AN INVESTIGATION OF
THE MOVEMENT OF WATER AND PETROLEUM THROUGH ROCK
UNDER HIGH PRESSURE

by

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INTRODUCTION

When working upon the problems of underground water supply, ore deposits, and petroleum accumulations, the lack of definite information regarding the laws which govern the movement of liquids through the rocks making up the earth's crust is a great stumbling block to investigation. In the fall of 1916 the writer undertook to study the laws which govern the movement of water and petroleum through rocks with conditions of pressure as nearly as possible like those deep in the earth.

Because of the limited time available and the difficult mechanical obstacles which had to be overcome, an exhaustive investigation was not possible, but the work has established several points which will be of interest.

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Apparatus.

The apparatus which was used in this work is illustrated by Plate I. (A) is a pump designed to operate at pressures up to 3,000 pounds per square inch. The pump was arranged to operate by hand or by the electric motor (B). The motor-starting switch (C) was connected to the pump lever by a cord, which when the lever reached the lowest point of its stroke the switch opened and allowed the weight (D) to force the lever down. By changing the length of the cord the stroke of the pump could be correspondingly changed.

Apparatus.

- A. High Pressure Pump.
- B. Operating Motor.
- C. Operating Switch.
- D. Lever Weight.
- E. Tube for Unconsolidated Material.
- F. Test Piece in Clamp.
- G. Header Tube.

By moving the weight (D) along the pump lever any pressure desired could be maintained. The liquid in use was contained in the base of the pump.

The method of handling the different classes of material tested is also shown by Plate I. When indurated, i. e., solid rock was used the clamp (F) was fitted to the cube of rock as illustrated. For the tests on shale or sand or mixtures of the two the tube (E) was ~~made use of~~ ^{used}. The small upright pipe (G) was placed in the pump discharge line to act as an air chamber or header and equalize the pressure.

Procedure.

Indurated rock was obtained in cubes 6 by 6 by 6 inches. A hole was drilled into the rock and carefully cleaned of all cuttings or dust. The clamp (F) was then fixed on the cube, so that a steel disc, into which the discharge pipe of the pump screwed, was held very firmly against the rock. Lead gaskets were used between the disc and the rock.

In testing sand or shale the material was placed in the tube (E). A little cotton waste was put in the end of the pipe which was connected to the pump to hold the material in place. The discharge end cap was pierced by many small holes and filled with cotton waste.

DETAILS OF THE EXPERIMENTS

Series I.

The rock used in this series of tests was furnished by the Carthage Marble and White Lime Company, Carthage, Mo., and the Phenix Marble Company, Kansas City, Mo.

Both sets of samples were very dense, crystalline limestone and contained small stylolites, sometimes called "suture joints" or "crows feet" by the quarrymen. (See Plates II and III.) Buckley¹ reports the porosity of the Carthage limestone as 1.34 per cent and that of the Phenix stone as 1.94 per cent.

The Carthage cubes were tested first. Before attaching the rock to the pump the gauge was tested and the pump discharge calibrated for different strokes.

Cube 1 was then fixed in the clamp and a pressure of 1,500 pounds per square inch applied. After twelve minutes a small bead of water appeared on the surface of the rock along the point marked (X), Plate III. Although the pressure was maintained between 1,500 and 2,000 pounds during one hour, only a few drops of water escaped from the cube. At the end of one hour the pressure was gradually increased until the cube split. This took place at a pressure of 2,800 pounds per square inch.

¹Buckley, E. R., Mo. Bureau of Geology and Mines, Vol. II, 2d series, Table VI.

PLATE II

Phenix Limestone.
Showing stylolites

Cube No. 2 was submitted to a pressure of 1,500 pounds per square inch for six and one-half hours. At the end of this time there had been introduced into the rock 5 cubic centimeters of water, through a surface of 2.966 square inches. This is equivalent to 0.013 gallons per square inch. When the pressure was raised in an attempt to test the flow at higher pressures the rock broke. This failure took place at 1,800 pounds pressure per square inch.

Cube No. 3 gave essentially the same results, showing movement of water by capillarity only.

Series II.

The material tested in this series was the limestone furnished by the Phenix Stone and Lime Company from Phenix, Mo. The stone is similar in all respects to the material tested in Series I. (See Plates II and III.) Buckley² gives its porosity as 1.94 per cent.

An attempt was made to study the effect of pressures above 1,500 pounds per square inch, but in every case the rock burst before quantitative results were obtained.

The failure of the rock under pressures as high as 2,300 pounds per square inch resulted in the formation of

²Buckley, E. R., Mo. Bureau of Geology and Mines, Vol. II,

2d series, Table VI.

Carthage Limestone Showing Stylolite.

Water Penetrated at (X)

minute cracks, and the water escaped from the cracks in the form of a fine mist. At no time was it noted that an increase of pressure increased the flow of the water a measurable amount. This does not mean that such an increase did not take place, but if so it was too small to be measured. The amount of water forced into the rock at 1,500 pounds pressure per square inch was but little if any greater than normal capillary action would absorb.

Owing to the extreme resistance of this class of rocks, i. e., dense crystalline limestone, to penetration by water no attempt was made to use petroleum in the tests. Although the drill cut several of the stylolite joints, the one mentioned under Series I was the only case of leakage at any pressure. In no case did the rock burst along the stylolite.

Series III.

The rock tested in Series III was a limestone from Lamb Brothers quarry, St. Louis County, Mo. It was selected because it contains enough petroleum to discolor the rock and give it a distinct petroliferous odor when freshly broken. The rock is rather porous, and in places the pores or small vugs are filled with viscous petroleum. Unfortunately the test piece was from the less porous phase of the rock. One face of the test cube consisted of a shaly zone 0.5 inch thick. (See Plate IV, D.)

PLATE IV

Petroliferous St. Louis Limestone.

At a pressure of 250 pounds per square inch water came out in the form of small beads on the surface of the rock, especially along several minute cracks which were not visible until the water was forced in. When the pressure was raised to 500 pounds per square inch, the rock burst. A second hole was drilled in the rock and although the rock failed a second time at 500 pounds pressure per square inch the following observations were made before the accident took place.

Water was found to be following a curved route through the rock. It was forced in at hole (A) (See Plate IV) but first appeared at the point (B). The rock face between the points of entrance and exit remained free of water. The hole (C) was not drilled until after this test. From the facts observed it seems that the water must have taken a route shown by the dotted line. (See Plate IV)

At the time of failure of the test piece no petroleum had been removed from the rock by the water, nor had water penetrated the shaly zone mentioned in the description of the rock. Unfortunately an analysis of the rock is not available and the petroleum content is not known.

Series IV.

A sandstone from Nevada, Mo., was tested in Series IV. The grains of the sandstone were angular, medium in size, and poorly cemented with limonite. The cementing.

material was not uniformly distributed throughout the rock. Across one corner there was a zone $1/4$ to $1/2$ inch wide which, owing to the large amount of cementing material present, was not permeable to water or petroleum (See Plate VI).

At a pressure of 500 pounds per square inch the flow of water through this sandstone was found to be 703.2 gallons per square foot per hour. At 700 pounds pressure per square inch the flow was 869.7 gallons per square foot per hour. This is a flow increase of 84 per cent for 100 per cent increase of pressure. Schultz³ in working with confined sand found that an increase of 100 per cent in the applied head of water gave a flow increase of 70 per cent. He reports that in a deep well at Madison, Wis., a pressure increase of 100 per cent gave only 63 per cent increase of flow. The difference in flow is perhaps due to the direction of movement with respect to the hole. In the work of Schultz the water moved to the hole from the rock, thus causing the water to flow in a constantly decreasing number of channels, with a corresponding increase in friction, while in the present work the movement was from the hole into the rock, thus allowing the water a constantly increasing area of flow.

Using 84 per cent as an index of the ratio of flow increase to pressure increase we can figure the flow at 1,500

³Schultz, A. R., Some Observations on the Movements of Underground Water in Confined Basins, Jour. Geol., Vol. 15, 1907.

pounds pressure per square inch, a pressure too great for the sandstone to withstand without support.

The resulting flow would be 1,181 gallons per square foot per hour. This is a permeability 14,492 times as great as that of the limestone used in Series I and II, while the porosity of the sandstone is only 14.4 times as great.

After determining the flow of water in the sandstone, petroleum from the mid-continent field, of specific gravity .848, was introduced into the rock. The rate of flow was found to be 12.7 gallons per square foot per hour when a pressure of 500 pounds per square inch was applied. These figures indicate that this petroleum is 56 times more resistant than water to movement in this rock at a pressure of 500 pounds per square inch.

In addition to the above data the following interesting facts were noted during this experiment. The water came to the surface first along the bottom and lower part of the sides of the cube. It was only after a pressure of 500 pounds had been maintained for sometime that the sandstone became saturated in the upper portion. As this result was also noted in the case of the other sandstones tested it is probable that gravity by directing the water into the lower pores can influence the direction of flow of liquids, even when they are being forced through the rock under high pressures.

Nevada Sandstone.

Illustrating differential removal of petroleum by water.

(See text)

When the sandstone was thoroughly saturated with petroleum, water was forced into the rock. The rate of flow was very slow at first, corresponding to that of the petroleum for the same pressure, but after the water had reached the surface of the stone in a few places the rate increased to almost that attained before the rock was saturated with petroleum. This increase took place in a short time after the water was started into the rock. In other words, the water after clearing enough channels of oil to allow it to reach the surface did not force out more petroleum. By increasing the pressure more petroleum was forced out, but unless the pressure was increased the petroleum yield soon ceased. No attempt was made in this test to get quantitative results.

Series V.

Three cubes of sandstone from Warrensburg, Mo., with a porosity of 16.77 per cent⁴ were used in these tests. A series of trials was made using water in the pump in order to find the permeability of the rock when compared with that from Nevada. The results are given in table I.

It will be noticed that although the porosity of the Nevada sandstone is only 1.28 times as great as that of the Warrensburg sandstone the permeability is 54.3 times as great.

⁴Buckley, E. R., Mo. Bureau of Geology and Mines, Vol. II.

Table I.

Novada Sandstone		Warrensburg Sandstone	
P	F	P	F
		250	8.44
		375	10.03
500	703.2	500	12.95
700	869.7	800	22.02

P = Pressure in pounds per square inch.

F = Flow of water in gallons per square foot per hour.

In an attempt to saturate this rock with petroleum it was allowed to absorb oil for 36 hours, and at the end of this period oil was forced into it by means of the pump. A pressure of 800 pounds per square inch was maintained for 4.5 hours, when the failure of the rock made it necessary to abandon the experiment. The resulting penetration is well shown by Plate VIII.

Plate VII (b) illustrates the penetration by absorption for 72 hours. The piece is one-half of a 6-inch cube. The lineal rate of absorption was about one inch per 24 hours, and under a pressure of 800 pounds per square inch the lineal movement was .75 inch per hour.

Series VI.

Having found it impossible in the time available to saturate another cube of the Warrensburg sandstone, a

Nevada Sandstone Showing Differential Absorption

(See Text)

Petroleum Penetration Tests.

A. Carthage limestone, 60 day immersion.

B. Warrensburg sandstone, 2 day immersion.

piece of the Nevada sandstone was tested. The cube was dried by heating to 250 degrees Centigrade for several hours, and then weighed. Petroleum was then forced into it until all surface pores were saturated. The excess oil was blotted from the rock and it was re-weighed and found to contain 340 cubic centimeters of petroleum. This is 89.6 per cent of complete saturation. The resistance of the thin zone shown in Plate VI accounts in part for saturation not having been reached.

A test was made to find the yield of petroleum by forcing in water, and the amount recovered for each 1,000 cubic centimeters of water forced through the rock is given in table II.

Table II, Showing Yield of Petroleum from Nevada Sandstone.

1,000 cubic centimeter charges of water	Cubic centimeters of oil
1st	88
2d	19
3d	11
4th	9
5th	5
6th	2
7th	2
<u>8th</u>	<u>1</u>
Total 8,000	137

The total yield was 47.58 per cent of the petroleum in the rock, but by prolonged use of the water the yield

Warrensburg Sandstone.

Inner zone represents penetration of petroleum at 800 pounds per square inch during 4.5 hours.

Outer zone represents penetration of petroleum by immersion for 36 hours.

could possibly have been increased to 48 or 49 per cent. One significant feature brought out in this test was the difference in the completeness of removal of petroleum from this rock and the piece used in Series IV. It will be recalled that the petroleum was forced into the rock used in that test while the pores were saturated with water, whereas in this test the rock was first dried thoroughly before the petroleum was injected. The contrast is brought out in Plate V. Piece (A) was used in Series I and piece (B) in the test just described. The wet surface of the grains in (A) prevented the petroleum from adhering to the grains and thus resisting removal, while the petroleum in (B) because of its adhesion to the sand grains was able to resist removal by the water.

Series VII.

In these experiments a coarse sand with well rounded grains was used in the tube (E) shown on Plate I. It is a standard sand used at this University in preparing cement tests, and its most remarkable feature is the uniform size of the grains. Sarinsky⁵ reports its porosity as 35.4 per cent when rammed, i. e., when compacted by jarring in the container.

The tube (E) was stoppered at the end to which the pump is attached, by a small wad of cotton waste, and sand was then introduced and compacted by jarring the pipe. When

⁵Sarinsky, Isador, An Investigation of Fine Aggregates. Unpublished thesis, University of Mo. Engineering Department.

no more sand would enter, the perforated iron cap filled with cotton waste was screwed in place. The pipe was then attached to the pump and although the pump was operated at full capacity no pressure was registered, due to the great permeability of the sand. After water had been run through the sand for sometime, petroleum was introduced and the pressure rose at once to 165 pounds per square inch and remained at this point as long as the petroleum was forced in. The rate of flow was the same in the case of petroleum as of water, so that the pressure gives the relative resistance of the two liquids to movement through coarse, round sand of uniform grain.

To test the yield of petroleum from this type of material, 200 cubic centimeters were introduced into the tube after it had been filled with rammed sand. Water was then forced in and from time to time the discharge from the tube was measured. The amount of water and oil present in each successive portion measured is shown in table III below. These portions were taken in order to show the relative decrease in the yield of petroleum for a given amount of water forced through the sand when compared with the same amount previously discharged. At (a) in table III it will be noted that an increase of pressure and the corresponding increase of flow caused a material increase in the petroleum yield per unit of water discharged.

Table III.

Test No.	Cubic centimeters of water	Cubic centimeters of petroleum
1	809	109
2	891	20
3	976	17
4	952	8
5	1,053	7
6	1,080	10
7	890	4
8	870	2
9	(a) <u>918</u>	<u>5</u>
	8,447	182

(a) Rate of flow of water increased 4.5 times. Note
increase in the yield of petroleum.

The total yield of petroleum was 91.1 per cent of the amount present in the sand.

The tube was again charged with the same sand, but this time 200 cubic centimeters of petroleum were mixed with the sand before it was placed in the tube. The results are given in table IV.

A comparison of tables III and IV shows a striking difference in the yield of petroleum which was mixed with the sand before it was placed in the tube and that which was introduced after the sand was in place. The yield in the first case was 71 per cent and in the second 91 per cent. Although extra efforts were used to increase the yield in the

test where the sand was mixed with the oil, the yield was 20 per cent less. It is the opinion of the writer that this difference was caused by the petroleum being trapped between the grains, in voids which were inaccessible to the inflowing water. When sand is allowed to absorb petroleum after being placed in a tube only those voids are filled which communicate with the ends of the tube, and therefore the water can force out most of the petroleum.

Table IV.

Test No.		Cubic centimeters of water	Cubic centimeters of petroleum
1		850	98
2		874	11
3		840	6
4	(a)	808	10
5		875	1
6	(b)	953	8
7		976	8
8	(c)	<u>1,000</u>	<u>0</u>
		6,276	142

(a) Rate of flow increases X 4.5.

(b) Tube was jarred by striking it with a hammer to agitate the sand.

(c) Rate of flow decreases X 4.5.

The total yield of petroleum was 71 per cent.

Series VIII.

Unwashed Hinkson Creek sand was used in this series. The porosity of the rammed sand as given by Sarinsky⁶ is 36.89 per cent. Two tests were run on this sand; test A (represented by table V), in which the sand was placed in the tube and rammed before petroleum was admitted, and test B (represented by table VI), in which petroleum was mixed with the sand before being placed in the tube. The petroleum contained by the sand in test B was 9.1 per cent more than that contained in test A. The yield in test B was 11.3 per cent more than that in test A.

Table V.

Test No.	Cubic centimeters of water	Cubic centimeters of petroleum recovered
1	790	130
2	803	10
3	855	6
4	875	2
5	<u>924</u>	<u>1</u>
Total	4,247	149

Per cent yield, 56.5.

⁶Sarinsky, Isador, An Investigation of Fine Aggregates. Unpublished thesis, University of Mo. Engineering Department.

Table VI.

Test No.	Cubic centimeters of water	Cubic centimeters of petroleum recovered
1	860	170
2	913	7
3	752	5
4	840	2
5	<u>820</u>	<u>1</u>
Total	4,185	185

Per cent yield, 64.4

Series IX.

A silt with grains smaller than 0.01 inch, i. e., a very fine grained aggregate obtained by sifting Hinkson Creek sand and using only that part which passed a sieve with 100 meshes to the inch, was used in this test.

Tube (E) filled with this silt absorbed 285 cubic centimeters of petroleum. The yield obtained is given in table VII.

Table VII.

Test No.	Cubic centimeters of water used	Cubic centimeters of petroleum recovered
1	674	138
2	713	25
3	770	5
4	803	4
5	<u>762</u>	<u>2</u>
Total	3,722	174

The per cent of recovery was 60.6.

Table VIII is a comparison of the pressures, given in pounds per square inch, required to force the same amount of oil or water through the various sands examined.

Table VIII.

	<u>Ottawa sand</u>	<u>Hinkson Creek sand</u>	<u>100-mesh silt</u>
Water	5 - 10 ?	250	1,500
Petroleum	165	750	2,500

Series X.

In Series X two tests, called A and B, were made on composite material.

Test A was made with the tube filled as follows:
18 inches of 50-mesh sand.

6 inches of 100-mesh silt with 65 cubic centimeters of petroleum.

6 inches of 50-mesh sand.

16 inches of powdered limestone with 250 cubic centimeters of petroleum.

The yield of petroleum obtained by forcing water through this composite material for each successive portion measured is given in table IX.

Table IX.

Test No.	Cubic centimeters of water used	Cubic centimeters of petroleum recovered
1	225	25
2	218	32
3	68	26
4	288	12
5	110	8
6	232	18
7	44	4
8	398	20
9	<u>276</u>	<u>22</u>
Total	1,859	167

Per cent yield, 55.9. Note irregularity.

When the pump was started in test A the pressure was 500 pounds per square inch, but at the end of the experiment it was necessary to use a pressure of 2,500 pounds per square inch to obtain a flow of liquid. The per cent yield in test A, Series X, was 55.9. The yield in this experiment, although lower than the results obtained in series VIII and IX, would have been still lower had the material not been supersaturated with petroleum. Upon removing the contents of the tube after the experiment the ground limestone was found to have occluded a large amount of petroleum; globules visible to the eye were still disseminated through the mass.

Test B, Series X, was carried out as follows:

A quantity of shale was ground in a ball mill until powdered, and the fine material was then allowed to absorb 125 cubic centimeters of petroleum. The mixture was then placed in the testing tube with 15 inches of 100-mesh silt between the powdered shale and the intake end of the tube, and the remainder of the tube was filled with 100-mesh silt.

Water was forced against this charge at 3,000 pounds pressure for six hours without result; that is to say, 3,000 pounds pressure did not cause a movement of water or petroleum through the material in the tube.

SUMMARY

The following points have been demonstrated by the experiments described above:

- (1) The movement of water through dense crystalline limestone is not increased by increasing the pressure upon the water (Series I, II).
- (2) The movement of water in rocks with minute pores is due entirely to capillary action (I, II).
- (3) The porosity of a rock is not an index of its permeability (Series IV, V).
- (4) Water will remove from a porous rock only sufficient petroleum to produce a channel through which the water may flow (Series IV, V).
- (5) A fine grained sandstone offers much more resistance to the movement of petroleum than a coarse grained sandstone (Series IV, V).
- (6) It is the adhesion of petroleum to the grains of a sandstone which prevents its removal by water and is inversely proportional to the size of the grains (Series VII, VIII).
- (7) The manner in which petroleum gains access to a rock has much to do with its subsequent displacement by water (Series IV, VI).
- (8) Petroleum which has gained access to a rock through pore channels is readily forced out by ground water (Series IV).
- (9) Petroleum which is contained in disconnected pores of the rock will not be removed by ground water (Series IV).

Practical Application.

The work outlined in this paper was undertaken with the hope that it would lead eventually to results which would throw light on some of the problems which must be met in developing petroleum deposits or underground resources.

Although the investigation is but well started, the writer feels that the bearing of some of the points brought out by the tests should be pointed out.

Development of Underground Water.

The ideal ground water supply for industrial and domestic use should have the following qualities:

- (1) Adequate supply.
- (2) Free from organic matter and bacteria.
- (3) The amount of material in solution, such as lime, iron, etc., should be low; that is to say, it should be soft.

The ideal place for the accumulation of such a water supply is a bed of coarse sandstone. As shown by the tests of series I, II, and III, limestone is only in special cases permeable to water. If water is found in a limestone one is almost certain that the drill has penetrated a joint crack or a solution cavity in the limestone. The water from such a source would in most cases fail to meet at least two of the conditions mentioned above. It should be suspected of carrying injurious bacteria, and would often be high in lime salts.

By consulting the University the probability of finding a water-bearing sandstone under a given locality can be learned.

When the drill has penetrated a water-bearing sandstone it is best to continue the well almost through the stratum of sandstone, for as indicated by the experiments in Series IV the water will occupy the lower part of the rock to which it is confined unless the whole stratum is completely saturated.

When two or more sandstones are available the one having the largest grains would yield the greater flow, provided other conditions were equal.

Development of Petroleum Deposits.

A porous formation is essential for the accumulation of a petroleum deposit. Rocks with a porosity of less than 5 per cent are not known to yield petroleum in commercial quantities. The following list of rocks is arranged according to the probability of petroleum deposits occurring in them. The first named rock is most often found to be the source of large deposits, while the last has very rarely been found to yield oil in paying quantities.

<u>Rock name</u>	<u>Structure</u>	<u>Texture of rock</u>
1. Sandstone	beds	coarse to fine grained
2. Sandstone	lenses	coarse to fine grained
3. Limestone	beds	cavernous
4. Shale	beds	fissured

The experiments described in Series VI illustrate the movement of a liquid through a porous limestone. Although this class of rock may become very cavernous, due to the solvent action of water, and has been known to have a high porosity, the openings or voids in the rock may not be connected by direct channels. This means a low permeability, and should a drill penetrate such a rock the flow of oil would not be large. However, by shooting the well, cracks would be formed which would probably intersect many of the channels and thus allow a large amount of oil to reach the well.

The sandstone used in Series VI represents the most common form of oil-bearing rock. It will be noted that the amount of oil obtained from this rock was 47.5 per cent of the oil present. This yield was obtained under ideal laboratory conditions and it is probable that 40 per cent is about the average yield under field conditions.

In other words, in an oil sand with a porosity of 30 per cent and a good degree of permeability the yield per acre under pumping conditions would be 5,215 barrels per foot of sand.

The above figures are based on a medium grained, poorly cemented sandstone. When the sand grains are large and well rounded a greater yield can be expected (See Series VII). On the other hand, a fine grained sand or silt, though it may contain more oil than a coarse grained sand, may not yield enough to pay for the well. This phenomenon

is caused by several factors. The pore space, although large when considered in the aggregate, is made up in the case of fine sand of very minute openings. This causes a tremendous frictional resistance to the movement of viscous liquids like crude oil (See Series X, Test B). In addition to this we have a much greater surface area in the case of fine grains of sand than when the grains are coarse. The oil tends to adhere to all surfaces with which it comes in contact and the greater the surface the more oil remains behind on the sand grains. If we decrease the size of the grains of a sandstone by ten, i. e., if we break each rock grain in ten parts the surface would be increased at least ten times yet the amount of sand is not increased. When the larger amount of surface present even in coarse sand is considered the influence of the size of the grains on the amount of oil adhering to them is at once apparent. Not only is the amount of oil occluded increased inversely as the size of the sand grain but the resistance to the movement of the oil in a fine sand is very great (See Series V). If the grains are very minute we have a condition, represented in Series X, Test B, where no available pressure will cause movement.

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Format	Book
Content type	Text [with images]
Source ID	010-004908906
Notes	Pages typed and single-sided. Title page has perforated property stamp. Call number written on page 1. Pages 5 and 8 have handwritten corrections. Photographs are pasted in. Inside front cover has label pasted in. Inside back cover has barcode and call number. Pocket and date due slip pasted in at end.

Derivatives - Access copy

Compression	Tiff compressed with LZW before conversion to pdf
Editing software	Adobe Photoshop CS5
Resolution	600 dpi
Color	Grayscale and color
File types	pdf
Notes	Grayscale pages cropped, canvassed, and images brightened. Color pages cropped and canvassed. Blank pages removed.