NOTES ON THE MEASUREMENT OF SOME PHYSICAL AND OPTICAL PROPERTIES OF THE NEW SOUTH WALES TORBANITES.

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(Four Text-figures.)

[Read 30th July, 1941.]

Introduction.

In the investigation of the New South Wales torbanites, it has been found that certain physical and optical properties are of considerable importance, providing fundamental data and results which have a direct bearing on classification, micro-constitution and the nature of the materials which vary widely in type and quality.

The present paper is confined mainly to descriptions of methods and principles involved in the investigation of some of the more important physical and optical properties which promise to be of value in different branches of the study of torbanite.

The Determination of Percentages of Essential Constituents.

Certain essential constituents are present in all the torbanites occurring in the Kamilaroi Coal Measures of New South Wales (Dulhunty, 1938). The accurate determination of the quantities of these constituents or macerals, constitutes an important part of the microscopical study of the torbanites and the investigation of the inter-relationship between optical, physical and chemical properties.

Alternative Methods.

The essential constituents are extremely small, necessitating the use of thin transparent sections of torbanite and the employment of microscopic methods for determining the amounts present. Such methods depend directly or indirectly on the estimation of the total area occupied by each of the constituents in the thin section being examined.

By using a microscope fitted with an eyepiece containing a fine net, and an objective giving a magnification of at least one hundred diameters, the number of squares occupied by each of the constituents can be counted in the microscope field, and the percentages by volume determined. In using this method it is necessary to make a number of determinations at different points, in order to obtain average results for the whole section. This is slow and particularly trying to the operator, as numerous determinations are necessary and considerable difficulty is experienced in counting the squares by inspection through the eyepiece.

The foregoing method may be considerably improved by projecting the microscopical field onto a ground-glass plate on which a net has been marked. This may be achieved by using a strong light source and a microscope fitted with an eyepiece and an objective giving a magnification of about forty diameters. A ground-glass plate marked with one-tenth inch squares is placed at a distance of twenty-four inches from the eyepiece. The field is focussed onto the ground plate, giving a magnification of 100 to 150 diameters, and the number of squares occupied by each constituent may be counted with much less difficulty than in the case of the eyepiece net.

In either of the above methods the degree of magnification required means that a very small area of the thin section, no more than one millimetre in diameter, is examined in each determination. Consequently it is necessary to make as many as ten estimations on a thin section of one square inch, to obtain average results. It is possible in this way to reduce the limits of error to about two per cent.

An alternative and much more successful method of estimating the quantities of the constituents is by using a mechanical stage fitted with an integrating micrometer, on a
microscope giving a magnification of about one hundred diameters. With this instrument a line is taken across the full width of the thin section, and the sums of the small distances occupied by the different constituents along the line are determined. From these figures the percentage by volume for each constituent is readily calculated. Estimations are made along several lines across the section, and the results, with an error of no more than one per cent., may be obtained quickly and easily. The integrating micrometer has many advantages over the methods involving the use of a net. The estimations are more rapidly carried out, giving much more accurate results, and each estimation is made across the full width of the thin section, as compared with the small circular areas in which the net counts are made.

Relation Between Apparent Percentages and Thickness of Section.

The most important factor influencing the accuracy of percentage determinations by either of the methods already described, is the thickness of the transparent sections of torbanite. The bodies of gelosite and retinosite are roughly disc shaped, appearing round in sections cut parallel to the bedding and ellipsoidal in sections at right angles. The discs are separated from each other and completely surrounded by the opaque matrix of the torbanite. As a result of this arrangement, the area occupied by the transparent bodies increases as the thickness of the section is reduced during the grinding process. Estimates of percentages will therefore increase as the section becomes thinner. Theoretically the absolute percentage by volume would be obtained only at infinite thinness, and all other estimates would represent apparent volumes. Actually the rate of increase of apparent volume decreases as a function of the thickness. Thus the error in volume determinations due to thickness of section rapidly becomes very small as the thickness is reduced, and it is negligible at thickness less than 0.01 mm. This may be illustrated by plotting apparent volumes against thickness during the preparation of a thin section. Fig. 1 shows curves obtained in this manner for three different types of torbanite (A, B and C) containing varying quantities of the transparent constituents gelosite and retinosite. It will be noted that the same general relationship exists in each case, although the actual volume of constituents varies greatly, and the increase in volume becomes negligible after a thickness of about 0.01 mm. is reached. It is evident from the shape of the curves that the shape of the gelosite and retinosite bodies is not the only factor involved in the rate of increase of apparent volume. Such features as variations in the size of the bodies in any one section, and differences in the

![Diagram illustrating the relation between apparent volume of transparent constituents and thickness of section for three different torbanites, A, B, and C.](image-url)
numbers of bodies of certain sizes, would also affect the relationship between apparent volume and thickness. Therefore such curves could not be used in correcting volume estimations for different thicknesses, and it is necessary to reduce all torbanite sections to less than 0.01 mm, before estimating the percentages of constituents.

The Determination of Thickness of Section.

The accurate determination of the actual thickness of section may be made by using a microscope fitted with a micrometer screw focussing adjustment graduated to at least 0.005 mm., and an objective giving a magnification of not less than 150 diameters. The difference between two readings made at the positions of focus on the top and bottom of the section gives its thickness. The focussing mechanism of the microscope should be in good order, and the accuracy of the micrometer adjustment should be checked against a micrometer screw gauge by determining the thickness of a thin glass plate such as a cover-glass. After some practice sections can be accurately measured to 0.005 mm. and estimated with reasonable accuracy to 0.0025 mm.

If it is desired to measure the thickness of a section at various stages during the grinding down process, for the purpose of obtaining relationships such as the increase in apparent volume of constituents with decreasing thickness of section, the following procedure may be adopted. A slice of torbanite is prepared by polishing one side and cementing to a glass slide with Canada balsam. It is ground down with fine carborundum powder till the first signs of transparency appear. The surface is then made as smooth as possible by rubbing on a fine grained and high quality honing stone in a stream of water. When smooth, a cover-glass is attached to the surface by means of a drop of oil or water, and the thickness of the section, the quantities of gelosite and retinosite and any other determinations may be made. The cover-glass is then removed and the section made a little thinner by rubbing on the honing stone. This may be repeated, determinations being made at intervals of about 0.005 mm. until the section is as thin as it can be made, usually between 0.005 and 0.0025 mm.

The Transmission of Visible Light.

In preparing thin sections of torbanite, the first evidence of transparency is obtained at a thickness varying between 0.05 and 0.025 mm., the colour being dark red. As the section is made thinner the colour becomes lighter, passing from dark red through light red to orange-yellow, and in some cases pale yellow, as greater amounts of visible light are transmitted. The study of the relationship between transmission of visible light and the nature and volumes of constituents, as well as other properties of torbanite, constitutes an important part in the investigation of the fundamental nature of the material of which it is composed.

Apparatus and Results.

For the purpose of obtaining values representing the degree of transparency or amount of light transmitted by thin sections of torbanite, the use of photo-electric determination appears to be the most satisfactory. A constant light source is arranged so that a beam of light, about half an inch in diameter, may be directed onto the photo-electric cell of an exposuremeter at constant distance. The thin sections of torbanite, mounted in the usual manner for microscopic examination, are placed in the beam of light close to the lens of the exposuremeter. A reading is made for the amount of light passing through the glass slide, film of Canada balsam and cover-glass, away from the section of torbanite. The slide is then moved so that the thin section comes into the beam of light and a second reading is made. The difference between the two readings represents the amount of light reduction due to absorption by the thin section of torbanite. This is inversely proportional to the amount of light transmitted, so that values suitable for general practical purposes in comparing the degrees of transparency of different torbanites may be obtained by means of the following simple formula, in which \( V \) is the required value, and \( a \) and \( b \) are the first and second readings respectively on the exposuremeter:

\[
V = 100 - \frac{(a-b) 100}{a}
\]
The amount of light transmitted depends primarily on the thickness of the section, so that it is necessary to determine its thickness before making the test. This may be accomplished by using a microscope fitted with a micrometer screw adjustment, as already described in this paper.

The amount of light transmitted depends also on the quantities and inherent nature of the constituents present in the particular torbanite being examined. The relationship between the light-transmitting power and the quantity of gelosite and retinosite in different torbanites can be studied by determining the amount of light transmitted and the percentages of essential constituents in sections of standard thickness, usually 0.01 mm. Such results are important in connexion with variations in the nature of gelosite and retinosite in different types of torbanite.

During the preparation of a thin section of torbanite, the apparent percentages of gelosite and retinosite, and the amount of light transmitted, both vary as the section becomes thinner. The relationship between the rates of increase of these two factors is important in connexion with the possibility of estimating the percentages of constituents by determining the amount of light transmitted by sections of known thickness, and also in studying the light-transmitting power of the constituents in any one type of torbanite. For the purpose of investigating these features, determinations should be made at different thicknesses during the preparation of sections, using the method already described for examining the relation between apparent volumes of constituents and thickness.

Curves showing the relationship between light transmission and thickness of section for different types of torbanite are illustrated in Fig. 2. The form and positions of the curves are influenced by the rate of increase in apparent volume of transparent constituents, the absolute volumes of constituents and the intrinsic light-transmitting power of the transparent macerals. It will be noted, however, that all the curves, if projected beyond the thickness at which the last determination was made, would reach a point representing 100 per cent. of light transmission at infinite thinness. This constitutes an important check on the accuracy of the apparatus and methods used in making the determinations.

Fig. 2.—Diagram illustrating the relationship between transparency and thickness of section, for three different torbanites, A, B and C.
The Transmission of Infra-red Radiation.

Apparatus and the Preparation of Standard Thick Sections of Torbanite.

It has been found that sections of torbanite sufficiently thick to be opaque to all visible light, will transmit varying amounts of infra-red radiation. In the method devised for determining the relative powers of transmission possessed by different torbanites, sections of standard thickness and orientation with regard to direction of bedding-planes are subjected to a strong electric light source and the infra-red transmitted by the section is recorded photographically on an infra-red sensitive film. The amount of infra-red radiation transmitted by the torbanite determines the density of the exposure on the film, and this may be measured by means of a suitable densitometer or photo-electric cell exposuremeter.

The apparatus used is illustrated in Fig. 3. The infra-red radiation is produced by means of a 100 watt electric lamp, (a). An exhaust fan, (b), is necessary to keep the film and torbanite sections cool, and avoid any secondary radiation of infra-red from the metal or torbanite. The metal holder, (c), consists of two compartments which contain the film, (d), and two sections of torbanite (e₁ and e₂). The compartments are separated by a metal plate with two holes three-eighths of an inch in diameter, placed opposite openings of the same size in the outer wall of the compartment containing the sections. These holes allow the passage of the infra-red through the torbanite onto the film.

The amount of infra-red transmitted varies with the direction in which the section is cut in relation to the bedding-planes of the specimen of torbanite. Transmission is maximum in sections cut at right angles to the bedding, and minimum in those cut parallel to the bedding. It has been found most convenient to use sections cut at right angles to the bedding in all cases.

Transmission also varies as a function of the thickness of the sections. In the case of certain torbanites, sections two millimetres in thickness will transmit appreciable amounts of infra-red. The standard thickness adopted as being the most suitable is 0.75 mm. Such sections are opaque to visible light, and require reasonable short exposures in the infra-red tests.

The actual length of exposure varies according to the nature of the torbanite, from one second to thirty minutes. Any section, 0.75 mm. in thickness, which gives no result at an exposure of thirty minutes may be considered opaque to infra-red radiation. Such sections have been exposed up to two hours without result.
The standard sections are prepared by grinding down slabs of torbanite three-quarters of an inch square to about 1.5 mm. in thickness using coarse carborundum. Then a fine carborundum powder, of grade 500, is used on a glass plate to reduce the sections to the standard thickness of 0.75 mm. A micrometer screw gauge is used in measuring the thickness of the section. It is necessary to use a carborundum powder of standard grade to complete the sections, so that the depth of the grain cuts on the surface of the torbanite will be the same in each case.

Method of Recording Results.

The following method is suggested by the writer for obtaining relative numerical values in comparing the power of different torbanites to transmit infra-red radiation.

In each determination two sections are used, one of unknown value being tested against one for which a value has already been determined. The densities of the two exposed spots on the film are then compared and a value allotted to the test piece. This method has been adopted as the results obtained are reasonably independent of length of exposure and variations in the processing of the film, provided that greatly over- and under-exposed spots are avoided.

Before making the actual test on an unknown torbanite, it is necessary to make a trial test to determine the approximate length of exposure which will produce a spot of medium density on the film. A torbanite section of known value is then selected which will give a spot of suitable density at the exposure required by the test piece, and the two are tested together. To obtain numerical results in comparing the densities of the two exposed spots on the film, a photo-electric exposuremeter is used in a manner similar to that already described for determining the transmission of visible light by thin sections of torbanite. The exposed spots are placed in the beam of light, and the amount of light reduction in the case of each spot is determined by making direct readings with the exposuremeter.

The torbanite from the Ulan deposit has been selected as an original standard and given a value of 100. In calculating results, the transparencies of other torbanites are compared with the original standard and allotted relative values depending on their powers of transmitting infra-red by the following method:

If \( V_t \) is the required value for the test piece, \( V_k \) the value already determined for the torbanite section against which it is being tested, and \( t \) and \( k \) the exposuremeter readings for the test piece and known sections respectively, then the difference between the two can be expressed as a percentage, which is

\[
\% = \frac{k \times 100}{t} - \frac{t \times 100}{k}
\]

Then the relative value of the test piece compared with the known section will be

\[
\frac{k \times 100}{t} = \frac{V_t \times 100}{V_k}
\]

which simplifies to

\[
V_t = \frac{k \times V_k}{t}
\]

This formula can be used in comparing a test piece with the Ulan material or any other torbanite for which a value has been determined.

It has been found that the power of infra-red transmission possessed by any particular torbanite depends more on the inherent nature of the constituents than the actual amounts present. The study of this property constitutes yet another means of investigating the fundamental differences which exist between the macerals of torbanites from different deposits; thus it is important in connexion with classification and the interrelationships between the various properties of different torbanites.

The Power of Expansion and Contraction of Torbanite when Heated and Cooled.

The Determination of Expansion.

The apparatus devised for measuring the linear expansion of torbanite when heated is illustrated in Fig. 4. The piece of torbanite \((t)\) to be tested is held between two invar rods \((a\) and \(b)\). One rod \((a)\) is clamped firmly to the framework and the other rod \((b)\), which moves through the supports \((c\) and \(c)\), is held against the torbanite...
Fig. 4.—Diagrammatic illustration of apparatus used for the determination of linear expansion of torbanite when heated.

by means of a light spring (d). A micrometer gauge (e) is clamped to the framework so that the movement of the rod (b) can be measured. The electrically heated chamber (f) is so constructed that it may be moved back along the rod (a) for the purpose of introducing and removing the piece of torbanite. The micrometer gauge support is insulated from the framework at the point (g). A small electric light globe and single cell battery are connected in series to the micrometer and framework. When the actual point of contact is obtained between the rod of the micrometer and the movable rod (b), the circuit is closed and the globe lights up. This enables the amount of movement of the rod (b), due to expansion of the torbanite, to be measured very accurately. The temperature of the electrically heated chamber is controlled by means of a suitable variable resistance. A thermocouple (h) is situated within the chamber, and the temperature recorded by means of a pyrometer. The horizontal supporting rods (i and j) are constructed from a nickel-iron alloy possessing a constant coefficient of expansion between the limits of temperature resulting from external radiation by the heating chamber.

Rods of torbanite 40 mm. in length and about 7 mm. square are used for the expansion tests. The length of the rods must be exact and may be measured by means of a micrometer gauge. The cutting of torbanite in preparing such rods presents considerable difficulty as the finely divided silica in the torbanite prevents the use of a metal saw, and the soft elastic nature of the material makes the use of a diamond armed metal disc impossible. It has been found, however, that a rotating aluminium disc armed with a paste of carborundum and water will rapidly cut the torbanite without excessive abrasion of the disc. The carborundum becomes embedded in the aluminium and successfully cuts the torbanite. The aluminium disc used for this purpose is one-sixteenth of an inch in thickness, nine inches in diameter and rotated at 1,400 revolutions per minute by means of a one-quarter horse power electric motor.

The accuracy of the instrument may be tested by carrying out determinations on a metal rod of definite length and known coefficient of expansion. Readings are taken at intervals over the temperature range required in testing torbanite, and the calculated expansion of the metal rod deducted from the amount of expansion recorded by the instrument. A curve showing the amount of error involved at any temperature may be obtained in this way, and used in correcting subsequent torbanite expansion determinations. Using the apparatus described, it is possible to obtain results varying by less than 0.5 per cent, when duplicate determinations are carried out on torbanite rods cut from the same specimen.

In any one specimen of torbanite the coefficient of expansion varies considerably in different directions in relation to the bedding-plane. Expansion is always greatest at right angles to the bedding, and minimum in parallel directions. Thus it is necessary to cut the rods of torbanite in known directions in relation to the bedding. The amount
of expansion also varies greatly with different specimens from the same deposit, as well as specimens from different deposits.

The Development of Permanent Expansion and Contraction.

A rod of torbanite cut in a direction normal to the bedding when heated will undergo a certain amount of expansion, but on cooling it will not contract to its original length. A certain amount of permanent expansion is developed. This may represent as much as 25 per cent. of the total expansion when heated, but usually lies in the vicinity of 5 to 15 per cent., amounting to about 1-2 per cent. of the original length of the torbanite rod. The amount of permanent expansion developed is approximately proportional to the rise in temperature up to 350°C. This suggests that the development of permanent expansion is due to some physical effect rather than the result of chemical changes which would be expected to be more pronounced at the higher temperatures.

A rod of torbanite cut parallel to the bedding, when heated and then cooled, will contract to less than its original length, thus developing permanent contraction. The amount of permanent contraction developed is not always proportional to the rise in temperature, but a certain amount is always developed for all temperature rises. It has been noted that in the cases where it is not proportional a greater amount of permanent contraction is developed between 30° and 200°C than between 200° and 350°C. This indicates a physical rather than a chemical change, as in the case of rods cut normal to the bedding. The amount of permanent contraction developed at any given temperature, may be equivalent to as much as 50 per cent. of the total expansion when heated, but usually amounts to about 15 to 20 per cent., representing about 0-6 per cent. of the original length of the rod.

Considering the permanent contraction and expansion to be the amounts of permanent linear distortion caused when rods parallel and normal to the bedding respectively are heated, then the permanent distortion in relation to the total expansion is greatest in the case of rods parallel to the bedding, although the actual amount of distortion is always less than in the case of rods normal to the bedding.

Permanent Volume Changes and Specific Gravity.

The fact that torbanite when heated develops permanent contraction parallel to the bedding and permanent expansion in a direction at right angles means that permanent volume changes occur when a piece of torbanite is heated. The amount of volume change depends on the relative amounts of permanent contraction and expansion developed, and also the shape of the piece concerned. Considering rectangular blocks with sides parallel and at right angles to the plane of the bedding, the fact that permanent expansion is greater than permanent contraction, will mean that there will be an increase in volume after heating, unless the dimensions of the block parallel to the bedding-plane are sufficiently great to give a decrease in volume.

The foregoing results may be of considerable importance in connexion with different branches of scientific research on torbanite, as well as mechanical and industrial processes. An important application is to be found in the determination of the specific gravity of torbanite. In the usual method, the specimen is weighed in air, then boiled in water to remove air bubbles and finally weighed in water when cold. During this procedure the specimen is heated to 100°C., which means that a permanent volume change is almost certain to occur, resulting in an apparent value being obtained for the specific gravity. If an irregular piece of torbanite is used it is impossible to apply corrections, but this may be accomplished if a rectangular block cut at right angles to the bedding is employed, and the amounts of permanent contraction and expansion developed on heating to 100°C. are known. The correction would be as follows:

If \( S \) and \( S_a \) are the true and apparent specific gravities respectively, \( E \) and \( C \) the permanent expansion and contraction developed at 100°C, in inches per inch, \( a \) the dimension of the block normal to the bedding and \( b \) and \( c \) the dimensions parallel to the bedding-plane in inches, then:

\[
S = S_a \times (1 + E_a b c - 2 C a b c). 
\]

For example, a specific gravity determination was made on a specimen of torbanite from the Newnes deposit. The material developed a permanent expansion of 0-017 in.
per in. in a direction normal to the bedding and a permanent contraction of 0.004 in. per in. in a parallel direction, when heated to 100°C. The specific gravity was determined on a block which measured two inches at right angles to the bedding, and one inch in each direction parallel to the bedding. The result was a value of 1.230. The necessary correction factor for volume change due to boiling in water was calculated to be 1.018, giving a true specific gravity of 1.252. These results illustrate the possibility of an appreciable error occurring in specific gravity determinations where methods have been used involving the boiling of the specimen in water. This may be of important consequence in connexion with scientific research or the estimation of reserves in a torbanite deposit for industrial purposes.

In addition to the bearing which the study of expansion and contraction has on specific gravity determinations, there is evidence that certain relationships exist between these properties and the fundamental differences between various types of torbanite. It has also been noted that the powers of expansion of different specimens of torbanite from any one deposit are related to their contents of volatile hydrocarbons.

Reference.


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