I was told had belonged to Francis Chantrey. It froze at 32° Fahrenheit. Then the next specimen I examined was a quartz from Ceylon, with fluid cavities of perhaps $\frac{1}{50}$ of an inch in diameter. I reduced

the temperature far below the freezing point of water and it would not freeze. Still I felt persuaded that it was water, from other considerations, and that caused me to investigate the effect of the freezing of water in minute tubes, and I found that when it is in capillary tubes and small cavities that you can reduce the freezing point of the water far below its usual one; but if the least portion of ice were in contact with it it would freeze immediately. But you may reduce the temperature to below 10°, I believe, without freezing it, if no ice is present.

But that the substance was water was easily ascertained by its optical properties, because they are so different to the optical properties of ice. The above will explain, then, why it did not freeze in small cavities. Then one could determine the rate of expansion that agreed with water.

Then there was another method. You see cavities filled with fluid in the quartz, and you know the diffusion of steam will burst the cavities if you heat the specimen. I had a tube and put the crystal at the bottom, then pumped thoroughly dry air into the tube. Then I had a freezing mixture. After heating the crystal I got a deposition inside the tube of what looked like hoar frost and had all the character of frozen water. I now put this into salt and water below the freezing point, and found as soon as the temperature rose and got to the melting point of ice, the material obtained in this manner thawed.

But the liquid is not pure water. In some cases it contained chloride of sodium or chloride of potassium.

Sometimes the cavities are large crystals of these substances, this being especially the case in volcanic rocks, so that some of the salt so present then can be dissolved at the ordinary temperature.

That was the kind of evidence on which I relied in determining that the liquid in the cavities was water.

In addition to the two chlorides named, I think there is sometimes hydrochloric acid; but that is rather doubtful, because it may have been set free by the action of the quartz on the chlorides.

Of course, many cavities contain liquid carbonic acid. I first established that fact by proving that the rate of expansion was the same as that of carbonic acid, and very unlike that of anything else.