DEPARTMENT OF SUPPLY AND SHIPPING

MINERAL RESOURCES SURVEY BRANCH

REPORT No. 1944-1

REPORT ON PERMEABILITY, POROSITY AND OTHER PHYSICAL PROPERTIES OF A NUMBER OF ROCKS AND MINERALS

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INTRODUCTION.

This report is written primarily to present the determination of the permeability and porosity of a number of rocks and minerals, but it has also been considered advisable to give a brief description of the different kinds of apparatus designed and used in making the determinations.

The materials on which the tests were carried out included a suite of specimens from No. 10 bore, Lakes Entrance, two specimens of limestone from the shaft which is being sunk at Lakes Entrance, a specimen of sandstone from one of the bores at Roma, Queensland, and a number of Australian diatomites.

The method of presentation adopted in this report is, firstly to describe the apparatuses used in making the determinations and the technique adopted in preparing the specimens for testing and secondly to discuss the results obtained for each set of specimens.

In addition to the permeability and porosity tests already mentioned, a number of tests of compressive strength were made on wet and dry samples of glauconitic sandstone from Lakes Entrance.

The writer wishes to acknowledge the assistance given to the investigation by Professor C. R. McRea, Principal of the Sydney Teachers' College who made available the facilities of the College workshop. Mr. R. Cullen of the workshop staff made the mechanical parts of the apparatuses and the design of the model II sample holder was largely influenced by his helpful criticism and advice.

Acknowledgement is due also to Mr. L. Thornton, Roads and Bridges Section, Department of the Interior for permission to use the diamond drilling machine for preparing the test samples and other machines used in determining the compressive strength of the glauconitic sandstone. Thanks are also due to Dr. F. W. Clements, Director of the Commonwealth Institute of Anatomy who made available some of the auxiliary apparatus used in making the determinations and calibrating the permeameter flowmeter.

APPARATUS AND METHODS USED.

I. Permeability.

The apparatuses used in making the permeability and porosity determinations were designed by the writer and were constructed in the workshops of the Sydney Teachers' College.

Two separate apparatuses were used in the permeability tests. They are similar in principle but differ in the way in which the sample is held and in the construction of the flowmeter and manometer. They will be referred to as models I and II permeameters.

A. Model I - Permeameter.

Fig. 1 shows the general layout of the permeameter. It consists of (a) a sample holder in which cylindrical samples are held under compression in a tapered rubber stopper, (b) a flowmeter comprising a capilliary tube connected across a differential manometer, (c) a needle valve for controlling the rate of flow through the system. Auxiliary equipment includes a drying tube on the intake side of the sample holder and a vacuum pump.

The manometers are filled with oil of low vapour pressure and of specific gravity 0.865.

(a) Preparation of the samples.

The material to be examined is first saturated with water. It is then mounted in a diamond drilling machine and a cylindrical core of diameter approximately 1 inch is cut from it. If the sample being prepared is stratified the axis of the core is made parallel, or normal, to the known bedding depending on whether the permeability in the direction of, or normal to the bedding is to be determined.

The cores are then cut into desired lengths (from 0.5 to 2.0 cm.) by means of a hacksaw, mounted in a special holder (see Fig. 3) and the ends made flat and normal to the axis of the core by means of coarse emery paper or a coarse file.

The prepared samples are then thoroughly dried in a hot air oven at a temperature of approximately 150°C. If any appreciable quantity of oil is present in the sample it must be removed by extraction with redistilled benzene or other suitable solvent. An apparatus was constructed for forcing benzene through the samples for the purpose of washing them, but it was obvious from the lack of discolouration of the emerging benzene that no appreciable quantity of oil was present in the samples so treated.

(b) Mounting the Sample for Testing.

The design of the model I sample holder follows that described by H. C. Pyle and J. E. Sherborne (1939).(1) The dried cylindrical samples are mounted by pushing them into the cylindrical hole (diameter slightly less than 1 inch) in a tapered rubber stopper which in turn is mounted in the tapered brass sleeve of the sample holder. This sleeve is then seated on the rubber gasket in the base of the holder and cap is fitted. Pressure is applied through the cap to the rubber stopper by means of the compression screw. The action of this screw is to force the rubber stopper into the tapered sleeve, at the same time compressing the rubber and making a tight seal between it and the sides of the sample.

The drying tube, manometers, needle valve and vacuum pump are connected as shown in Fig. 1 and the apparatus is ready for making a permeability determination.

(c) Reading.

The vacuum pump is now started and the needle valve adjusted until the oil level (H_1) in the left hand manometer tube rises about 2 inches. The oil is maintained at this level by manipulating the needle valve while the levels H_1, H_2 and H_3 are read. This process is repeated with H_1 at different levels from 0 to the maximum obtainable. The maximum obtainable depends on the reading H_3 which is always greater than H_1 by an amount depending on the rate of flow and hence the drop in pressure through the capilliary tube. The apparatus is provided with interchangeable capilliary tubes so that a wide range of rates of flow can be handled conveniently.

The small U-tube manometer mounted at the top of the drying tube is observed from time to time to make sure that there is no drop in pressure across the drying tube. The rates of

(1) References at the end of the report.

flow generally observed are found to be too low to cause readings other than zero on this manometer.

The vacuum pump used in these tests is a small oil pump, but this could be replaced by a water jet pump because the vacuum pump need only provide a vacuum of approximately 10 cm. of mercury at a low pumping rate to provide satisfactory working conditions.

(d) Calculation of Permeability from the Readings.

Providing the flow is 'streamlined', the rate, Q, at which a fluid will flow through an area A depends on:-

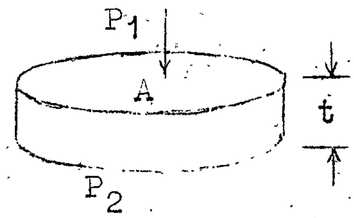
(1) The area A.

(2) The thickness of material t.

(3) The pressure difference P_1-P_2.

(4) The viscosity of the fluid N.

(5) and a factor characteristic of the specimen and called its specific permeability (K).



These parameters are connected by the following expression:-

$$(A)\quad K = \frac{Nt}{A} \cdot \frac{Q}{P_1-P_2}$$

In the case of a compressible fluid (air) the rate of flow Q must be expressed as the mean rate of flow within the specimen (usually written $\bar{Q}$). Q is determined experimentally by measuring the drop in pressure across the capilliary tube, i.e. by (H_3-H_1). An initial calibration gives the values of Q corresponding to different values of H_3-H_1. This calibration is made with the inlet end of the capilliary tube at atmospheric pressure, i.e. $H_1 = 0$. The values of Q obtained experimentally must be adjusted to the mean rate of flow $\bar{Q}$ by means of a correction factor which depends on the values of H_1 and H_3.

The drop in pressure(P_1-P_2) across the sample is determined by the reading H_1 (H_2 being assumed zero) because P_1 = atmospheric pressure, and P_2 = atmospheric pressure - H_1 inches of oil.

If the flow through the specimen is viscous (streamlined) over the observed range of values of H_1 then a straight line will be obtained by plotting $\bar{Q}$ against P_1-P_2. Conversely if a straight line is obtained by plotting $\bar{Q}$ against P_1-P_2 then the flow through the specimen is streamlined and the relationship (A) can be applied.

In practice it is found that small experimental errors are present and a 'mean' straight line is drawn through the points. The slope of this 'mean' line is used as the ultimate value of $\bar{Q}/P_1-P_2$. If $\bar{Q}$ is expressed cc/sec., P_1-P_2 in atmospheres, t in cm., A in cm^2 and N in centipoise, then K according to equation (A) is in darcies. It is usual to express permeabilities in millidarcies and this practice has been followed in expressing the results obtained in this investigation. Fig. 4 and the tabulation accompanying it represent a typical set of readings and illustrate the method of working out the results.

B. Model II - Permeameter.

This apparatus is identical in principle with Model I but the sample holder, flowmeter, and manometer designs are different. This permeameter is 'direct reading' because the pressure difference in atmospheres and the rate of flow in cc/sec., are given directly by readings on the appropriate scales. Fig. 2 illustrates the general set up.

(a) The Sample Holder.

The sample holder is designed to mount hollow cylindrical samples up to 5 cms. in diameter and 5 cms. long.

The samples are seated on a soft rubber gasket having a central hole coinciding with the air outlet. The top of the sample is covered by a soft rubber gasket and metal disk on which the compression screw bears. Pressure is applied by means of this screw and the sample is held firmly between the gaskets in such a way that no leakage can occur between the gaskets and sample.

A small bell-jar covers the mounted sample and pressure screw and makes a gas-tight seal with the sample holder base plate. The air, which flows through the sample, enters the space enclosed by the bell-jar through a tube let into the base plate as shown in Fig. 2. After passing through the sample, the air is drawn through the outlet tube in the centre of the base plate and passes through the flowmeter.

(b) The Manometer.

A U-tube manometer of special design is connected across the inlet and outlet sides of the sample holder. The LHS of the manometer comprises 1.5 cm. diam. tube connected at its lower end to the reservoir (diam. 4 cm.) and also connected near the top to the drying tube and air intake.

The RHS tube is 0.5 cm. diam. but is enlarged to 1.5 cm. diam. where it joins the outlet of the sample holder and the connection to the flowmeter. The manometer is filled with oil of low vapour pressure and of S.G.0.865. The scale on the RHS is calibrated directly in atmospheres and represents the drop in pressure across the sample under test.

(c) The Flowmeter.

This part of the apparatus comprises a capillary tube connected across a differential manometer. The manometer is filled with oil (S.G.0.865) and the scale on the RHS gives directly the rate of flow in cc/sec.

In the instrument described, full scale reading of the flowmeter is approximately 8 inches of oil corresponding to a flow rate of 1 cc/sec. This range is sufficient for permeabilities up to 500 millidarcies but for values greater than this a second flowmeter reading up to 10 cc/sec. would be necessary.

(d) The needle valve.

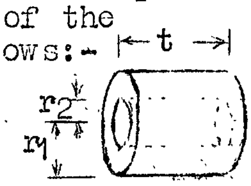
The needle valve is the same as that used in the Model I apparatus and serves the same purpose.

(e) Method of Using Permeameter.

In operation this apparatus differs from Model I in the direction of the flow of air through the sample. The samples are prepared in a manner similar to that described before except that the cylinders are cut into lengths of from 2 to 3 cm., and the ends filed flat and parallel to the axis of the cylinder. The samples are then mounted in a lathe and a hole (diam. about 7-8 mm.) drilled through them. The surfaces of this hole are roughened by means of coarse emery paper to remove any fine material which might clog the pores and, after drying, the samples are ready for mounting.

It will be appreciated that the air flow in this case is radially inward. For such a direction of flow, the expression connecting the permeability (K) with the dimensions of the sample, pressure differences and rate of flow is as follows:-

$$\text{(B)}.\quad K = \frac{\bar{Q}\,N}{2\pi t} \cdot \frac{\log_e \frac{r_1}{r_2}}{P_1 - P_2}$$



where K, $\bar{Q}$, N, t and P1-P2 have the same meaning as in equation (A).

(f) Reading.

The procedure adopted in taking readings is similar to that for Model I, the values of Q and (P1-P2) being given directly by readings on the appropriate scales. The value of Q obtained must be corrected to the value $\bar{Q}$, i.e. the mean rate of flow within the specimen, the correction factor depending on the values of Q and (P1-P2).

As in the previous case, values of $\bar{Q}$ are plotted against (P1-P2) values. A straight-line plot represents streamlined flow and hence (B) may be applied.

Fig. 5 represents a typical set of readings and plot and illustrates the method of working out results. It will be noticed that the straight line drawn through the points on the $\frac{\bar{Q}}{P_1 - P_2}$ graph does not pass through the origin. This is due to the flowmeter having a slight zero error which was corrected for later tests.

The permeability (K) follows from the application of the equation (B), the mean slope of the graph being used for the value of $\frac{\bar{Q}}{P_1 - P_2}$.

II. Porosity Apparatus.

Fig. 6 represents the layout of the porosimeter. The apparatus comprises two glass vessels of known volumes V1 and V2 connected by a glass tap (3 mm. bore).

The upper vessel (V1) is a cylinder approximately 2.5 cm. in height, 2.5 cm. in diameter, terminated at its upper edge by a ground glass flange. It can be sealed by means of a plate glass cover through one edge of which a small hole has been drilled. The seal is made airtight by applying a smear of vaseline or vacuum grease to the ground glass flange. The volume enclosed between the glass tap and the plate glass seal is carefully measured by filling the vessel with mercury, applying the cover plate and allowing the excess mercury to escape through the small hole.

The volume of the lower vessel, between the glass tap and zero mark is also carefully determined.

The lower vessel is attached at its bottom end to a manometer tube 4 mm. diam. and approximately 30 inches long which in turn is connected at its bottom end to a second manometer tube approximately 40 inches long (also 4 mm. diam.). The manometer tubes can be filled with mercury from the mercury reservoir which is attached to their lower end by means of rubber tubing. The mercury reservoir is mounted on a sliding carrier which is fitted with a clamping screw and level adjustment screw. The length of the slide is such that the reservoir can be elevated to a height slightly in excess of that of the upper vessel and lowered to the base of the apparatus.

(a) Method of Using Porosimeter.

Cylindrical samples are prepared in the same manner as for the permeability determinations. The upper vessel, into which the sample is placed for testing, will permit the use of a sample 2.5 cm. diam. by 2.5 cm. in height.

The lower vessel is first evacuated. This is done by raising the mercury reservoir until the mercury rises through the lower vessel and reaches the base of the tap. The tap is then closed and the mercury reservoir lowered to its lowest level. In doing so, the level of the mercury in the lower vessel is made to fall below the zero mark on the LHS manometer tube and a vacuum is created above it. It is generally found that a certain amount of air adheres to the glass walls of the lower vessel and this air is yielded up upon the evacuation of this vessel. The mercury reservoir is raised and lowered a number of times (the tap meanwhile remaining closed) to assist in the elimination of the 'adhering' air and finally the level is raised once more, the tap opened and any air collected is pushed through the tap into the upper vessel. The mercury level is adjusted so that the mercury fills the hole in the tap without entering the upper vessel. The tap is now closed and the reservoir again lowered until the mercury in the LHS manometer tube stands level with the zero mark. The reading on the RHS manometer tube gives the atmospheric pressure in inches of mercury.

The sample, after careful drying, is placed in the upper vessel and the vessel sealed by placing the cover plate on the ground glass flange which has been smeared with a thin coating of vaseline or vacuum grease. The cover plate is first fitted so that the hole connects with the upper vessel, the cover plate pressed firmly onto its seat and then slid sideways until the hole no longer connects with the upper vessel. If an airtight seal has been made the vaseline or vacuum grease will appear clear and free of air bubbles. This procedure ensures that the sample is sealed in the upper vessel at atmospheric pressure.

The vessels are now interconnected by means of the tap and the reservoir level adjusted until the mercury in the LHS manometer tube is level with the zero mark.

Owing to the air from the upper vessel expanding adiabatically, some time is required for the temperatures to adjust themselves. One hour was found to be necessary when using solid cylinders, 2.5 cm. by 2.5 cm.

Let V1 be the volume of the upper vessel.
V2 " " " " " lower "
Vc " " " " " specimen (obtained by measurement).
Vp " " " " " air spaces within the specimen.
At " " atmospheric pressure in inches Hg.
(At-H) " " final pressure when the two vessels are interconnected and temperatures adjusted (in inches of Hg).

Before interconnection we have a volume of air equal to (V1-Vc) + Vp at atmospheric pressure.

After interconnection we have a volume (V1-Vc) + Vp + V2 at a pressure of (At-H).

By Boyle's Law.

$$\left\{ (V1-Vc) + Vp \right\} At = \left\{ (V1-Vc) + Vp + V2 \right\} (At-H)$$

from which

$$Vp = V2 \left(\frac{At-H}{H}\right) - (V1 - Vc)$$

The percentage porosity is $\frac{Vp}{Vc} \times 100\%$

III. Results of Tests.

A. Glauconitic Sandstone, Bore 10, Lakes Entrance.

The accompanying tabulation sets out the results of permeability, porosity and strength tests made on a representative suite of specimens from No. 10 bore at Lakes Entrance, Victoria.

The bore log compiled by H. G. Raggatt and J. W. Binney is given in the first three columns. The fourth column gives the depth from which the specimens used in the test were taken. The fifth column gives the distinguishing number appropriate to each test piece or sample while the sixth column shows the measured permeability expressed in millidarcies. The direction of flow relative to the bedding is indicated by means of the letters P N or C depending on whether the rate of flow, and hence permeability, is measured parallel to the bedding, normal to the bedding, or part normal part with the bedding.

The following columns are devoted to the porosity, measured and calculated, apparent density and compressive strength.

1. Permeability Results.

(a) Previous Determinations.

Reference can be found to two previous determinations of permeability of Lakes Entrance glauconitic sandstone. I.C.H.Croll of the Victorian Mines Department (2) gives the results of a number of tests on specimens from No. 1 Government bore, No. 2 Lakes Entrance Development bore and the No. 1 Kalimna bore, Lakes Entrance. For the location of these bores see Fig. 7.

Permeabilities measured ranged from 450 to 4 millidarcies. Croll's analysis of the results shows an average permeability of 223 millidarcies along the bedding and 15 millidarcies across the bedding with an approximate mean permeability of 77.5 millidarcies. After discussing possible sources of error in his determinations, Croll concludes that "the weight of evidence is in favour of regarding the results calculated from those tests as being lower than the actual permeability."

The only other reference that can be found for permeability measurement occurs in a report by K. Washington Gray and I.C.H.Croll (3). On page 98 reference is made to a test conducted by Oliver Streeton on a specimen of the "normal rock" (glauconitic sandstone) using Lakes Entrance crude oil. He found that with a plate of rock 2 mm. thick and half a square inch in area at a temperature of 50°F. and a pressure differential of half an atmosphere, the rate at which the oil would pass through the rock after it had been thoroughly saturated was 0.1 cubic cms. per 12 hours.

Making use of equation (A), page 3, and putting

$N = 6.25$ poise (by extrapolation from figures given by Croll in Redwood units).

$Q = 2.3 \times 10^{-6}$ cc/sec.

$P1-P2 = .5$ atmospheres.

$t = .2$ cm.

$A = 3.2$ cm^2

we find that K is equal to 0.18 millidarcies. This figure differs considerably from Croll's average figure (77.5 millidarcies), but a study of the tabulation will show that permeabilities as low as 0.18

millidarcies are not uncommon in the specimens from No. 10 Bore.

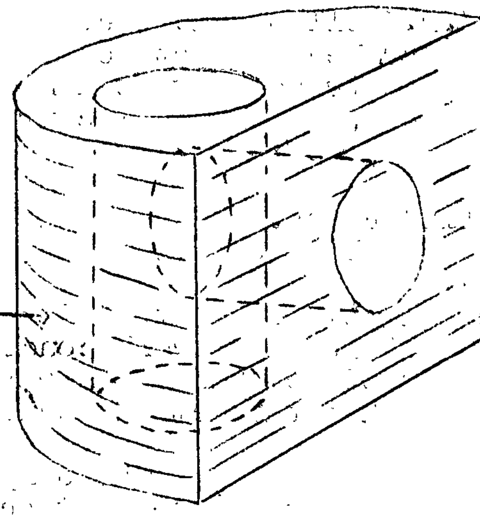
(b) Results of Tests.

The specimens used in these tests were selected by the Victorian Mines Department as representative of the glauconitic sandstone proved in No. 10 Bore, Lakes Entrance. Twenty-one specimens were forwarded, of which 18 represented the hard strata in the section and 3 the soft. The specimens of the hard strata comprised half sections of drill core approximately 5 inches in diameter and averaging three inches in length. They had been split in halves in an axial plane.

Test samples were prepared from all the hard specimens but none from the soft. The soft material comprised small lumps of unbroken rock cemented by drilling mud. Attempts were made to drill samples from the largest of these lumps, but they became semi-fluid and disintegrated when drilling was attempted.

Cylindrical samples were prepared from the specimens by means of a diamond drill as explained in an earlier section of this report. The accompanying sketch illustrates the way in which these cylinders, 2.5 cm. in diameter and up to 4 inches in length, were cut so that their axes were normal to the bedding or parallel to the bedding.

Sketch of half section of 5 inch drill core showing 2.5 cm. diameter cylindrical samples cut parallel and normal to bedding.



The glauconitic sandstone exposed in the No. 10 Bore yielded oil at the rate of approximately 10 gallons per day during bailing tests, but a remarkable feature of the specimens tested was that without exception they appeared to be free of oil.

Earlier reference has been made to the fact that when redistilled benzene was forced through some of the samples no discolouration was noticed. A number of specimens had a faint oily smell and these were tested for the presence of oil by pulverizing a piece of the specimen and boiling it in a small quantity of benzene. As no discolouration of the benzene was noticed in any of the tests so made it is concluded that none of the specimens were oil-bearing. The specimen, 1259 feet - 1261 feet, corresponds to a part of the glauconitic sandstone section where oil has been reported as occurring in streaks throughout. The extremely low permeability (0.12 millidarcies) found for this specimen would seem to preclude the possibility of the specimen losing much oil if any had been present. The fact that no oil could be detected in this specimen suggests that the three inch piece submitted for examination corresponds to an unproductive part lying between the streaks of oil recorded when the two foot section was first cored.

A similar reason may account for the absence of oil in the other specimens submitted for examination and for this reason the permeability results may not be a true indication of the permeability of those parts of the section which have yielded oil.

Between 1255 feet and 1291.5 feet, which has been logged as glauconitic sandstone, permeabilities varied over wide limits, the lowest value was 0.01 millidarcies and the highest (1272 feet - 1273 feet) was 38.3 millidarcies.

The average value for each specimen is shown in column 8 and the mean value of these averages (1255 feet - 1296.5 feet) is 2.16 millidarcies.

Specimens from 1291.5 feet to 1300 feet were more sandy in appearance than those higher in the section and were not included in the glauconitic sandstone section when the bore log was originally compiled. They were originally excluded because the quartz grains seemed more polished and abundant than in the higher specimens and the typical greenish colour of the glauconitic sandstone was masked through water seeping in from the bottom and wetting them. Some time later when the cores had dried out it was evident that they had the typical colour of the glauconitic sandstone and they were subsequently included in the glauconitic sandstone section. They were later examined by the Commonwealth Palaeontologist and their classification as glauconitic sandstones confirmed. This classification makes the glauconitic sandstone series 45 feet thick instead of 36 feet 6 inches as shown in the original log.

Permeabilities of the samples corresponding to the interval 1291 feet - 1294 feet 6 inches range from 4.8 to 138 millidarcies with average values of 60.4 and 31.5 for the two specimens examined.

The reason for such large variations in permeability was made apparent when a number of the hollow cylindrical test samples were mounted in the oil extraction apparatus. This apparatus was designed to force benzene from the inside of the sample, through the walls to the outside where the benzene accumulated in a vessel surrounding the specimen. The apparatus made provision for forcing only a limited amount of benzene through the sample and it was noticed that after this had passed through and the sample submerged in the effluent, the compressed air which had been used to force the benzene through issued from the core in a very irregular fashion. For example in sample 53 (1291 feet 6 inches - 1294 feet 6 inches) which was a hollow cylinder 2.5 cms. diam. by 2.24 cms. high, it was observed that the greatest part of the air issued from an area of approximately 2 $cm.^2$ of the cylinder's surface. From a study of the size, number and distribution of the emergent air bubbles, it was possible to form a picture of the relative permeability of various sections of this sample. It was estimated that 2 $cm.^2$ of the total surface area of 17.5 $cm.^2$ was responsible for not less than 80% of the total permeability. On this basis, it is estimated that the small very permeable section of the sample has a permeability of approximately 120 millidarcies, which is comparable with the highest permeabilities found for the test samples. Other samples showed similar irregularities in the distribution of the permeability.

A notable feature of the distribution was that it was obviously not an effect due to bedding. The very permeable section of No.53 sample appeared on only one side of the cylinder and was not distributed over any particular layer within the sample as would have been the case if bedding had been the chief factor.

The glauconitic sandstone in general is heterogeneous in lithology with small inclusions of material differing considerably in permeability from the average for the specimen. The large variations in the observed permeability must, therefore, be explained in terms of this heterogenity made noticeable by the fact that the test samples were small in size.

(c) Effect of Bedding on Permeability.

In the preceding section it has been shown that variations (such as the size, distribution or arrangement of the grains) due to bedding were not responsible for the variations in permeability observed in a set of test samples cut from the one specimen.

Variations in the lithology of the glauconitic sandstone at different horizons, which may be called a bedding effect, are accompanied by variations in the average permeability and in this sense it may be said that permeability varies with the bedding. For instance the beds at the base of the glauconitic sandstone section are much more permeable than those higher in the section. Tests were made to determine whether there was any appreciable change in permeability when the fluid flow was measured in the direction of the bedding or normal to it. The results of these tests are tabulated below:-

Permeability in Millidarcies

Sample	In direction of bedding.	Normal to Bedding.	Part normal - part with bedding.
1277'-1278' Nos.22 to 28	2.40 2.04 0.71	5.86 0.41	1.31 0.48
1291'-1294' Nos.36 to 42	135 119 32.5 19.7	83.3 6.4	26.8
1291'6"-1294'6" Nos.48 to 56	82.0 47.2 26.7 16.3 12.1 11.9	45.7 4.8	60.9
1294'-1300' Nos.57 to 63	55.5 40.5 26.0	56.0 34.0 64.0	39.5

The permeabilities tabulated above show variations within wide limits but there is no consistent difference between permeabilities normal to the bedding and those in the direction of the bedding. The results for samples 57 to 63 (1294 feet - 1300 feet) which are more uniform than the others suggest that the permeability is the same whether measured normal to or parallel to the bedding. It is obvious from the results that a vast number of determinations would need to be made before satisfactory average figures could be arrived at. The weight of evidence however, suggests that the permeability is not influenced by the direction of flow relative to the bedding. This is contrary to Croll's findings for specimens from No.1 Government Bore, No.2, Lakes Entrance Development and No.1 Kalimna bores. Croll prepared his specimens by shaping them into 2 cm. cubes and measuring the permeability between opposite faces. The variations in measured permeability were ascribed to bedding and on this basis he arrived at the following averages:-

Permeability along bedding 223 millidarcies.
" across " 15 "

If the glauconitic sandstones examined by Croll are heterogeneous in lithology like those examined by the writer from No. 10 Bore, it seems more likely that the variations noted by Croll are due to local variations within the specimens rather than to a bedding effect. If Croll's interpretation of his results is correct then it is obvious that the lithology of the glauconitic sandstones in the bores from which his specimens were derived differ considerably from those in No. 10 Bore.

(d) Effect of Moisture on Permeability.

The permeabilities given in the main tabulation refer to oven dried specimens in which the free water content was very small. The permeabilities of three samples 54, 55 and 56 were measured after air-drying and repeated after the samples had been dried in the oven. It was found that the permeability increased appreciably upon drying. In order to confirm this and to see if any relationship existed between percentage moisture content and permeability, the test was repeated on nine specimens which were weighed before and after drying to determine the loss of water on drying. The results of this test are set out in the following table.

Permeability: Dry and Wet.
Millidarcies.

Specimen	Dry	Wet	Per Cent. Moisture.	Per Cent. Change Per 1 Per Cent. Moisture
1291'6"-1294'6" No. 54	11.8	11.6	-	-
No. 55	16.4	14.3	-	-
No. 56	60.9	54.5		
1277'-1278'				
No. 22	0.48	0.28	3.8	~~19~~ 11.0
No. 23	1.31	0.83	4.1	~~14~~ 8.9
No. 26	0.71	0.42	3.6	~~19~~ 11.3
1291'-1294'				
No. 36	19.7	17.0	2.8	~~3.0~~ 4.9
No. 37	32.5	28.7	4.4	~~3.5~~ 2.7
No. 38	26.8	21.7	3.9	~~4.8~~ 4.9
1294'-1300'				
No. 57	55.5	48	2.8	~~5.4~~ 4.8
No. 58	40.5	38.8	2.3	~~1.9~~ 1.8
No. 62	39.5	38.2	2.1	1.6

The figures in the fifth column are arrived at by expressing the change in permeability between dry and wet samples, as a percentage of the dry value and dividing this total percentage change by the percentage moisture content of the wet sample.

A study of the results shows that there is an increase in permeability when the sample is dried. The relative amount of this increase varies for the different samples tested, being considerably greater in the low permeability samples from 1277 feet - 1278 feet than in the samples from 1291 feet - 1294 feet and 1294 feet - 1300 feet. These last mentioned two samples are similar in appearance and are much coarser grained than the first mentioned. The reason for the change in permeability is not definitely established. Two possibilities will be considered.

(1) That moisture occupies and partly closes some of the air channels and in effect reduces their cross section. Such a reduction might conceivably be responsible for the increase in resistance to flow which is apparent in the changed permeability. In connection with this possibility it is of interest to note that similar wet-dry tests were carried out on a number of diatomite specimens. These tests showed that up to 15 per cent. moisture could be present without seriously affecting the measured permeability. This being so, it can reasonably be assumed that the small moisture content in the wet glauconites does not reduce the air channel cross section in the manner suggested above.

(2) An alternative possibility is that the glauconite, or some other constituent of the rock swells under the influence of the added water and that this swelling is responsible for the reduction in the cross section of air channels. Such swelling would probably affect the porosity of the specimen and this seemed to offer a method of checking the alternative possibility. Unfortunately the porosity apparatus was broken before such tests could be carried out. However, the suggested test will be made as soon as the porosity apparatus is repaired and opportunity offers.

Although the cause is unknown, it is an observed fact that permeability of glauconitic sandstones is largely influenced by the presence of moisture. The observed data is insufficient to arrive at any satisfactory basis for estimating the permeability when 'dry' permeability and moisture content are known. If some sections of the glauconitic sandstones in situ are saturated with water, it is probable that their permeability would be less than half their 'dry' value.

(e) Accuracy of Results.

An examination of the results shows that large variations in permeability occur between samples cut from relatively small specimens. For instance the specimen representing 1277 feet - 1278 feet was approximately 30 cubic inches in volume, but permeabilities of the seven test pieces cut from this specimen varied between .41 and 5.86 millidarcies.

It is obvious, therefore, that a high degree of accuracy for each individual test is unnecessary and all that is required of the permeability determination is that it should give the order of magnitude. Nevertheless, the procedure followed and precautions observed were based on the A.P.I. standard procedure for determining permeability (4) and it is of interest to make an approximate determination of the probable error in any individual result.

Errors may be classified as being of two kinds, namely (1) changes in permeability introduced through poor or incorrect technique in preparing the test samples or (2) errors in measurement.

(1) Errors in Preparation.

The principal source of errors in the preparation of the test samples are:-

(a) Clogging of pores by mud introduced during the cutting processes.

(b) Incomplete removal of oil and water.

(a) Every care was taken to ensure that these errors would be as low as possible and the precautions listed in the A.P.I. Code were followed. In addition, tests were made in the Model I apparatus on cylindrical tablets with 'fracture' faces and faces prepared in the fashion outlined in the opening sections of this report. These tests showed that no serious clogging resulted from grinding the faces on coarse emery paper.

(b) As regards removal of oil and water, it has been mentioned above that no trace of oil could be discovered in the specimens subjected to test so that the necessity for removing oil did not arise. As regards water removal, it is believed that the prolonged heating to which the samples were subjected effectively removed all free water. The temperature (150°C) at which the samples were dried was higher than recommended in the A.P.I.Code. Some tests were carried out in which the permeability of a sample was determined before heating and after heating 24 hours, 48 hours and 60 hours respectively. The permeability changed due to loss of water during the first 24 hours heating, but remained unaltered by the additional 24 hours and 48 hours heating. These tests showed that prolonged heating at 150°C did not alter the permeability and it is assumed that apart from the loss of free water the samples were unaltered by the heating.

(2) Errors in Measurement.

In Model I apparatus the permeability is given by the expression:-

$$(A)\quad K = \frac{Nt}{A} \times \frac{Q}{P_1 - P_2}$$

The viscosity of air (N) was known to within ± ½%. The measurements of the thickness (t) and the diameter (D) were subject to errors of approximately ± 1%. The area, A, was proportioned to D^2 and hence was subject to an error of ± 2%.

The value of $\frac{\bar{Q}}{P_1 - P_2}$ was subject to errors in calibrations of the flowmeter and manometer tubes, but a number of determinations was made for each sample and the error in the average value is certainly not greater than ± 1%.

K was, therefore, accurate to better than ± 5%. In Model II permeameter, similar errors in measurement apply and K as measured by this instrument has an accuracy better than ± 5%.

Errors due to leakage past the rubber gaskets holding the specimens can be regarded as negligible.

2. Porosity Results.

(a) Previous Determinations.

The only reference that can be found to previous determinations of porosity occurs in the previously mentioned report by K. Washington Gray and I.C.H.Croll.(3) On page 97, mention is made of two determinations by J. C. Watson of the Victorian Mines Department on samples from Foster's Bore, the location of which is shown on the plan, fig. 7. Effective porosities of 54 per cent. and 53 per cent. respectively were obtained for samples from 2 to 3 feet and 16 to 17 feet below the top of the glauconitic sandstone. In addition to Watson's results mention is made of a determination by Oliver Streeton on a sample from 15 feet below the top of the glauconitic sandstone in the same (Foster's) bore. Streeton's figure was 29 per cent.

(b) Results of Tests.

The apparatus used to measure porosity is described in an earlier section of this report. It should be noted that the method measures the apparent or effective porosity, i.e. the porosity of the inter-connected pore spaces and any pore spaces completely sealed would not influence the results.

Porosities were relatively uniform throughout the glauconitic sandstone series and varied from 29.1 to 43.5 per cent. for the individual samples; but the averages for each horizon were more uniform, varying between 35.6 and 39.7 per cent.

In addition to porosities measured with the apparatus, a number of porosities were calculated from the apparent density of the samples. The calculations were based on the assumption that the solid matter comprising the 'frame work' of the glauconitic sandstone had a density of 2.62. The calculated porosities are shown in the main tabulation and they are (with one exception, viz. No. 26) lower than those measured. The average value of nine calculated porosities is 32.6 per cent. compared with the average measured porosity of 37.3 (23 determinations).

If a density of 2.8 is assumed for the solid matter then the calculated porosities become approximately equal to the measured.

The average measured porosity is intermediate in value between Watson's (53-54%) and Streeton's (29%) determinations.

(c) Accuracy of Results.

The accuracy of any porosity determination depends on the accuracy with which the various factors used in the calculation are measured. A figure for the theoretical accuracy can be arrived at by applying to each factor involved a relative accuracy and then calculating the mean and maximum value for porosity assuming that all the individual errors are additive.

For the case.

$V_1 = 17.40 \pm .05$ cc.

$V_2 = 5.07 \pm .05$ cc.

$V_c = 10.0 \pm .2$ cc.

$A_T = 28.00 \pm .02$ inches.

$H = 8.67 \pm .02$ inches.

Then $V_p = 3.9 \pm .4$ cc. and $\frac{V_p}{V_c} \times 100 = 39 \pm 5$.

The above calculation gives the maximum possible error for any one determination, but it must be borne in mind that the probability of the maximum possible error occurring (or in other words of all the individual errors acting in the same sense) is infinitesimally small. The accuracy of the apparatus and technique was tested by placing in it a solid brass cylinder of zero porosity. The porosity calculated from the volume and pressure readings was - 0.25% (instead of zero).

In addition to the above test, determinations on a single glauconite sample were repeated and the measured porosity could be repeated with an accuracy of better than ± 2%.

It is believed that in practice the porosities determined by means of the apparatus are within 5 per cent. of their correct value, a degree of tolerance which is quite sufficient for most purposes.

3. Relationship Between Permeability & Porosity.

An examination of the corresponding permeabilities and porosities from the separate test samples brings out clearly the fact that there is no relationship between these two quantities. Although the porosity of various zones within the glauconitic sandstone varies very little, the permeabilities varies over wide limits. In connection with this point the following tabulation, based on permeability and porosity measurements made by the writer on various materials is of interest.

Material	Porosity Per Cent.	Permeability Millidarcies	Remarks
Mt. Gambier limestone	52	5,182	One determination.
Roma 'Gas' sandstone	16	57.0	Average of seven determinations.
Glauconitic sandstone No. 10 Bore, 1255' - 1291'	38.2	2.16	Average of 35 determinations.
Glauconitic sandstone No. 10 Bore, 1291' - 1300'	36.6	45.7	Average of 28 determinations.
Diatomite	72	24.3	Average of seven determinations.

4. Apparent Density.

The apparent density of dry glauconitic sandstone was determined for nine samples with values ranging from 1.67 to 1.89 grm./cc.

5. Compressive Strength.

Tests of compressive strength were carried out in the testing laboratory of the Department of the Interior on a Tinius Olsen testing machine capable of providing loads of up to 1200 kilograms. The machine was designed for moulding concrete cylinders 1 inch diameter, but was eminently suitable for compression tests on cylindrical specimens of this diameter and of low strength.

Test samples were drilled from the raw material by means of the diamond drill mentioned previously and cut into lengths of approximately 1 inch. The ends of the cylinders were made truly parallel to one another and normal to the axis of the cylinder in the special holder (Fig. 3).

Tests were made on a number of samples which had been oven-dried and a number which had been saturated with water.

The pressure in lbs. per square inch necessary to crush the specimen was calculated and a correction applied for the finite size of the specimen. This correction in effect converted the measured pressure into the pressure per square inch needed to crush a cylindrical sample of height equal to twice its diameter, i.e. the compressive strength of the material.

The results of these tests appear in the main tabulation.

It will be observed that there is a considerable difference in compressive strength between dry and wet glauconitic sandstone.

Seven samples from the glauconitic sandstone section 1255 feet - 1291 feet were oven-dried before testing and their average compressive strength was found to be 2590 lb. per square inch. Ten samples from the same section were saturated with water prior to testing and their average compressive strength was found to be only 1294 lb. per square inch or approximately half the average of the oven-dried samples.

Tests made on two samples of the more sandy and friable glauconitic sandstone, corresponding to the section 1291 feet to 1300 feet, proved them to be the weakest of any tested. A sample corresponding to the section 1291 feet - 1294 feet and saturated with water was found to have a compressive strength of 700 lb. per square inch. The second sample corresponding to the section 1294 feet - 1300 feet was tested after being saturated with water and found to have a compressive strength of 720 lb. per square inch.

The Victorian Mines Department had a test carried out on a sample of glauconitic sandstone from No. 10 Bore. The sample was $5\frac{1}{2}$ inches diameter and $3\frac{1}{8}$ inches long, but no indication is given as to whether the test piece was wet or dry.

The specimen broke under a pressure of 2420 lbs. per square inch. The application of a correction factor to convert the result to that for a standard cylinder reduces this strength to 1380 lb. per square inch. This figure is somewhat higher than the average value obtained by the writer for wet specimens, but as no indication is given as to what horizon the Mines Department sample represents it is not possible to make any direct comparison between the two results.

6. Permeability Calculated from Oil Production Figures, Imray Bore, Lakes Entrance.

The average permeability of a producing 'sand' can be calculated from the rate at which oil, water and gas are produced from a bore if the thickness of the 'sand' and the pressure within the 'sand' are known. The Imray bore appears to be a suitable one on which to base calculations of permeability because the glauconitic sandstone appears to have been successfully sealed off from water horizons above and below it. The fluid entering the bore casing appears to have come entirely from the glauconitic sandstone.

The location of this bore relative to No. 10 bore is shown on the locality plan, Fig. 7.

In the Imray bore, twenty feet of glauconitic sandstone are exposed which yielded 0.29 gallons of oil, 0.05 gallons of water per hour, and an undetermined but very small quantity of gas when the bore was bailed dry, i.e. when the pressure inside the bore was atmospheric. Upon standing for a period of approximately 24 months, the liquid level rose to within 100 feet of the surface under the influence of reservoir pressure. It is estimated that the level which would have been reached after an infinite time would have been approximately 30 feet from the surface. As the glauconitic sandstone is at a depth of 1250 feet, the reservoir pressure is not less than 34 atmospheres (assuming a specific gravity of 0.95 for the liquid column).

The equation for radial fluid flow can be used to calculate the permeability of the yielding layer from the above data if the gas flow is neglected.

The effective permeability may be expressed as:-

$$(D)\quad K = \frac{N\,A\,\log_e \frac{r1}{r2}}{2\,\pi\,t\,(P_1 - P_2)}$$

where N = viscosity in centipoise

Q = rate of flow in cc/sec.

t = thickness of producing sand.

$P_1 - P_2$ = pressure drive.

r_1 = radius of reservoir.

r_2 = radius of the bore hole.

Owing to the large difference in viscosity between the oil (N = 94 centipoise at 100^oF) and water (N = 0.6 centipoise at 100^oF) and the relatively small quantity of water yielded, the flow of the latter is neglected in the following calculations:-

For the Imray bore the following values hold:-

N = 94 centipoise (at 100^oF)

Q = .29 gallons per hour = .36 cc/sec.

log r_1/r_2 = 7.6 (assuming r_1 = 500 feet and r_2 = .25 feet)

t = 20 feet = 610 cm.

$P_1 - P_2$ = 33 atmospheres.

Placing these values in equations (D) we find that K = 2.03 millidarcies.

It is a remarkable result that this figure for the Imray Well should be so close to the average permeability (2.16 millidarcies) arrived at from tests on the glauconitic sandstone from the upper 36 feet of No. 10 Bore.

In the first place it has been assumed that the whole of the 20 feet exposed in Imray Bore has yielded oil. This is evidently not the case and the thickness (t) used in expression (D) should be modified to make allowance for this factor. If it were assumed that the whole of the production was from only 5 feet of sandstone whilst the remaining 15 feet were impermeable then the average permeability of this 5 feet would be four times as great as the figure given above, namely 4 x 2.03 = 8.12 millidarcies. Nevertheless the weighted average permeability for the whole 20 feet, under this condition would be the figure arrived at originally, namely 2.03 millidarcies.

The average permeability given for the upper 36 feet of No. 10 bore is not a'weighted'average, but merely the arithmetical average of a number of determinations. However, if the specimens examined are truly representative of the various horizons within the glauconitic sandstone then because the specimens were more or less evenly spaced throughout the section, the arithmetical average stated would approximately equal the weighted average.

The error introduced through neglecting the influence of water and gas flow in the calculations of permeability is probably small, but if these flows had been allowed for in the calculations of permeability, then the permeability finally arrived at would have been greater than 2.03 millidarcies. It must be conceded, therefore, that there is some justification for claiming that the calculations based on production from Imray Bore confirm at least in order of magnitude the permeability figure arrived at from measurement of specimens from No. 10 Bore.

7. Summary.

Permeability, porosity, apparent density and compressive strength tests have been carried out on a number of specimens of glauconitic sandstone from No. 10 Bore, Lakes Entrance.

Permeability varied widely throughout the section represented by the specimens, the average permeability for dry samples being 2.16 millidarcies for the top 36 feet and 45.7 for the lower 9 feet. A considerable part of the top section, however, was less than 1 millidarcy.

Permeability was found to vary with the moisture content of the sample and it is estimated that the permeability of water saturated glauconitic sandstone would be less than half the 'dry' sample value.

It is of interest to compare the permeability and porosity of the glauconitic sandstone with the permeability and porosity of known producing sands. Fancher, Lewis and Barnes (5) give a table in which the permeability and porosity of 127 sands, from American oil fields, are listed. Those sands exhibit a wide variation in permeability, ranging from over 3000 millidarcies for one sample of Woodbine sand to zero permeability under test conditions. The range in permeability found for 47 Bradford sands is comparable with that found in the tests described in this report. The maximum for the Bradford sand, 153 millidarcies, can be compared with the maximum for the glauconitic sandstone, namely 135 millidarcies. The comparison is also good for the lower values measured although the percentage of permeabilities lower than 0.2 millidarcies is much higher for the glauconitic sandstone than for the Bradford sand.

Other sands in the table, particularly Speechley, Windfall and Clarendon sands have permeabilities comparable with those found for the glauconitic sandstone.

As the sands tested by Fancher, Lewis and Barnes were taken from oil fields in which the productivity is greatly in excess of that of the Lakes Entrance field, it can be concluded that the low average permeability of the glauconitic sandstone is not entirely responsible for their low productivity.

Porosity was found to be relatively uniform throughout the section, the average value for the top 36 feet being 38.2 per cent. and for the bottom 9 feet 36.6 per cent. There was no correlation between permeability and porosity.

The porosity of the sands in the tables given by Fancher, Lewis and Barnes ranges from 2% for one of the Bradford sands to 28.8% for one of the Woodbine. The great majority, however, have porosities ranging from 10% to 20%. It is stated that the more representative samples of Bradford sand range in porosity from 11% to 13%.

None of the oil sands in the table have porosities as high as the glauconitic sandstone.

A search was made through numerous reports on the porosity of oil sands and in none was reference found to an oil sand with a porosity as high as that found for the glauconitic sandstone.

Its high average porosity (36% to 38%) therefore seems to place the glauconitic sandstone in a class apart from other known oil sands.

The occurrence of large quantities of glauconite in this sandstone, however, renders it different from oil sands listed by Fancher, Lewis and Barnes and other workers and it seems likely that the glauconite is in some way responsible for the high porosity.

Apparent densities varied between 1.67 and 1.89 grams per cc., averaging 1.72 for the top 36 feet and 1.76 for the bottom 9 feet.

Compressive strength tests showed substantial differences between wet and dry samples, wet samples having considerably lower strength than dry. The average 'dry' sample compressive strength for the top 36 feet was 2,590 lbs. per square inch while the average for wet samples from the same part of the glauconitic sandstone section was 1,294 lbs. per square inch.

Calculations based on oil production and known pressure drive in the Imray bore give an approximate figure of 2.03 millidarcies for the average permeability of the 25 feet of glauconitic sandstone exposed. This figure confirms, at least in order of magnitude, the average of the permeabilities observed (2.16 millidarcies) for the top 36 feet of the glauconitic sandstone in No. 10 Bore which corresponds stratigraphically to the glauconitic sandstone exposed in the Imray bore.

B. Polyzoal Limestone - Lakes Entrance Shaft.

Two specimens of polyzoal limestone were submitted for permeability tests. These corresponded to depths of 320 feet and 428 feet respectively from the surface in the shaft at Lakes Entrance. The position of this shaft is shown on the locality plan, Fig. 7. The specimens were found to have no appreciable compressive strength when thoroughly wet and were readily deformed by the pressure of the fingers. It was not possible to prepare test pieces in the standard fashion, but some cylinders were cut from the specimens by the diamond drill in the dry state.

These cylinders were cut into suitable lengths and the ends squared off in the special holder (Fig. 3). The sides of the cylindrical samples, however, were somewhat irregular and it was thought that serious leakage might occur down the sides of the samples when mounted in the rubber stopper of the Model I permeameter. In order to eliminate this possibility the sides of the cylindrical samples were sealed by means of plaster of paris. The samples were dampened to ensure that the plaster adhered but were not sufficiently wet to permit serious ingress of the plaster into the central part of the cylinders. The plaster when dried was smoothed by means of coarse sandpaper and after thorough drying the samples were mounted in the Model I permeameter.

No bedding was discernible in either specimen. Three cylindrical test samples were prepared from the specimen collected at a depth of 320 feet, but the orientation of their axes relative to the bedding was unknown. However, the axes of the three cylinders were parallel to one another.

Two sets of cylindrical test samples were cut from the specimen collected at a depth of 428 feet, the axes of the two sets being at right angles to one another, but their orientation relative to the bedding was unknown.

The results of the tests are set out in table form below.

Sample	Permeability millidarcies.
320' No. 1.	161
320' No. 2.	193
320' No. 3.	148
Average 320'	167
428' A No. 1.	87
428' A No. 2.	150
428' A No. 3.	172
428' B No. 1.	140
428' B No. 2.	139
Average 428'	138

Samples Nos. 1 and 2 (depth 320 feet) were slightly imperfect cylinders and had to be built to cylindrical shape with plaster of paris. The permeability figure given for these samples is, therefore, not as reliable as other figures quoted.

The axes of the cylinders cut from the samples marked A (depth 428 feet) were cut at right angles to those marked B. The fact that there is no appreciable difference in permeability between the A and B samples suggests that bedding has no appreciable influence on permeability although the possibility that each axial direction is at 45° to the bedding must be borne in mind. To be certain of the influence, if any, of bedding, a third set of values corresponding to samples with axes at right angles to A and B would be needed.

The average values of 167 millidarcies (320 feet) and 138 millidarcies (428 feet) were for dry samples. It is probable that permeabilities of corresponding wet samples would be considerably less than these figures.

C. Some Australian Diatomites.

The following notes cover the results of tests made on diatomites from three localities, namely - Gatton, Queensland (Black Duck deposit), Bowen Park and Barraba, New South Wales.

The following physical properties were studied:-

(a) Apparent density of dry diatomite.
(b) Porosity.
(c) Permeability.

Test samples were cut from lump material and were cylindrical in shape. The apparatus used in porosity and permeability measurements is described earlier in this report. The results of the tests are set out in the following table and are discussed below.

A	B	C	D	E	F	G
Sample Locality & Number	Density of Dry Sample	Porosity Calcul-ated %	Porosity Value Meas-ured %	Permeability (K) milliDarcies Sample Wet. m'darcies	% Mstre.	Sample Dry m'darcies
Black Duck Gatton, Qld. No. 1.	.43	79	73	13.8	6.65	13.4
Black Duck Gatton, Qld. No. 2.	.50	76	71	6.10	6.70	5.95
Black Duck, Gatton, Queensland. No. 3.	.48	77	67	11.4	6.68	11.6
Bowen Park, N.S.W. No. 1.	.39	81	77	48.5	15.7	46.5
Bowen Park, N.S.W. No. 2.	-	-	-	-	-	41.7
Barraba, N.S.W. No. 1.	.40	81	71	25.4	5.65	25.4
Barraba, N.S.W. No. 2.	.38	82	72	26.0	5.9	25.3

1. Apparent Density.

The samples were dried in a hot air oven at a temperature of 150°C. for approximately 30 hours and after cooling in a dessicator were carefully weighed. Their volume was calculated from the measured dimensions of the cylinder.

As the measurement of dimensions had an accuracy of not better than ± 1% the volume so determined is liable to an error of approximately ± 3%. The United States Department of Commerce, Bulletin 266 on "Technology and Uses of Silica and Sand" gives a table of apparent densities of some United States diatomites. Of the twelve diatomites cited, the average density is 0.58 gram per cc. Three diatomites are below 0.43, the lowest being 0.399.

Comparing the experimental results tabulated above with these figures we see that as far as density is concerned, the Bowen Park and Barraba diatomites compare favourably with the lowest density United States diatomites, while Gatton diatomite is lower than the average for the United States diatomites cited.

As low apparent density is one of the most desirable features, where heat insulation is concerned, it would seem that Bowen Park and Barraba diatomites might compare favourably with the better quality United States diatomites in this respect.

2. Porosity.

It will be observed that the tabulation gives two figures for porosity - one which has been calculated on the assumption that the true density of the material comprising the diatomite is 2.1 gm/cc. (see Eardley-Wilmot page 6)[6] and the other figure is the result of direct measurement by an expanding air method (Fig. 6). It will be noted that the calculated figure is higher in each instance. There are two possible explanations for this, namely:-

(1) That the material comprising the diatomites is less dense than assumed (2.1).

(2) That not all the air spaces within the specimens are inter-connected and that some are completely enclosed.

In order to make the calculated porosity equal to that measured it is necessary to assume densities of from 1.4 - 1.7 for the material comprising the diatomites. Such densities are far too low to be considered probable.

As regards the second possibility it must be emphasized that the method used to measure porosity demands that all the air spaces within the specimen should be inter-connected and able to contribute to the change of air pressure on which the method is based. The fact that the measured porosity differs appreciably from the calculated is taken as proof that such complete inter-connection does not exist and the difference between measured and calculated values is a measure of the degree of inter-connection.

There is no obvious relation between the degree of inter-connection so determined and permeability although it probably is a factor of minor importance in determining the permeability. The most important factor is presumably the area of cross section of the continuous air channels.

3. Permeability.

The figures of permeability given in the table are specific permeabilities, i.e. they are independent of the viscosity of the fluid used for the measurement.

Air was used in these determinations and permeabilities are expressed in millidarcies.

The cylindrical samples of diameter approximately 2.5 cms. were drilled from the material to be tested by means of a diamond drill - the specimen being thoroughly soaked in water prior to drilling. The ends were trimmed so that they were parallel to each other and normal to the axes of the cylinders, the length of the cylinders being approximately 2.5 cm. An axial hole of diameter approximately 0.8 cm. was then drilled through the cylinders and the prepared samples were mounted in the Model II permeameter so that the rate of flow of air in a radial direction could be measured.

After air drying for several days permeabilities were determined on the air dried samples which were then carefully weighed, thoroughly dried at a temperature of 150°C for several days, weighed again and finally the permeability was again measured.

The table above shows the results of this test. Under Columns E and F are shown permeability and moisture content respectively, of air dried samples while in Column G are shown permeabilities of oven dried samples.

The permeability was found to be the same before and after drying within the limits of experimental error.

In all except Black Duck No. 2, the axes of the cylindrical samples were normal to the bedding planes which were readily discernible upon wetting the raw material. With radial flow as measured in the permeability tests, the flow was parallel to the bedding. In the case of Black Duck No. 2, however, the axis of the cylindrical sample was parallel to the bedding and thus the radial flow was partly along the bedding and partly across the bedding. It will be observed that the permeability of this specimen (6.0 millidarcies) is approximately half that of Black Duck Nos. 1 and 3 which suggests that the permeability normal to the bedding is very much lower than in the direction of the bedding. On the other hand a measurement of permeability across the bedding was made in the case of Bowen Park No. 2 specimen and the figure (41.7) obtained did not differ greatly from that obtained in No. 1 specimen (46.5) for flow in the direction of the bedding.

D. <u>Roma Sandstone.</u>

During the construction and early stages of development of the permeability and porosity apparatus a number of rocks of varying types were prepared as test samples for the purposes of developing the technique. Amongst these rocks was a piece of sandstone which, according to a label attached to the specimen, was representative of one of the natural gas horizons at Roma, Central Queensland. The number of the bore and depth from which the specimen was taken are unknown.

The specimen was a piece of 3 inch drill core approximately 2 inches long and from it were drilled a number of cylindrical test samples 1 inch diameter and approximately 0.5 inches long. In all, six test samples were prepared and permeability tests were made on all of these and porosity tests on four. The results of the tests are set out below. The samples were oven dried before testing.

Sample	Permeability millidarcies	Porosity Per cent.
No. 1 A	61.7 and 62.1	A & B together.
No. 1 B	53	14.8
No. 1 C	59	16.8
No. 1 D	56.8	-
No. 2 A	53.7	16.8
No. 2 B	52.8	-
Mean Value	57.0	16.1

The direction of flow in each sample was parallel to the bedding.

The permeability figures are much more even than those obtained in tests on glauconitic sandstones, the maximum departure from the mean being less than 9 per cent. This can be attributed to the even-grain of the samples.

CANBERRA, A.C.T.
2nd February, 1944.

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Geophysicist.

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Fig.1. MODEL I. PERMEAMETER.

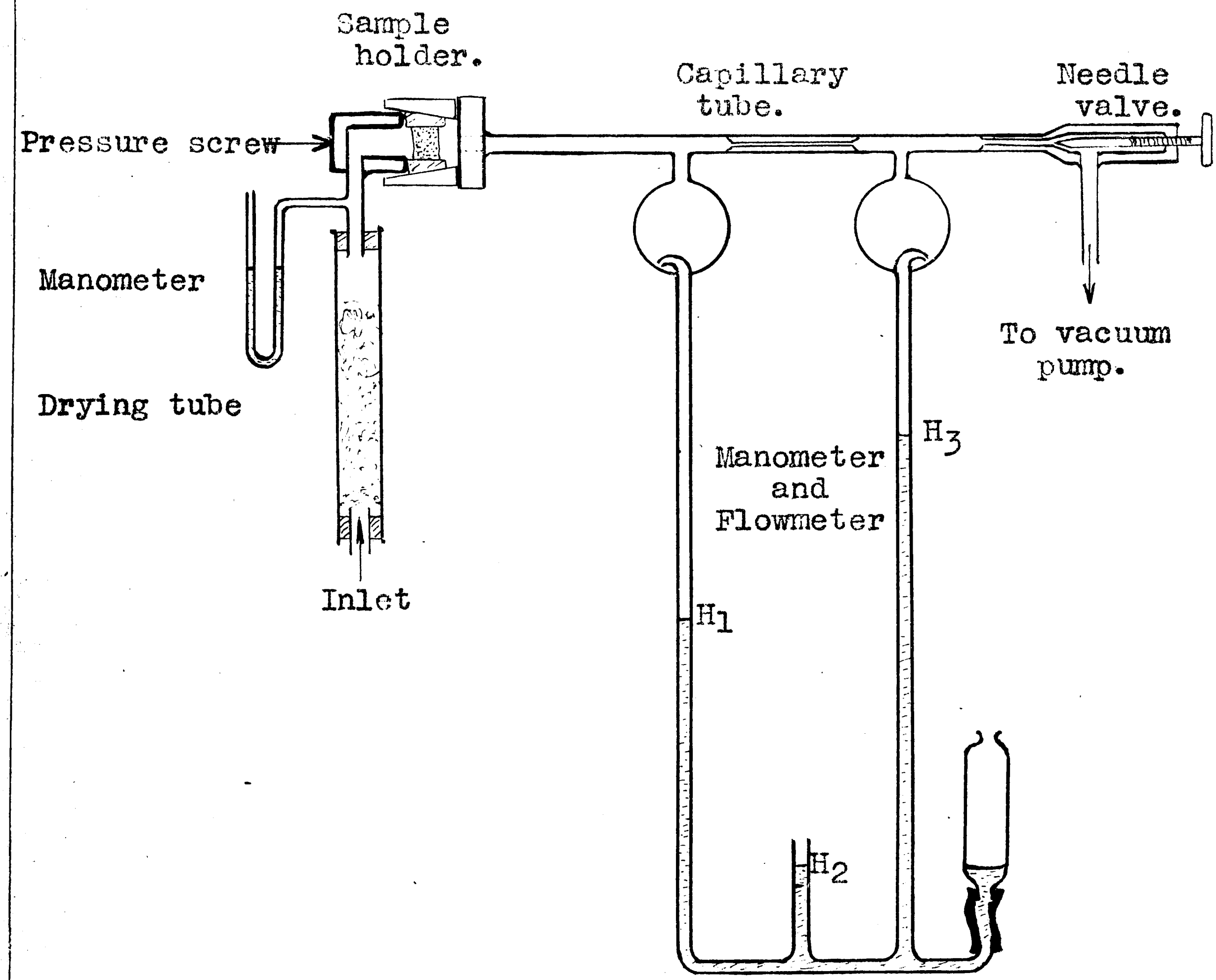


Fig.2.
MODEL II. PERMEAMETER.

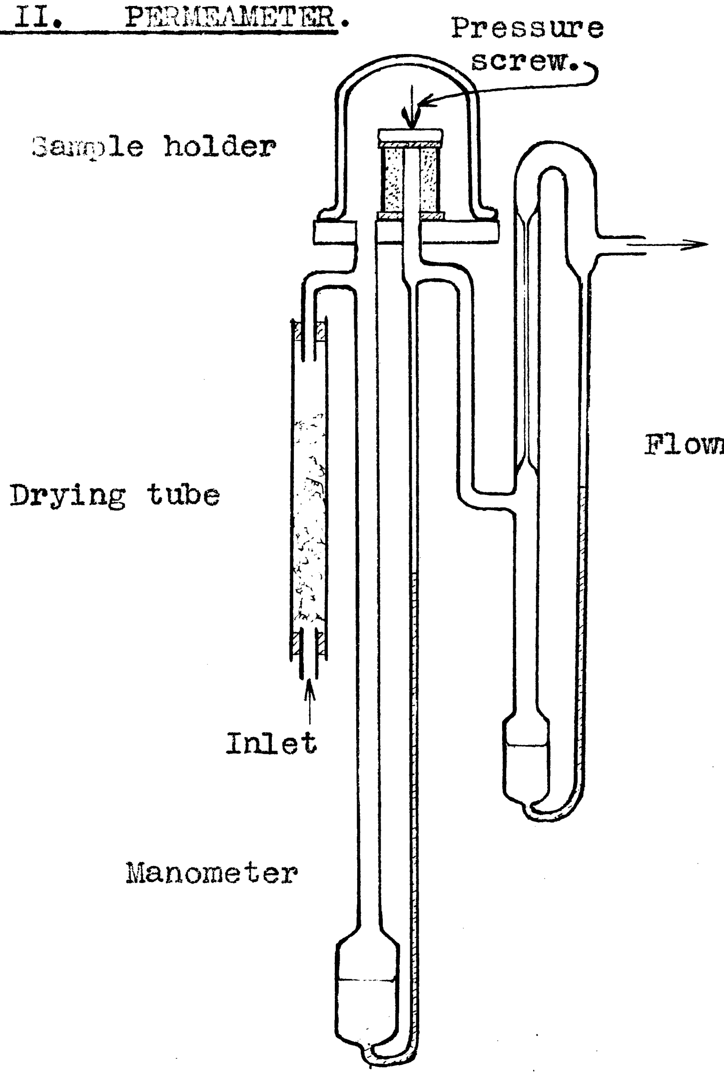


Fig.3.

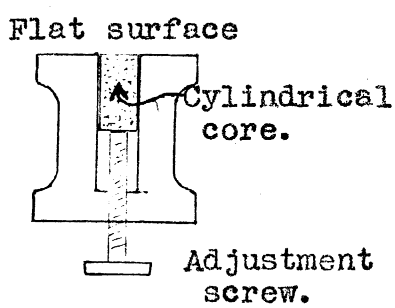


Fig.4.

MODEL I. PERMEAMETER.

Specimen:- Glauconitic sandstone, Bore 10, Lakes Entrance, 1291.5 ft. - 1294.5 ft., No.48.

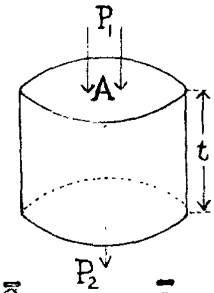
Diameter = .97 inches.

Area (A) = 4.75 cm^2.

Thickness (t) = .838 cms.

Air temperature = 62°F.

Air viscosity (N) = 181 x 10^{-4} centipoise.



H_1 Inches	H_2 Inches	H_3 Inches	H_1-H_2 Inches	P_1-P_2 Atmphs.	H_3-H_1 Inches	Q cc/sec	$\bar{Q}$ cc/sec	$\frac{\bar{Q}}{P_1-P_2}$
1.90	-.06	2.17	1.96	.0042	.27	.033	.033	7.85
3.37	-.12	3.88	3.49	.0075	.51	.062	.061	8.13
5.07	-.18	5.85	5.25	.0112	.78	.094	.093	8.29
6.98	-.23	8.06	7.21	.0154	1.08	.130	.129	8.38
8.69	-.32	10.05	9.01	.0193	1.36	.164	.162	8.40
10.52	-.36	12.13	10.88	.0232	1.61	.195	.192	8.28
12.29	-.41	14.19	12.70	.0272	1.90	.230	.226	8.32

$$K = \frac{N\ t\ \ \bar{Q}\ \ 10^3}{A\ \ (P_1-P_2)} \text{ millidarcies}$$

$$= \frac{1.81 \times .838 \times 8.35 \times 10}{4.75} = 26.7 \text{ millidarcies}$$

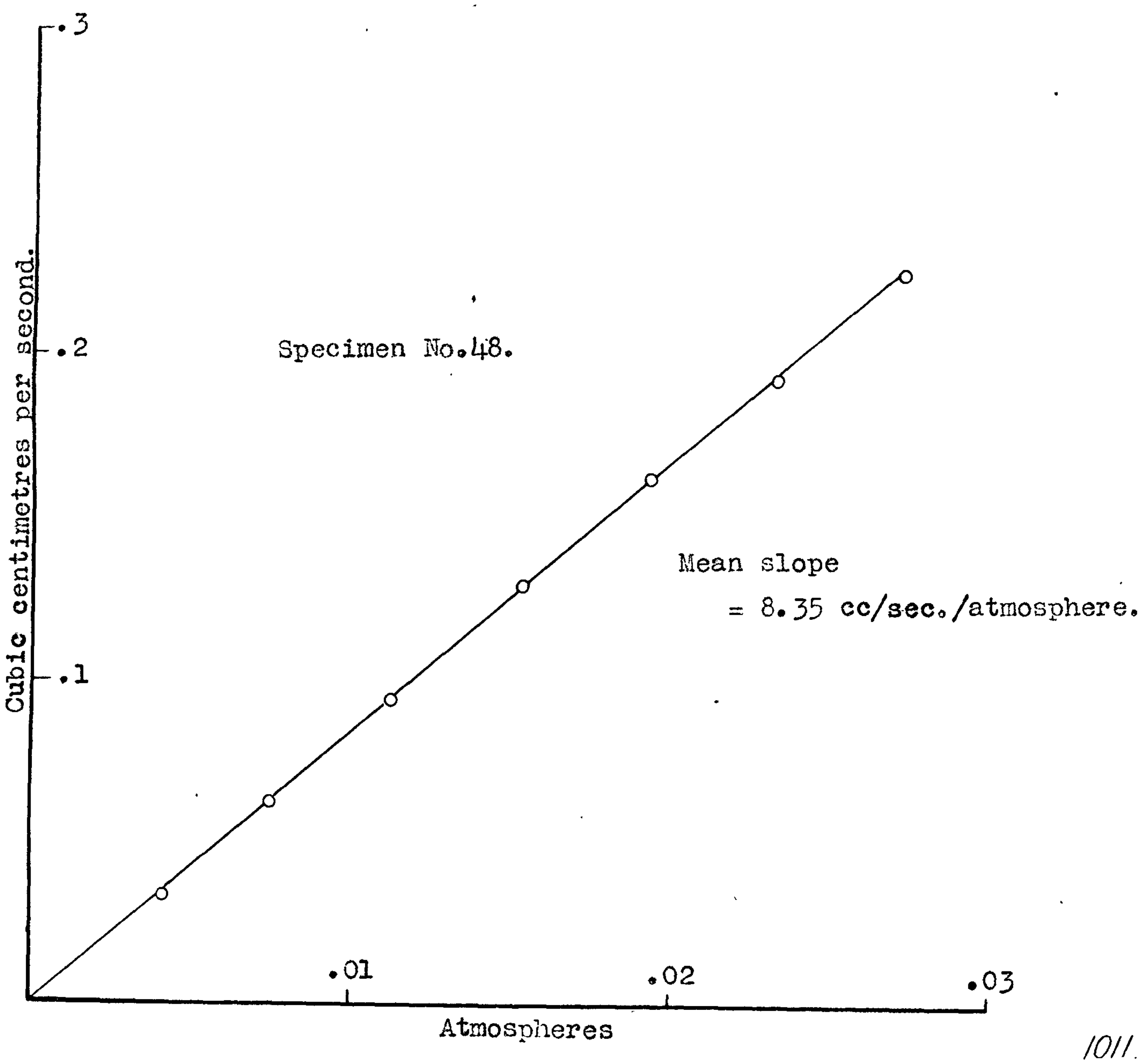
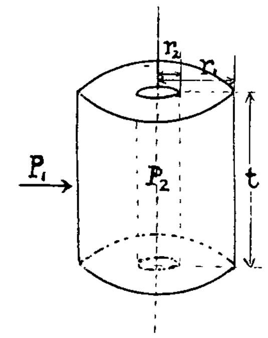


Fig. 5.

MODEL II. PERMEAMETER.

Specimen:- Glauconitic sandstone, Bore 10, Lakes Entrance, 1291.5 ft. - 1294.5 ft. No. 54.



External diameter = .99 inches ($2r_1$)
Internal diameter = .30 inches ($2r_2$)

Thickness (t) = 3.26 cms.

Air temperature = 63°F.

Air viscosity = 181 x 10^{-4} centipoise.

$P_1 - P_2$ Atmospheres	Q cc/sec	$\bar{Q}$ cc/sec	$\frac{\bar{Q}}{P_1-P_2}$
.0056	.060	.0595	10.6
.0107	.119	.117	10.9
.0160	.173	.171	10.7
.0205	.230	.226	11.0
.0252	.281	.276	10.9
.0302	.342	.335	11.1
.0353	.405	.395	11.2

$$K = \frac{N \log_e \frac{r_1}{r_2}}{2\pi t} \times \frac{\bar{Q}}{P_1-P_2} \times 10^3 \text{ millidarcies}$$

$$= \frac{1.81 \times 1.19 \times 11.15 \times 10}{6.28 \times 3.26} \text{ millidarcies}$$

$$= 11.65 \text{ millidarcies}$$

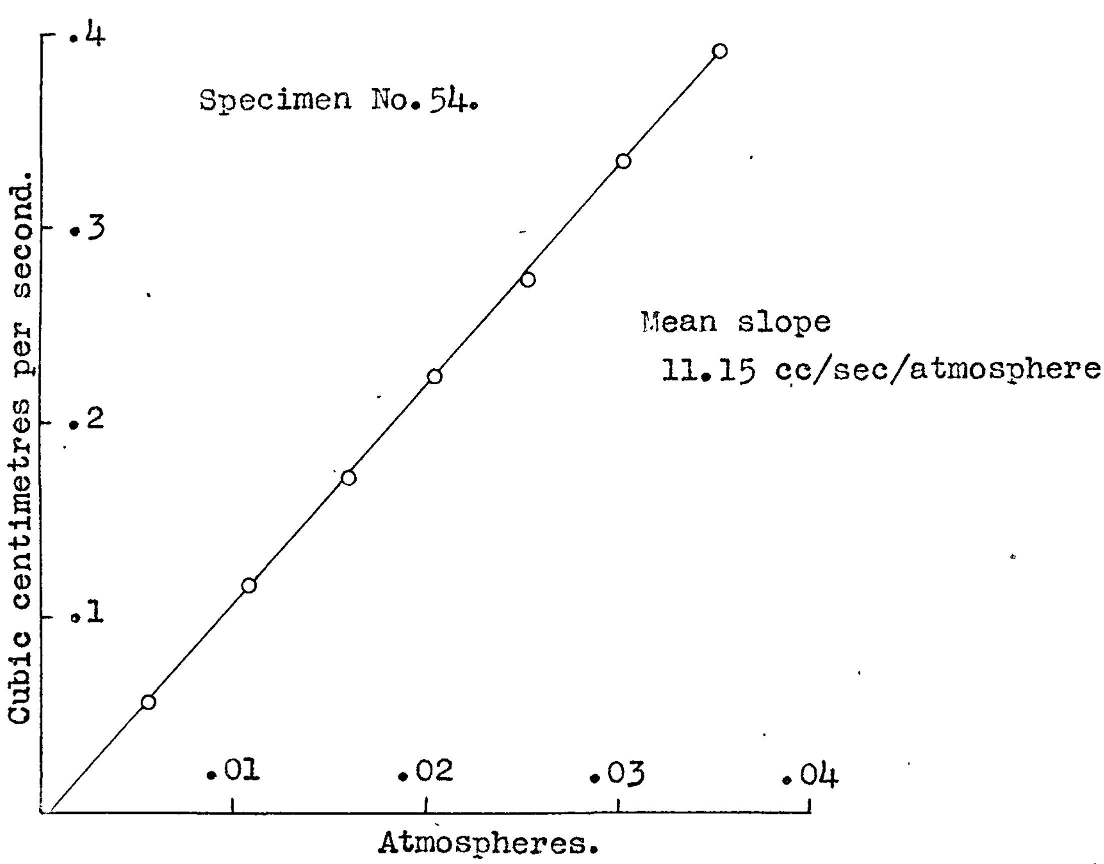
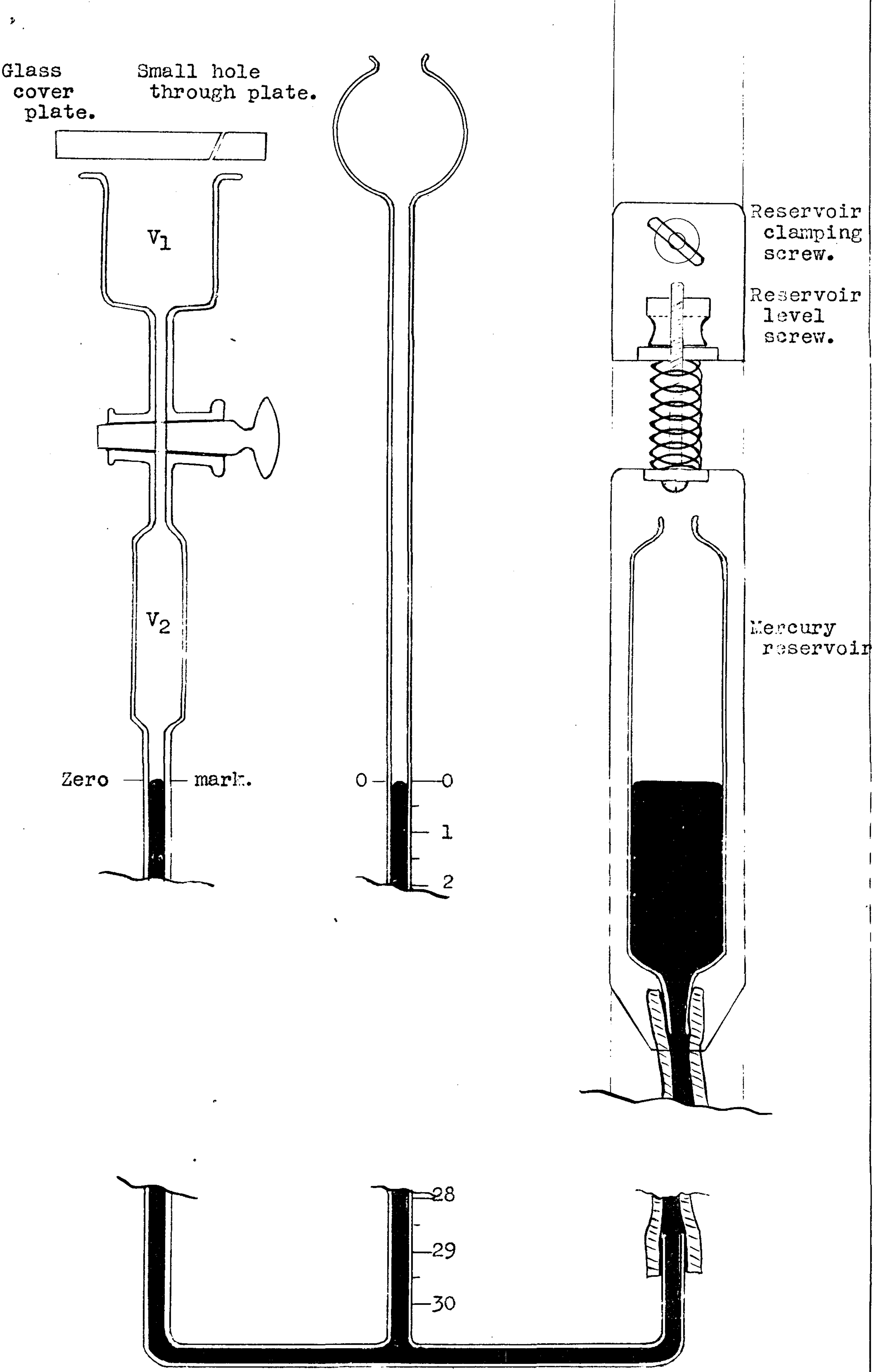


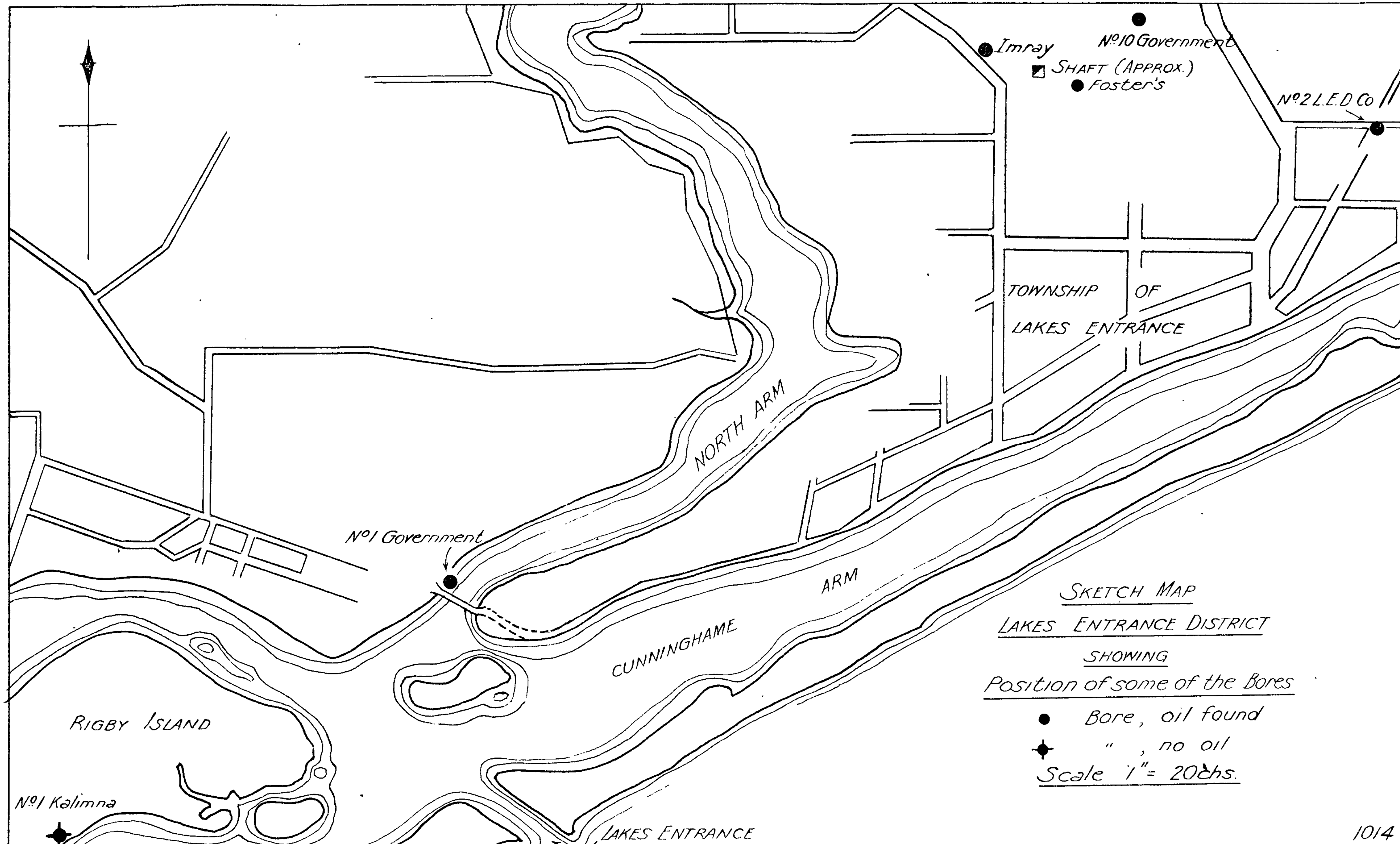
Fig. 6.

POROSIMETER



1013

FIG 7



No 10 Government
Imray
SHAFT (APPROX.)
Foster's
No 2 L.E.D Co
TOWNSHIP OF
LAKES ENTRANCE
NORTH ARM
No 1 Government
ARM
CUNNINGHAME
RIGBY ISLAND
No 1 Kalimna
LAKES ENTRANCE
SKETCH MAP
LAKES ENTRANCE DISTRICT
SHOWING
Position of some of the Bores
Bore, oil found
" , no oil
Scale 1" = 20 chs.
1014

PHYSICAL PROPERTIES OF GLAUCONITIC SANDSTONES, BORE 10, LAKES ENTRANCE, VICTORIA.

Description of Section No. 10 Bore (after H.G.Raggatt & J.W.Binney)			Position of Test Sample in Section	Sample Number	Permeability in millidarcies			Porosity Percent Voids			Density Gm/cc	Compressive Strength lbs/square inch
Depth	Thickness	Description			Observed		Average	Observed	Calculated	Average Observed		
			1257' to 1259		Specimen too soft to prepare for tests.							
1255' to 1257'	2'0"	Fine-grained. No oil.	1259' to 1261'	1 2	0.17 0.078	P P	.12					2860 Dry 1090 Wet
1257' to 1261'3"	4'3"	Medium-grained. Oil streaks throughout especially in lower 2 feet.	1261' to 1263'	3 4	1.33 1.08	P P	1.2					2420 Dry 1060 Wet
			1264' to 1265'	5 6 7 8	x 0.01 0.103 x 0.05 x 0.015	C P P P	.045	38.9 41.0 35.5 39.0		38.6		2680 Dry 2400 Dry 1240 Wet
1261'3" to 1264'	2'9"	Hard, Shelly. Slight oil showing.										
1264' to 1267'	3'0"	Hard, Shelly, Some thin soft bands with a little oil.	1265' to 1267'	9 10	0.20 0.52	P P	0.36					2980 Dry 1295 Wet
1267' to 1268'7"	1'7"	Several shelly bands, Oil streaks a few inches from top of core.	1268'		Specimen very shelly - unsuitable for tests.							
1268'7" 1272'1"	3'6"	Hard, Shelly with two soft bands near bottom, Dry	1268' to 1270'	11	0.154	P	0.15					1350 Wet
			1270' to 1272'	12 13 14	0.072 0.053 0.93	P P P	0.38					1450 Wet
1272'1" to 1273'7"	1'6"	Fairly Hard, Dry										
1273'7" to 1275'1"	1'6"	Slightly softer than previous 18", Dry	1272' to 1273'	15 16 17	11.8 38.3 1.39	P P P	17.2					1850 Dry 1010 Wet
			1273' to 1275'	18 19 20 21	x .08 x .2 x .03 x .07	P P P C	.13	32 37 37 39		36.2		1020 Wet
1275'1" to 1277'11"	2'10"	Very hard with two thin soft bands, Dry	1275' to 1276'		Specimen very hard - found impossible to shape test samples							
			1277' to 1278'	22 23 24 25 26 27 28	.48 1.31 2.04 2.40 .71 5.86 .41	C C P P N N N	1.86	43.5 42.2 33.7	34 34 34	39.7	1.72 1.73 1.715	1580 Wet
1277'11" to 1280'11"	3'0"	Alternating hard and soft bands. Oil showings in latter.	1278' to 1280'	29 30	7.12 4.25	P P	5.69					2960 Dry
1280'11" to 1283'11"	3'0"	Hard mainly, Three 1" soft bands, Dry	1280' to 1282'	31	0.096	P	0.096					
			1282' to 1284'	32 33	0.093 0.059	P P	0.076					1850 Wet
1285'11" to 1285'5"	1'6"	Hard, Shelly, Dry	1285'	34 35	.73 .99	N N	.86					
1285'5" to 1287'5"	2'0"	Top 1' soft, bottom hard			No samples available							
1287'5" to 1291'6"	8" 1'5" 1'0" 1'0"	Soft, Oily, loose fine, even grains highly polished and well rounded. Soft, slightly oily, fairly firm, oily at base.										
1291'6" to 1294'6"	3'0"	Friable, dark greenish-grey sandstone. No reaction with petroleum ether. (Core recovered 1'10")	1291' to 1294' (Sample from Victorian Mines Dept.)	36 37 38 39 40 41 42	19.7 32.5 26.8 6.4 83.3 119 135	P P C N N P P	60.4	37 35 38	31 32.4 36	36.7	1.82 1.77 1.67	700 Wet

Description of Section No. 10 Bore (after H.G.Raggatt & J.W.Binney) Depth	Thickness	Description	Position of Test Sample in section	Sample Number	Permeability in millidarcies Observed		Average	Porosity Percent Voids Observed	Calculated	Average Observed	Density Gm/cc.	Compressive Strength lbs/square inch
1291'6" to 1294'6"	3'0"	Friable, dark greenish-grey sandstone. No reaction with petroleum ether. (Core recovered 1'10")	1291'6" to 1294'6" (Sample from M.R.S. collection)	43	23.2	P		29.1 (43–44)				
				44	33.6	P						
				45	25.7	P		32.3				
				46	27.5	P						
				47	24.9	P						
				48	26.7	P						
				49	47.2	P	31.5					
				50	82.0	P		35 (50–51)		35.6		
				51	12.1	P						
				52	45.7	N						
				53	4.8	N						
				54	11.9	P						
				55	16.3	P		39.6				
				56	60.9	C		42.0				
1294'6" to 1300'0"	5'6"	Light grey, fine, even grained sand-stone with some coarser grained hard bands. Fossils at top. Very slight reaction to petroleum ether (Core recovered 5'6").	1294' to 1300'	57	55.5	P		38.39	31		1.81	
				58	40.5	P		41.2	33		1.75	730 Wet
				59	56	N						
				60	34	N	45.1			37.5		
				61	64	N						
				62	39.5	C		31.8	28		1.89	
				63	26	P						

<u>MEAN VALUES.</u>

	Permeability	Porosity	Density	Compressive Strength
1255' to 1291'6"	2.16	38.2	1.72	2590 Dry 1294 Wet
1291'6" to 1300'	45.7	36.6	1.78	715 Wet

x Permeability values marked thus are approximate.