GEOPHYSICAL INVESTIGATIONS IN ILLINOIS

SUMMER 1931

A Report to the Chief of the

Illinois Geological Survey

by

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The following report comprises the results of the author's investigations of several geological problems of Illinois during the summer of the year 1931 with regard to the applicability of geophysical methods of prospecting to their solution. The problems that he was called upon to investigate were: (1) the fluorspar area of Hardin County in southern Illinois, (2) the petroleum bearing structures of the state, (3) the lead and zinc area of the northwestern corner of Illinois, and (4) the waterbearing gravels of the glacial drift with a view to obtaining more abundant water supply where needed, as well as further gravel resources.

The method of procedure was to gather from personal discussions with staff members and from published reports the more significant geological information regarding the problems to be investigated, and to supplement this, when necessary, by reconnaissance field studies. After this recommendation was made regarding the method to be used, apparatus was acquired and a month of intensive field work was spent on three of the problems stated above.

PRELIMINARY STUDIES

Fluorspar Deposits.- The preliminary study of the fluorspar deposits showed that there are two principal types of deposits--(1) the vein deposits, and (2) blanket deposits. The former occurs in sheets averaging about 4 feet thick along the steeply dipping normal faults near Rosiclare; the latter are known to occur a few miles north of Cave-in-Rock in the form of a sheet parallel to the bedding plane between the Fredonia Limestone and the Rosiclare Sandstone and to have a thickness ranging from zero to 12 or more feet. The vein deposits extend from near the surface to the greatest depths mined, about 600 feet. The blanket deposits outcrop along the sides of hills and are as deep as 100 feet below the hilltops.

The problem of locating fluorspar by any prospecting method might be attacked from either of two ways--(1) by searching for fluorspar directly, or (2) by the use of indirect methods such as looking for faults or other associated geological phenomena. Similarly, geophysical prospecting might be conducted as an effort toward finding the mineral itself or directed at the location of faults.

Any geophysical investigation would have to be based upon some distinctive and measurable physical property.

By way of physical properties, fluorspar has a density of 3.18, being somewhat more dense than the 2.7 of calcite. The specific electrical resistivity of fluorspar is high, being of the same order of magnitude as calcite and crystalline limestone. It is, moreover, for all practical purposes, non-magnetic. Thus it appears that the only method of direct investigation that might be tried would be that based upon the greater density of fluorspar, or gravitational method by means of the torsion balance. Further study, however, indicated that the deposits are so small that their gravitational effect would be barely measurable with the most sensitive instrument, and that, furthermore, the topography would exercise so great an effect that it is doubtful if the effect due to the fluorspar could ever be discerned at all.

This leaves only the alternative of indirect investigation, or the finding of faults. This might be done in two ways--(1| by means of the seismagraph, which utilizes the difference of elastic properties on the opposite sides of the fault, or (2) by electrical methods, which make use of the difference of electrical conductivity (or resistivity) in the adjacent strata on the opposite sides of the fault. Of these two methods the expected results are very nearly equal, whereas the latter apparatus is relatively inexpensive to purchase and operate while the former is so expensive and requires so large and highly trained a technical crew as to be quite prohibitive.

Thus, by a process of elimination, the location of faults by means of electrical resistivity surveys seems to be almost the only practicable method of geophysical prospecting for fluorspar in southern Illinois.

Petroleum Structures.- The prospecting for oil has been largely by the indirect method of finding suitable structures for oil accumulation. In Illinois the known oil pools occur under anticlines in the south central part of the state. There are oil pools in the LaSalle anticline in the east central side of the state. There are other pools in the smaller anticlines of the region around St. Louis. Problem: Are there other oil-bearing structures underneath the glacial drift in the basin between these two areas? This immediately becomes a problem of locating anticlines beneath a blanket cover of glacial drift.

For this purpose the magnetometer has already been tried and found wanting. The results obtained have indicated that in general the magnetic anomalies do not bear any apparent relation to known geologic structures.

The Pure Oil Company has run a torsion balance line across the state from near St. Louis to the LaSalle anticline in a slightly northeastern direction. The results of this the author was not permitted to see, but he was informed by Mr. Wasson, the chief geologist of that company, that the effect of so large a structure as the LaSalle anticline was barely discernable. This makes it appear doubtful that lesser structures would be detected at all by this method of investigation.

The seismograph for problems of this sort has given very precise results, but will be considered for our purposes as being totally unfit because of its extreme expensiveness.

It seemed quite possible that an electrical profile might disclose a buried anticline under glacial drift, so that a trial of this method was recommended before attempting anything more expensive.

The Lead and Zinc Area.- Study of this area showed that the workable lead and zinc deposits have all been found in the Galena Dolomite, which has a thickness of about 200 feet. In general, the larger galena deposits have been found above water table, or within about 100 feet of the surface, while the sphalerite with some galena has been mined from near the bottom of the formation at a depth of about 200 feet.

Galena has a density of 7.5 and is a fairly good conductor of electricity. Sphalerite has a density of 4, but has a high electrical resistivity comparable to that of calcite.

Both of these minerals may, for practical purposes, be said to be non-magnetic.

It seems, therefore, that the possible geophysical methods of prospecting are gravitational and electrical. The determining factor for either of these is the size of the deposits. If there are still lead and zinc deposits in the area of the order of magnitude of the larger ones originally mined, it ought to be possible to detect them by the torsion balance, or the galena by electrical means.

Attention was accordingly directed toward obtaining an idea of the probability of there still being such undiscovered major deposits. An inspection of the known productive area showed that almost every outcrop of Galena Dolomite in the known producive area had been prospected. There were three or four prospecting shafts at present being sunk in different parts of the area. The dumps of these usually showed small fragments of galena. One hole had yielded about a half ton of this mineral.

Conversations with Mr. C. C. Patter of the Mineral Point Zinc Company gave the information that the thousands of diamond drill holes that had been sunk into the area had rarely encountered appreciablE amounts of galena. The same company had some electrical work done over about 200 acres of land near the Black Jack Mine, southeast of Galena, by the Swedish American Prospecting Company, with nagative results.

On the basis of the above data, the conclusion is drawn that there can be very few, if any, major mineral deposits left in the area. It therefore appears doubtful that any appreciable success would be had from geophysical investigations there.

As regards the regions further south, due to the fact that there the mineral bearing strata are considerably deeper, any mineral body would have to be correspondingly larger in order to produce an equal surface effect.

Water Supply and Gravel Deposits.- The preliminary study of this problem indicated that gravel deposits were of especial importance in the state, both because of the intrinsic value of the gravel itself and because any large body of gravel buried in glacial drift is usually a source of abundant water supply. The problem of locating water in glacial drift then becomes more or less synonymous with that of finding gravel.

The sub-surface department provided the additional information that buried pre-glacial valleys were usually sources both of gravel and ample water supply.

The problem, then, became that of finding gravel deposits, either directly, or indirectly, by means of finding buried valleys. Due to the fact that the glacial drift is usually less than 200 feet thick in the state and rarely more than 300 feet in thickness, it seemed that the electrical method of investigation was peculiarly adapted to this problem. The depths concerned are within the range of such a method; there almost certainly would be a marked contrast in the electrical conductivity of at least one pair in the glacial till-gravel-bedrock combination; and the bodies sought are of such magnitude as to be readily discovered.

Hence, for all of the problems which the author was called upon to study, the most likely method of investigation within the financial means of the State Geological Survey seemed to be that of electrical conductivity studies. Such was accordingly recommended and the requisite apparatus procured.

EARTH RESISTIVITY MEASUREMENTS

The Meaning of Resistivity. In electrical circuits there is a very close analogy between the flow of electric current and that of water. In the case of a waterfall we measure the amount of work that a given quantity of water can do by the height through which it falls; in the case of electricity we measure the amount of work a given current of electricity can do by the amount of voltage through which it falls. We have, moreover, the relation that when electricity is flowing through any given conductor, the amount of current measured in amperes is directly proportional to the difference in electrical potential, or voltage, between the two ends of the conductor. Some conductors with a given difference of potential between their two ends conduct much greater amounts of current than others. The property of resisting the flow of an electric current by a conductor is known as electrical resistance.

If V is the difference of potential in volts across a conductor, and I the current that flows through it, then the resistance, R,

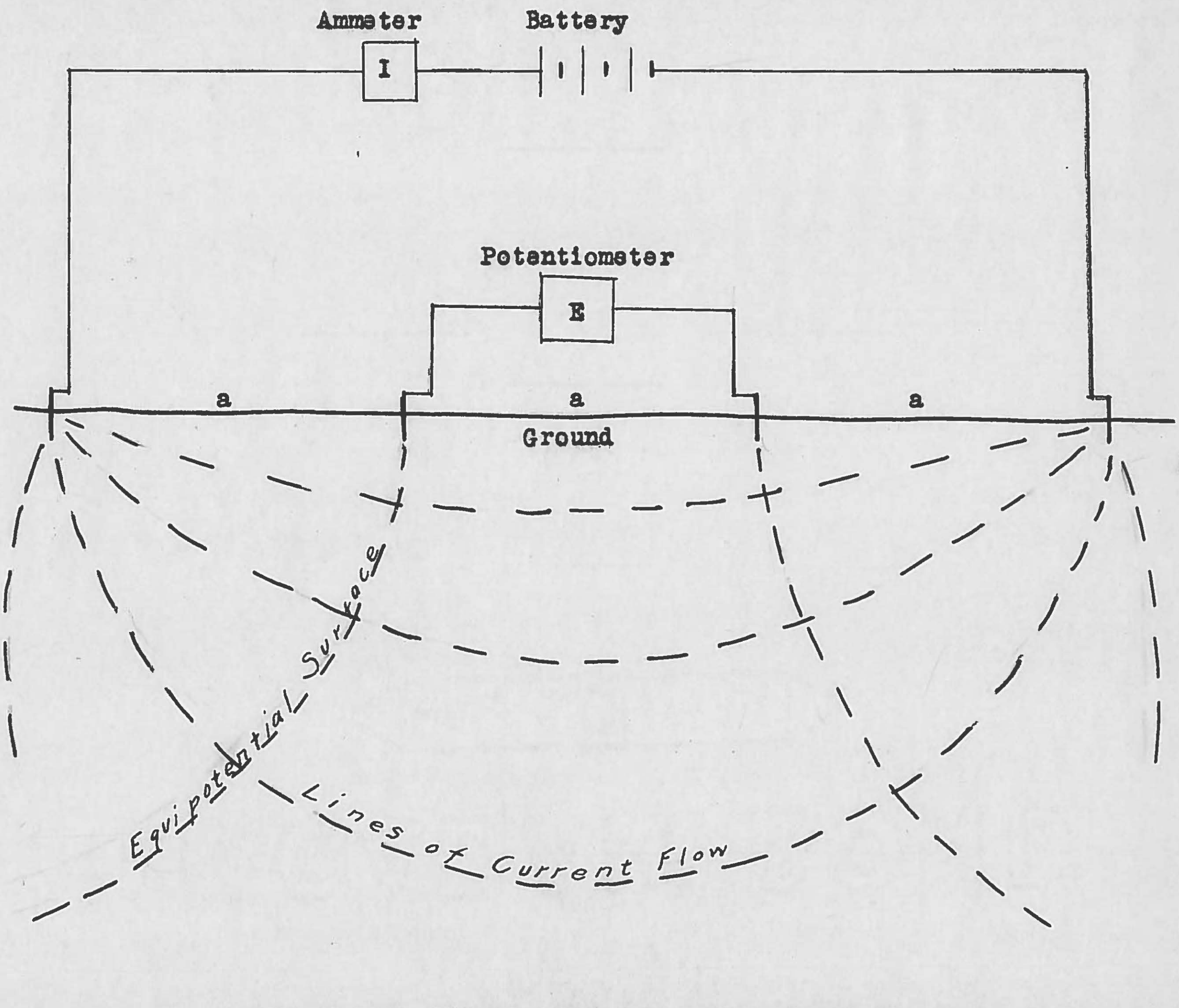

Fig. 1. Diagrammatic illustration of earth-resistivity apparatus and distribution of ground currents through a homogeneous medium.

of the conductor is

$$R = \frac{V}{I}. \tag{1}$$

The unit of resistance is the ohm; a conductor has a resistance of one ohm when it conducts a current of one ampere across a difference of potential of one volt.

<u>Specific Resistivity</u>. The resistance of any given material is directly proportional to its length in the direction of current flow, and inversely proportional to its cross-sectional area at right angles to that direction. The <u>specific resistivity</u> of a given substance is the resistance of a block of the substance having unit cross-sectional area normal to the direction of flow and unit length parallel to that direction. By nearly universal usage, specific resistavity is measured in ohms per cubic centimeter.

One of the essential problems in earth resistivity investigations is the determination of the mean specific resistivity of the earth materials <u>in situ</u> by means of observations made at the surface. An ideal case of this problem is to determine the specific resistivity of an electrically homogeneous medium having a plane surface and a semi-infinite extent. This problem is amenable of treatment and the method of measurement has been worked out by Wenner of the U.S. Bureau of Standards.

The experimental arrangement for this purpose consists of four electrodes placed all in the same straight line and all separated equally by an electrode interval, <u>a</u>. Lines are run from a battery or generator to the two outside electrodes, and a difference of potential,

V, is set up between them. Consequently, a current, I, is made to flow through the medium from one outer electrode to the other. I can be measured by means of an ammeter placed in the current circuit between the source of current and one of the outer stakes. An instrument called a potentiameter is placed in another circuit running from one of the inner electrodes to the other. This measures the potential difference, E, in volts between the two inner, or potential, electrodes.

It can be shown that the specific resistivity, ρ, of the medium is

$$\rho = 2\pi a \frac{E}{I} \tag{2}$$

In actual field investigation it is of course known that we are not dealing with a homogeneous medium, and that equation (2) is no longer rigorously correct. In this case ρ is computed exactly as if the medium were homogeneous, and then its changes from station to station are made to serve as an index or indicator of the major changes of resistivity along the profile.

There are two chief methods of investigation by this means-- (1) depth determinations, and (2) lateral or traverse profiles. In each case the point midway between the inner or potential electrodes is considered to be the location of the station occupied.

The current through the ground does not flow in a straight line from one ground electrode to the other, but instead it spreads out in broad loops in exactly the same pattern as the lines of force in the field around the two poles of a bar magnet. It has been found that changes in resistivity at depths greater than the electrode interval, a,

Fig. 2. Above: Complete field apparatus.

Below: Megger in use on Sullivan profile.

exercise relatively little effect in the value for ρ obtained, whereas for depths less than **a**, the effect of a sufficiently great change of resistivity is quite apparent. This provides a clue for the determination of the depth to a given disturbance.

Depth Determinations.- Socalled depth determinations are made by keeping the position of station fixed and increasing the electrode interval **a** by increments of 10 or 20 feet and taking a reading for each value of **a**. Then when ρ is plotted graphically as a function of **a**, the curve so obtained contains valuable information regarding the depth to any major change in resistivity.

Lateral or Traverse Profiles.- These are obtained by keeping the electrode interval **a** fixed and occupying successive stations along the line of traverse. Any degree of detail may be used. This ranges from taking successive stations only one electrode interval **a** apart up to only an occasional station--say, a half mile apart--depending upon the nature of the problem investigated.

A Longitudinal Traverse Profile.- This is a traverse profile having the line of electrodes parallel to the direction of the traverse.

A Transverse Traverse Profile.- This is a traverse profile having the line of electrodes transverse to the direction of traverse.

In all traverse profiles, the value of ρ obtained for each station is plotted as a function of the position of that station. The graph so obtained gives the mean, or apparent, specific resistivity along the line of the traverse to an effective depth of the electrode interval **a** used.

<u>The Megger</u>.- The apparatus actually used in this investigation was the "Megger" Ground Tester, which was built for testing resistance to ground in power line circuits, but which is also applicable to this type of investigation. It has the advantage of being very durably and compactly built. In place of a battery it has its own direct current generator, and a double commutator system which reverses the current in the ground at a rate of 50 cycles per second and at the same time rectifies the current from the potential leads. It has only one instrument to read--an ohmmeter which indicates the quantity $\frac{E}{I}$ directly in terms of ohms.

FIELD TESTS

Hardin County Fluorspar Area

<u>Faults</u>.- The prime consideration in the tests of this area was to determine whether known faults would be detected by earth resistivity. About two weeks was spent in the area and somewhat more than twenty profiles were run altogether. Some of the difficulty experienced was failure to locate evidence of faults shown on the geological map in the limited area inspected. Hence, in a number of the profiles, the fault was inserted according to the geological map, and not according to our own investigation.

In general, it was found that nearly every fault that could be identified in the field gave some kind of a disturbance in the profile. Some of the lesser faults on the map showing the same formation outcropping on both sides, failed to give identifiable results. Profiles across the much faulted fluorspar-bearing strip near Rosiclare showed marked irregularity, but the structure was too complex to enable any exact interpretation of the results obtained without more detailed work.

In order to obtain a generalized idea of the conductivities of the succeeding formations in the stratigraphic column of the area, a composite profile was taken over the upturned edges of the foundations away from the center of Hicks Dome.

Figure 3 is a cross-section and profile across a major fault in a road cut on the concrete highway northwest of Rosiclare. The fault itself outcrops in the road-cut, so that there is no question regarding its exact location. The profile was taken with $\underline{a} = 100$ feet, and stations 100 feet apart. The line of electrodes was parallel to the line of traverse. The curve forms a large $\underline{W}$ at the fault. It was suspected that this was due to the fault plane's being more highly conductive than the rocks on the two sides. To verify this, a transverse station was taken at the fault with the line of electrodes parallel to the fault. This gave a very low reading, as was expected.

Further verification was obtained by the experiment shown in Figure 4. Here a piece of sheet metal was immersed in a vessel of water having wooden sides and a sand bottom, as shown. A longitudinal profile with $\underline{a} = 6$ inches, and stations 6 inches apart, was taken. The result was a large $\underline{W}$ in the curve exactly like that obtained for the fault in Figure 2. The water in this case was much more resistant than the metal. It will also be noted that the flat part of the curve is lower to the right than to the left. This is due to the fact that the water is deeper to the right.

Figure 5 is a cross-section and profile taken along the same concrete road about two miles further west. There is a road cut in each of the hilltops, giving good geologic exposures. From west to east the profile runs from Fredonia Limestone across a fault, which outcrops, then to sandstone (Rosiclare?). The next road cut, about 600 feet further west, is crystalline Fredonia Limestone. From there the profile crosses a flat, where no outcrops were seen. The next hill top is sandstone, wich a much faulted and sheared zone about 100 feet in width.

In Figure 5 the solid curve is the longitudinal profile, and the broken one a transverse profile. Both curves show a faithful relation to the known geology, and indicate two more faults, which, from the topography, might be inferred but which were not actually observed. It is seen that the sandstone is a better conductor than the limestone. The shear zone to the east produced the familiar _W._ The transverse curve, it will be noted, is more square cornered and abrupt than the longitudinal one.

Hicks Dome Profile.- This (Figure 6) is a composite curve made of two separate parts plus an isolated sample or two in the middle. Time did not permit the running of the complete section.

Near the center of the dome it is significant that the hard, slate-like Chattanooga Shale was a very high resistor compared to the Devonian Limestone and Osage Chert on either side.

Farther up the section, the most significant feature is the alternation between sandstones and shaley-limestones. Over most of this it will be noted that the curve makes a peak over the sandstone and a trough when crossing the more conductive shaley-limestones. The last peak is due to the hard, crystalline Menard Limestone.

WATER SUPPLY AND GRAVEL DEPOSITS

The Taylorville Area.- The area around Taylorville, because of the trough-like shape of the bedrock (Figure 6), was selected as a suitable place to study with regard to water supply.

First, a line of depth determination at intervals of one-half mile was taken along the line of A - A'. This gave the result that the bedrock of Pennsylvania shale had a conductivity of the same order of magnitude as that of the glacial drift. This prevented successful determination of depth to bedrock. Along this line the results obtained from the various stations were very similar, except those from Station No. 9 near the town of Willeys. Here all the values were several times as large as the corresponding values for the previous stations. The depth determination at intervals of 20 feet from 0 to 300 feet indicated that this was due to a highly resistant body extending from near the surface to a depth of about 60 feet. Below that depth the material seemed to be normal glacial drift, such as was obtained in the preceding stations.

Next, a traverse profile was run from Station No. 9 westward taking $\underline{a} = 100$ feet and stations 100 feet. The results of the whole A - A' profile for $\underline{a} = 100$ feet is shown in Figure 8. It is seen that the resistant body diminishes rapidly to the westward, and has quite vanished within about a quarter of a mile.

Next, the profile B - B' was taken. All of these stations were normal except No. 11, which gave results very similar to those of No. 9, except that in No. 11 the resistant body appears to reach a depth of 140 feet.

Stations 12, 13, and 14 along the highway southwest of Willeys are all normal.

This peculiarity of two very abnormal stations out of a total of 16 stations, the rest being normal, led, naturally, to the question of the cause of the abnormalities. What material occurring locally in glacial drift could have such a markedly higher electrical resistivity than ordinary glacial till? From a knowledge of the geology of glacial drift, the most probable answer seemed to be <u>gravel</u>.

It was further noted that the two abnormal stations were both located approximately on the axis of the trough, as shown in Figure 7. Both of these stations were also on slightly higher ground than that to the west. The detailed work west of Station No. 9, and the fact that Nos. 12, 13 and 14 were normal, showed the deposit to be bounded rather sharply to the northwest. No detailed work was carried out to the southeast.

<u>The Princeton Area</u>. The next buried valley to be investigated was that shown in Figure 10, which is about three miles north of the town

of Princeton. The bedrock contours are taken from Cady's report on the Hennepin Quadrangle. In this case an east-west line was run and depth stations to depths of 300 feet were taken at intervals of one-half mile, except for the one mile off-set near the middle of the profile.

The results of these stations are plotted in three curves-- $\underline{a} = 100$ feet, $\underline{a} = 200$ feet, and $\underline{a} = 300$ feet, in Figure 10. For the curve $\underline{a} = 100$ feet, it will be noted that all the stations are normal except No. 13, which shows a very much higher resistivity than the others.

The curve $\underline{a} = 200$ feet is very similar to the first, except that the value for No. 13 is not quite so high, and Nos. 8 and 9 are beginning to emerge slightly above the others. The curve for $\underline{a} = 300$ feet shows No. 13 to be still less pronounced, which Nos. 8 and 9 stand out in a prominent peak.

The complete depth determination of Station No. 13 indicates that the resistant material extends from near the surface to a depth of about 80 feet.

The peak at Nos. 8 and 9 indicates a resistant material being encountered at about 200 feet of depth, and continuing indefinitely downward at those two stations.

Apparently the unknown resistant material in both these cases is of the same nature as that encountered at Taylorville, and that it is gravel still seems to be the most plausible hypothesis.

It next seemed desirable to find a known gravel deposit and investigate its effect on resistivity measurements. Such a deposit was found in the village of Webster Park, just east of Spring Valley. Here

Figs. 11 and 12. Two views of the Sitterly Gravel Quarry looking northward.

the gravel is being quarried in the Sitterly Gravel Quarry from a 60 foot face of coarse, cross-bedded gravel. The gravel extends deeper than the bottom of the quarry.

Two longitudinal traverse profiles were taken--one at A - A', Figure 13, and one at B - B', with a = 100 feet. It will be noted that both profiles show a very high resistivity over the known gravel. The curve A - A' declines rapidly until it reaches about a normal glacial till value near Station No. 13 or No. 14. The curve B - B' declines to about normal at Station No. 3, oscillates slightly (possibly due to lenses of gravel), and then flattens out.

From the curves alone, the boundary between the gravel and glacial till would be drawn about as indicated in Figure 13. Mr. Sitterly provided the information that his test pits had shown the boundary to be almost exactly as shown. Moreover, a well one city block north of A' reaches bedrock without encountering gravel. A depth station near B gave the depth to the bottom of the gravel to be about 80 feet.

<u>The Sullivan Gravel Deposit</u>.- About two miles south of the town of Sullivan (Figures 14 and 15), the well records show a gravel deposit, 60 feet beneath the surface. For a long distance it has a thickness of about 8 feet, but to the south it abruptly thickens downward. This deposit is full of water, whereas that at the Sitterly Quarry was largely drained. A profile was run here to determine whether, when saturated with water and at some appreciable depth beneath the surface, such deposits would still be detectable.

The profile shown in Figure 15, with a = 100 feet, was taken. The cross-section below was reproduced from a previous engineering report. Not only was the thickening of the gravel bed detected, but also there is indication that it occurs more abruptly than the cross-section indicates.

The Mattoon Area.- North of Mattoon there is an area, according to well log data provided by the Subsurface Department, which is underlain by a lens of gravel about three miles wide and 30 feet deep, which thickens gradually from 0 feet thickness at the edges to a maximum of 20 feet at the center. It was desired to know if this could be detected.

The profile A - A', Figure 16, was taken when a = 100 feet, and stations 100 feet apart. This profile shows, on the average, a gradual rise from minimum at the ends to a maximum in the middle.

The peak about Station No. 109 is interpreted to be a narrow strip where the gravel has thickened downward.

A few depth stations to a depth of 100 feet were taken on the line B - B', one mile further north. The cross-section B - B' is a tentative interpretation of the results obtained.

BURIED ANTICLINES

The LaSalle Anticline.- It was desired to get at least one profile across an anticlinal structure buried beneath glacial drift, in order to see if this method of investigation might prove useful as a means of locating unknown oil structures. For this purpose the LaSalle anticline at Tuscola was selected because of a convenient east-west road along which to run the profile, and because Bell had already made a subsurface map of the top of the Devonian limestone for this area.

Such a line was run from one half mile west of Tuscola to a point five miles farther east. An electrode interval, a = 200 feet, was taken, and stations were taken every 200 feet.

The results are shown in Figure 16. The cross-section is taken directly from Bell's map of the area, which was made prior to running the profile.

SUMMARY

The field tests show that positive results can be obtained on each of the problems investigated. In the fault investigations, it seems safe to say that faults not previously known were discovered. In the gravel and water supply studies, it seems practically certain that unknown major deposits of gravel have been located. The LaSalle Anticline profile was emphatically positive.

It seems, therefore, that a continuation of such studies may prove of considerable usefulness to the Illinois State Geological Survey.

DISCUSSION REGARDING APPARATUS AND FIELD CREW

The experience of the summer has given a great amount of useful information regarding the behavior of apparatus and field technique and crew of assistants.

The taking, computing, and plotting of data, as well as its interpretation and planning of future work, is essentially a one-man job. Assistants are necessary only as linemen and for such auxillary matters, so that no more special training is required than can be given in an hour or so of time. It has been found that for the most economical work there should always be two assistants, and in certain types of work as many as four.

It is therefore recommended that two permanent assistants be provided and that provision be made for the party chief to employ locally other temporary assistants when needed. The two permanent assistants should be low salaried men, such as freshmen or sophomore college students wanting work for the summer.

It is possible that some of the author's own students might be willing to work at a low salary for the summer in order to acquire experience, in which case, if convenient, the writer should prefer precedent in recommending them as his assistants.

Apparatus.-- The apparatus used is, as may be judged from the results obtained, highly effective. It still, however, has very marked limitations and defects for certain types of problems. It is quite probable that we shall wish to supplement it with additional apparatus at a later date. The writer has just been informed that the makers of the present instrument are at work on a new instrument especially designed for this type of investigation. If they succeed, such an instrument will doubtless prove a highly desirable addition to present equipment.

If it should be necessary to do certain kinds of work, such as detailing the highly faulted fluorspar area, it will be necessary to lay off a base map of station locations by plane table. This will necessitate either that a special plane table crew be detailed for this purpose, or that the party be equipped with plane table alidade and do their own surveying.

Should this latter alternative be adopted, it is urgently recommended that a new light, explorers' type Gurley alidade and 18-inch plane table be acquired as a part of its permanent equipment. The old instruments already on hand are much too big and cumbersome to fit in with the already over-abundant supply of equipment that must be carried.

Submitted October 10, 1931

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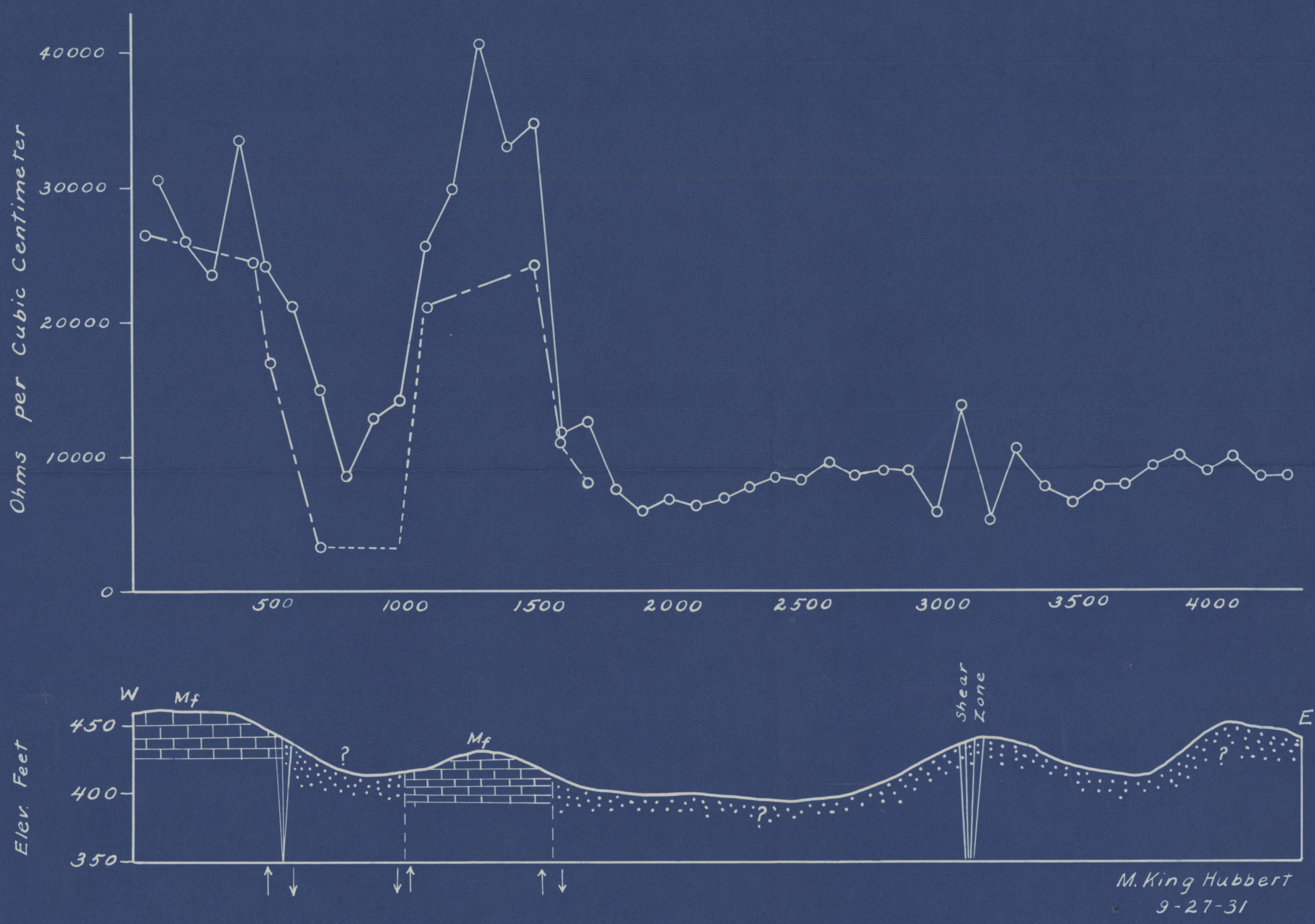


Fault Profile, Hardin Co.

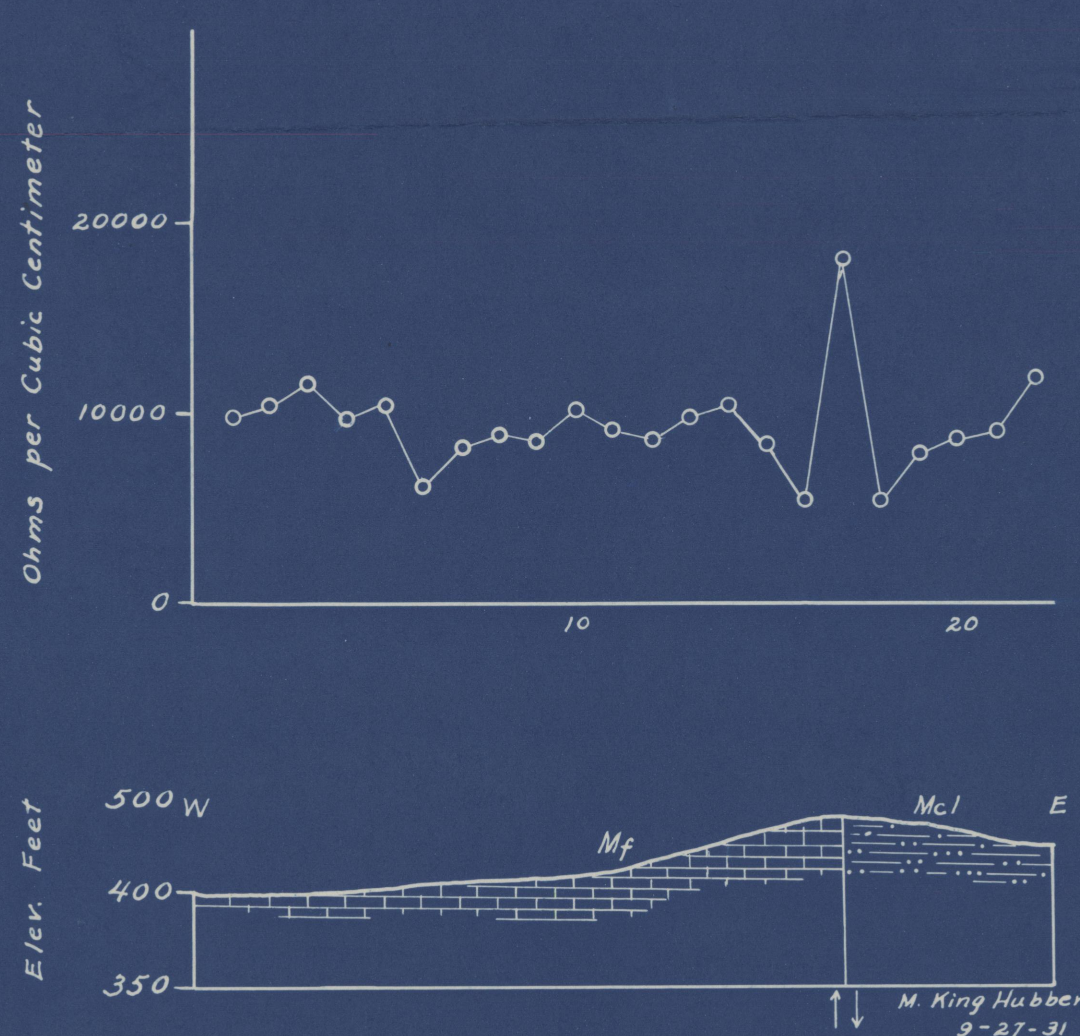
Secs. 23 & 24 T. 12 S. R. 7 E.

0 500 1000 1500 Ft.

Horizontal Scale

a = 100 Ft.

Fig 5



Profile No. 1 Hardin Co.

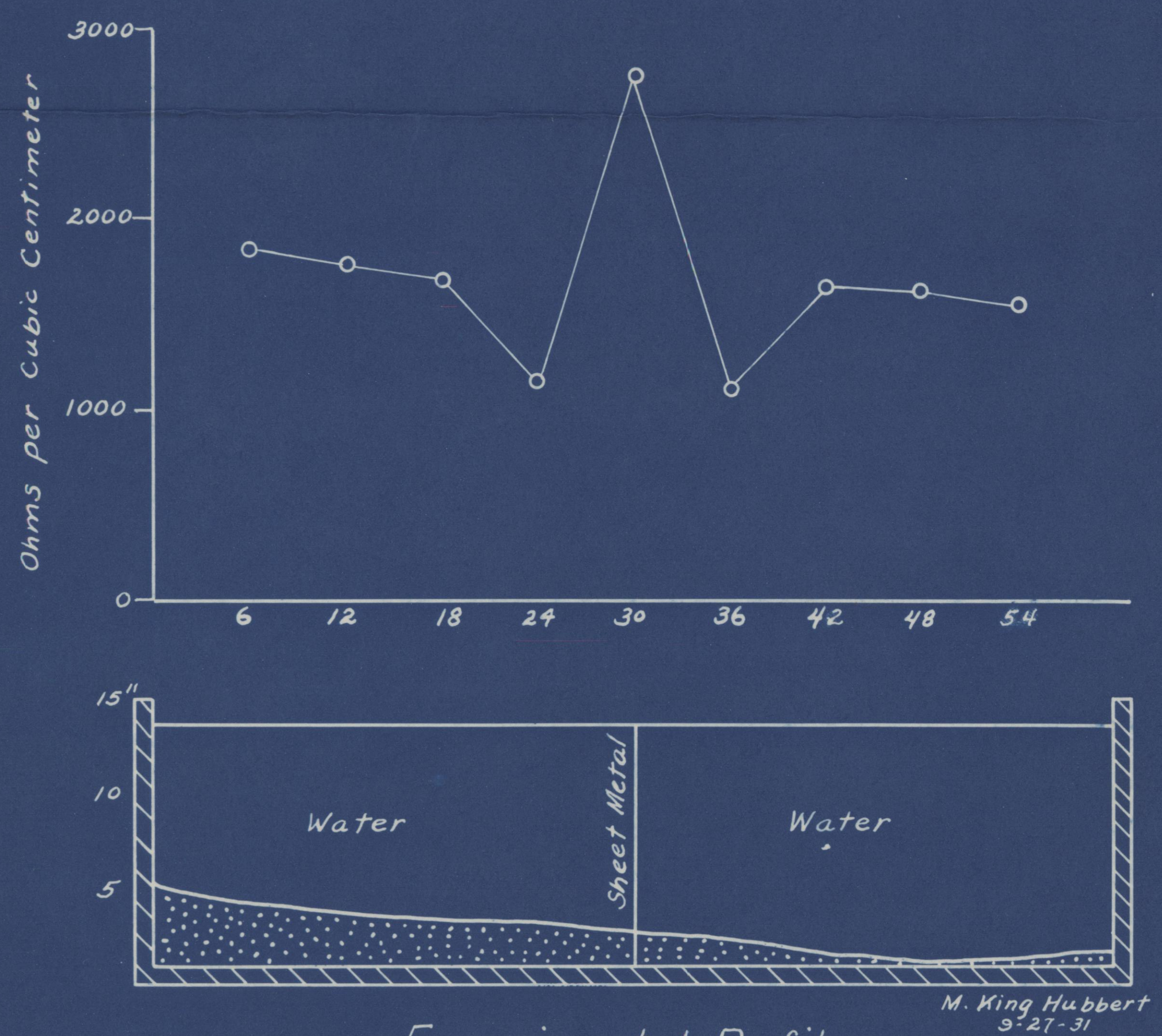
Sec. 9 T. 12 S. R. 8 E.

0 500 1000 1500 Ft.

Horizontal Scale

a = 100 Ft.

Fig. 3



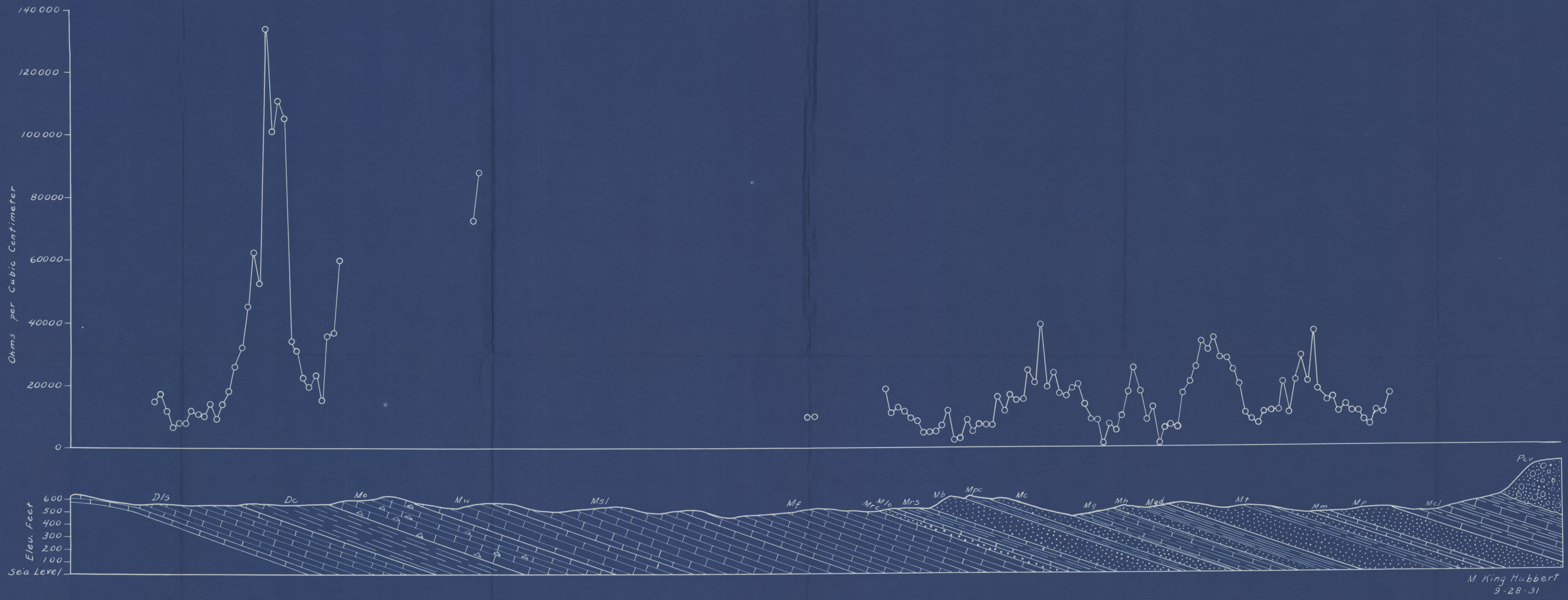
Experimental Profile

0 6 12 inches

Scale

a = 6 inches

Fig. 4



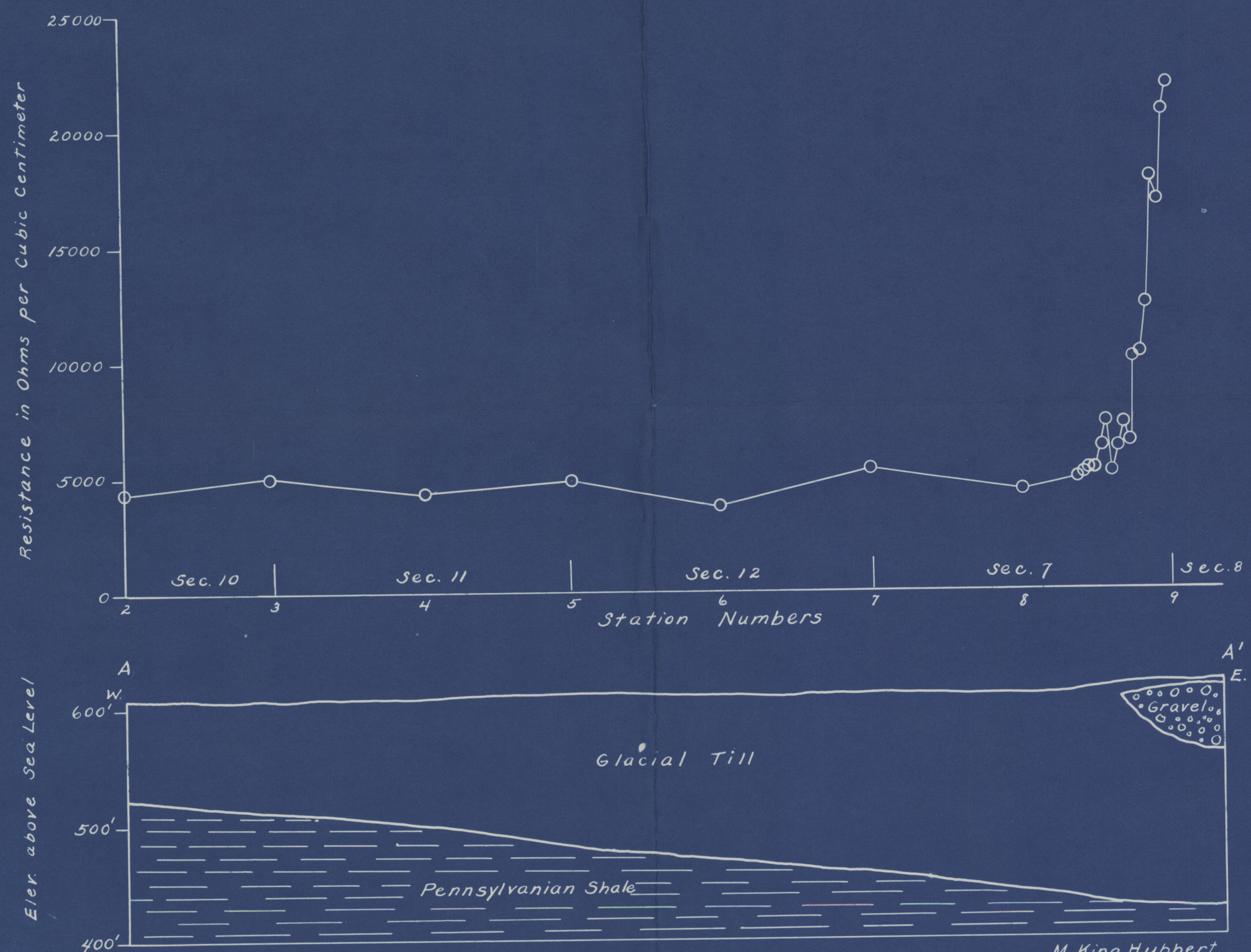
COMPOSITE PROFILE FROM HICKS DOME TO CASEYVILLE CONGLOMERATE

0 1000 2000 3000 4000 5000 FEET

HORIZONTAL SCALE

a = 100 FT.

Fig. 6

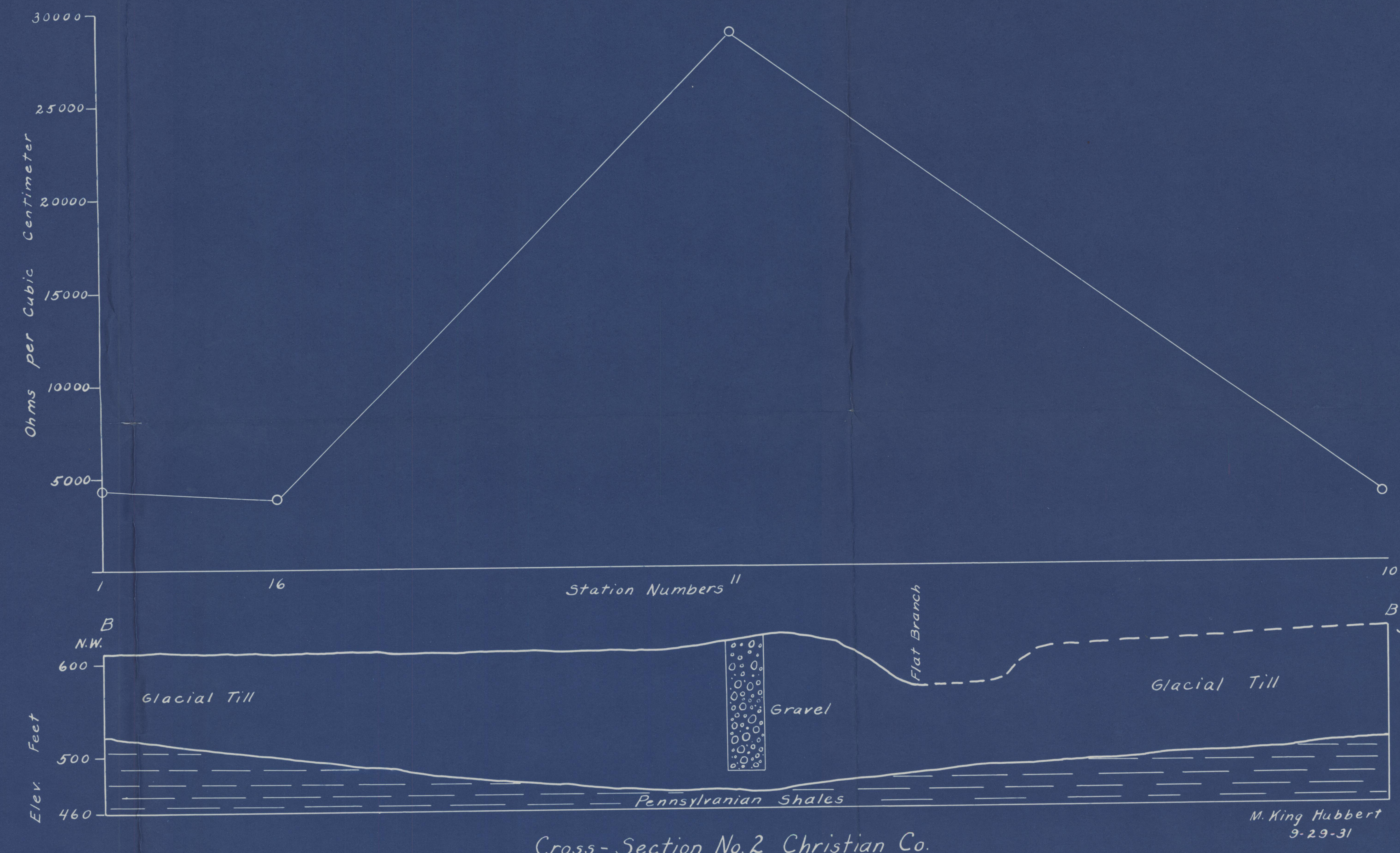


Cross-Section No. 1 Christian Co.

T. 13 N. R. 1 & 2 W.

0 2000 4000 6000 FT.
Horizontal Scale
a = 100 FT.

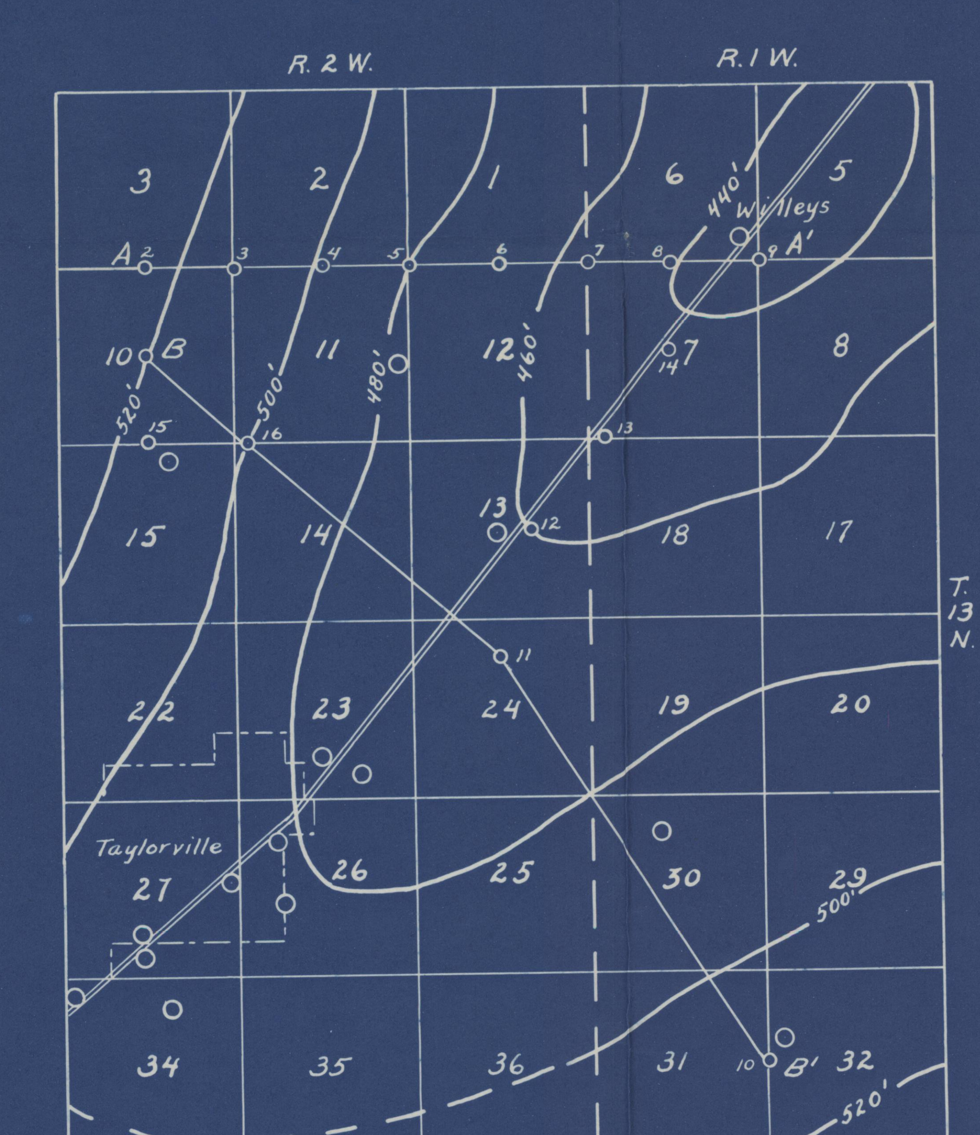
Fig. 8



Cross-Section No. 2 Christian Co.

0 2000 4000 6000 FT.
Horizontal Scale
a = 100 FT.

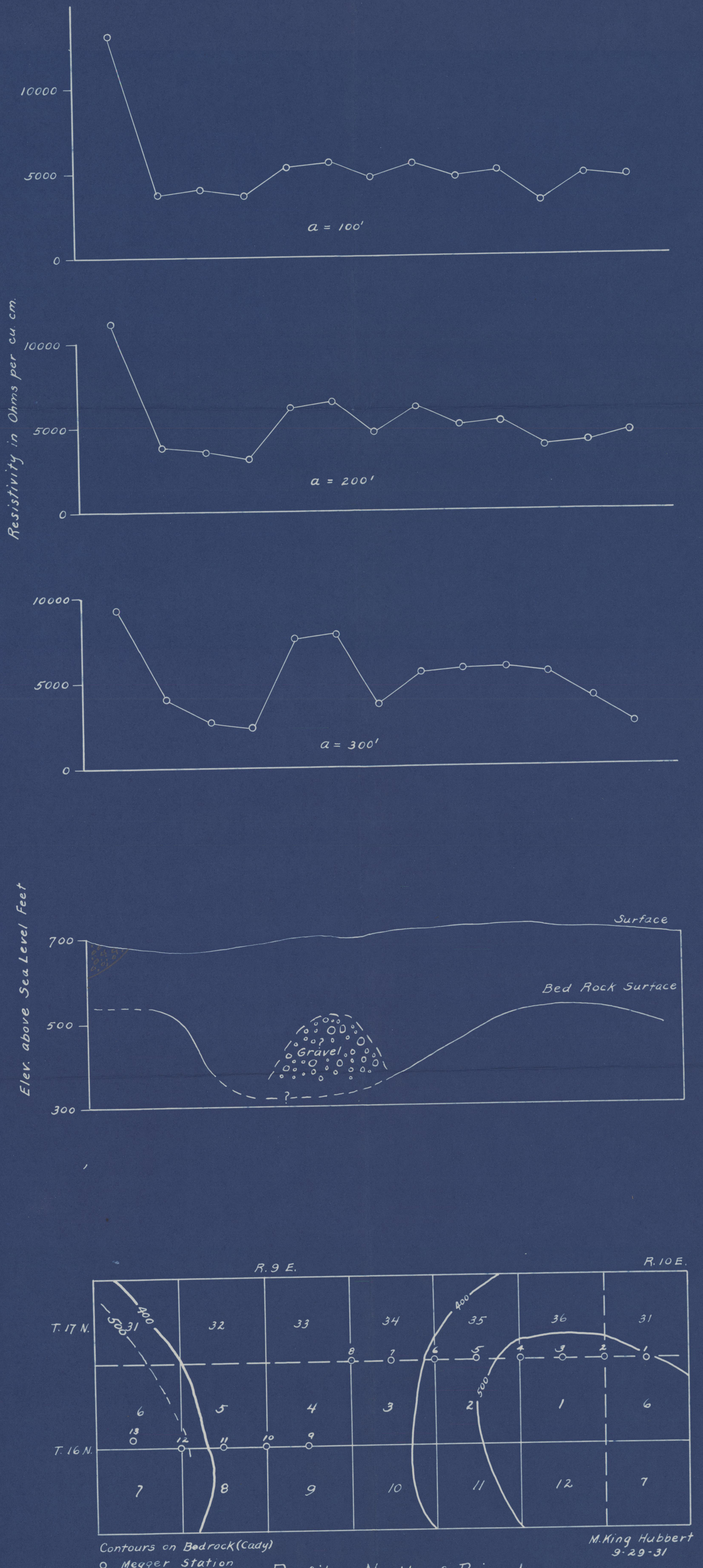
Fig. 9



○ Wells
○ Depth Profiles

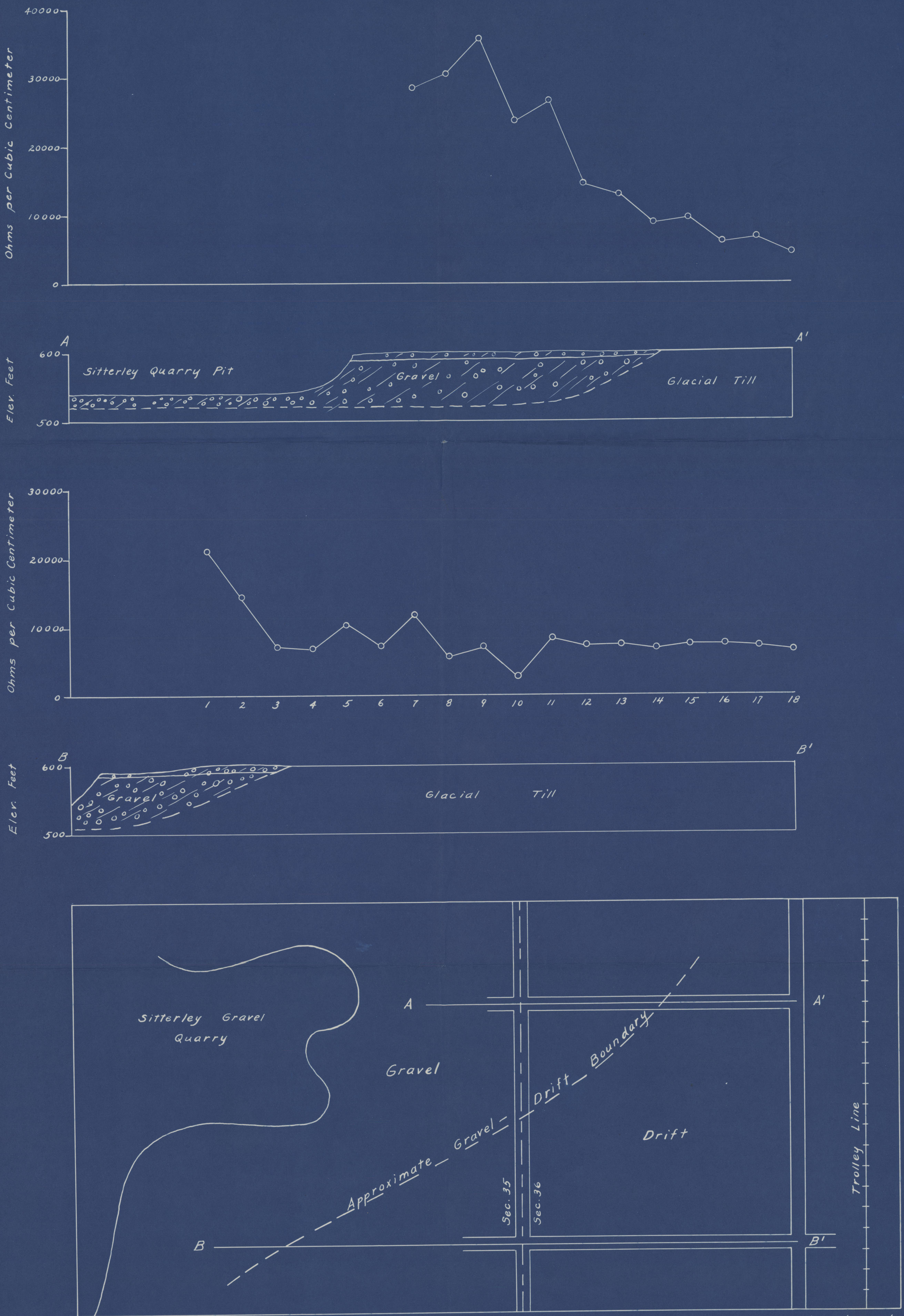
Taylorville Area
Contours on Bedrock Surface
(After Workman)

Fig. 7



Profiles North of Princeton

Fig. 10



Sitterly Gravel Quarry Profiles

Webster Park

0 200 400 600 Ft.

a = 100 Ft.

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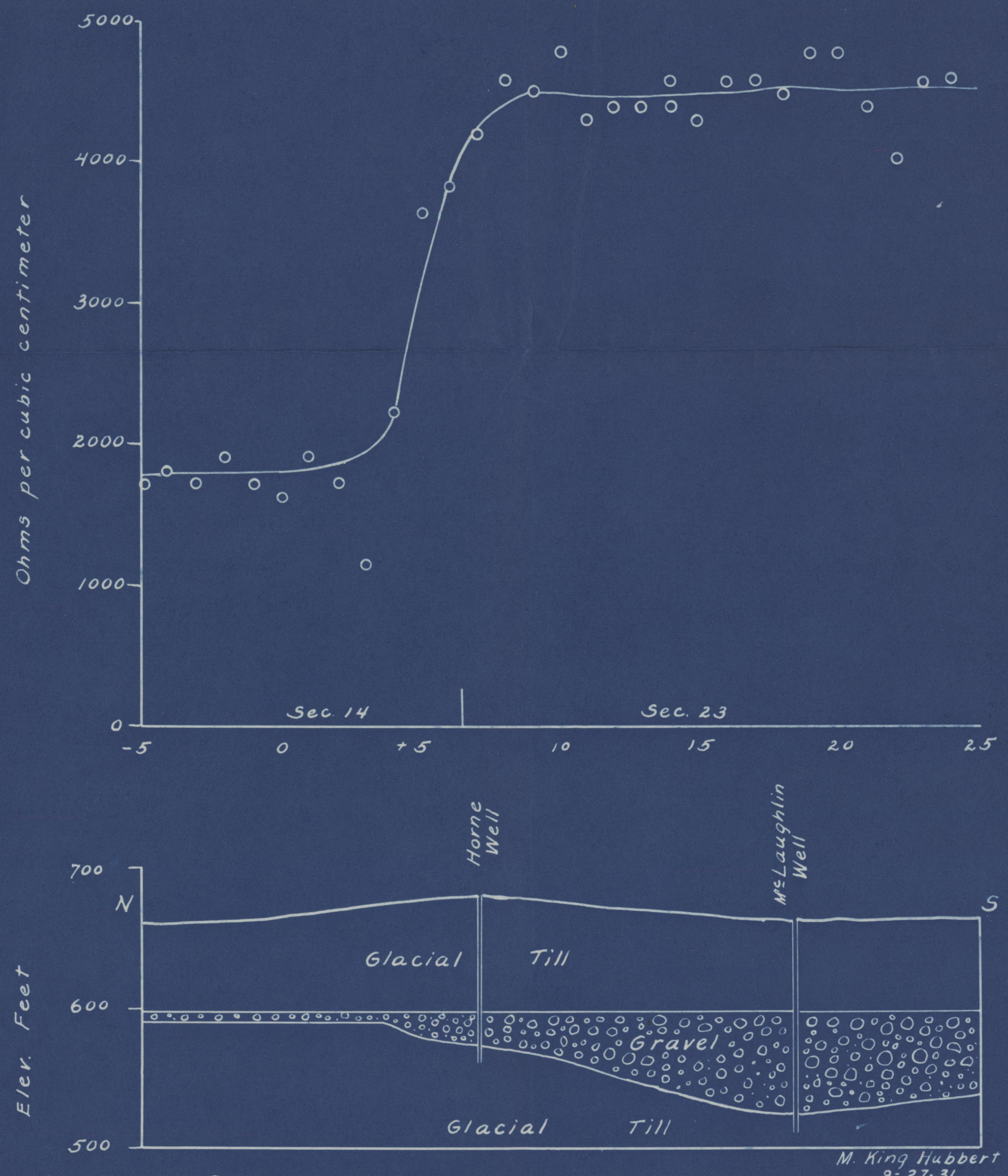
9-29-31

Fig. 13



Cross-Section and Profile Sullivan Area

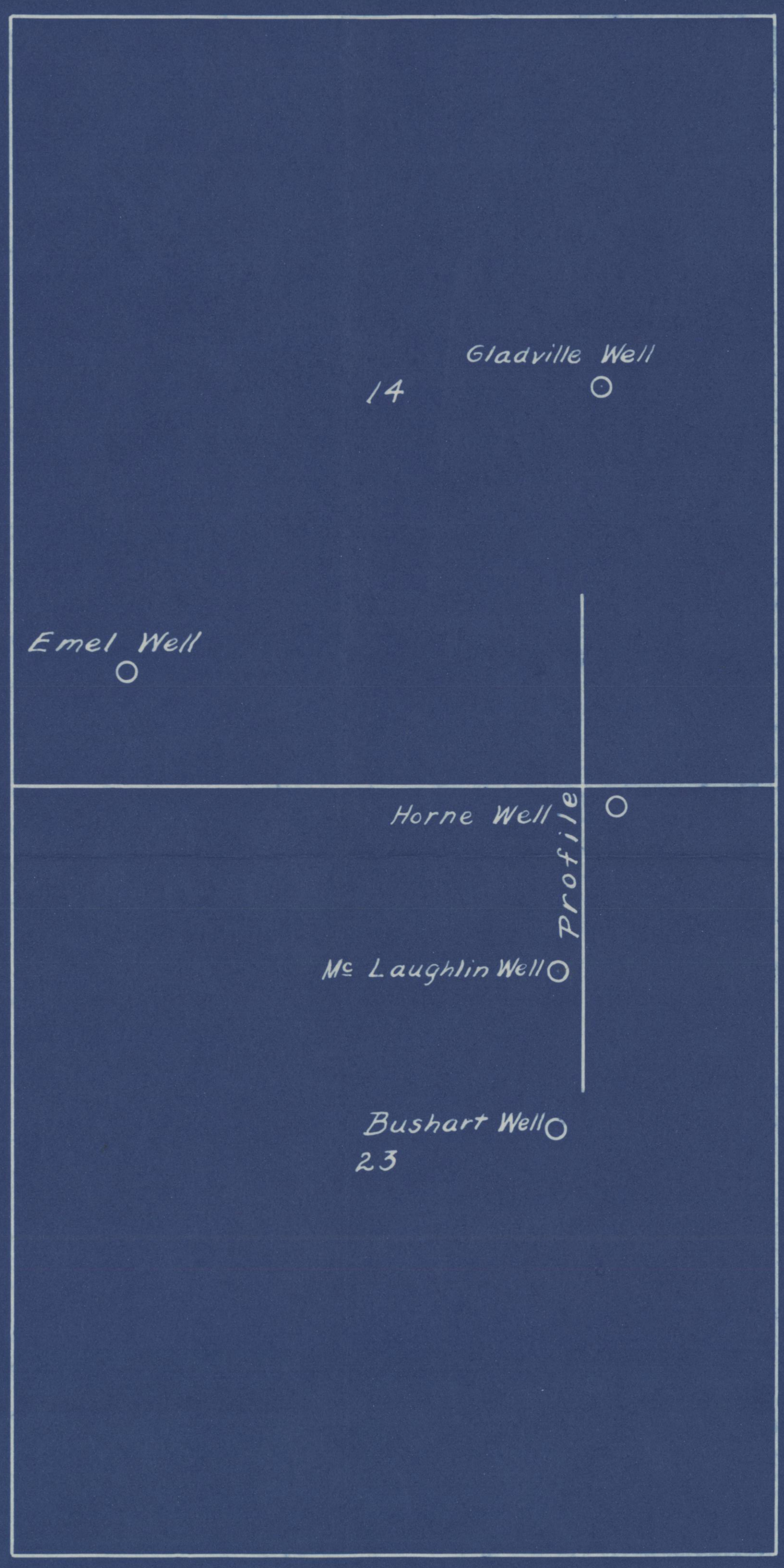
Secs. 14-23 T. 13 N., R. 5 E.

0 500 1000 Ft.

Horizontal Scale

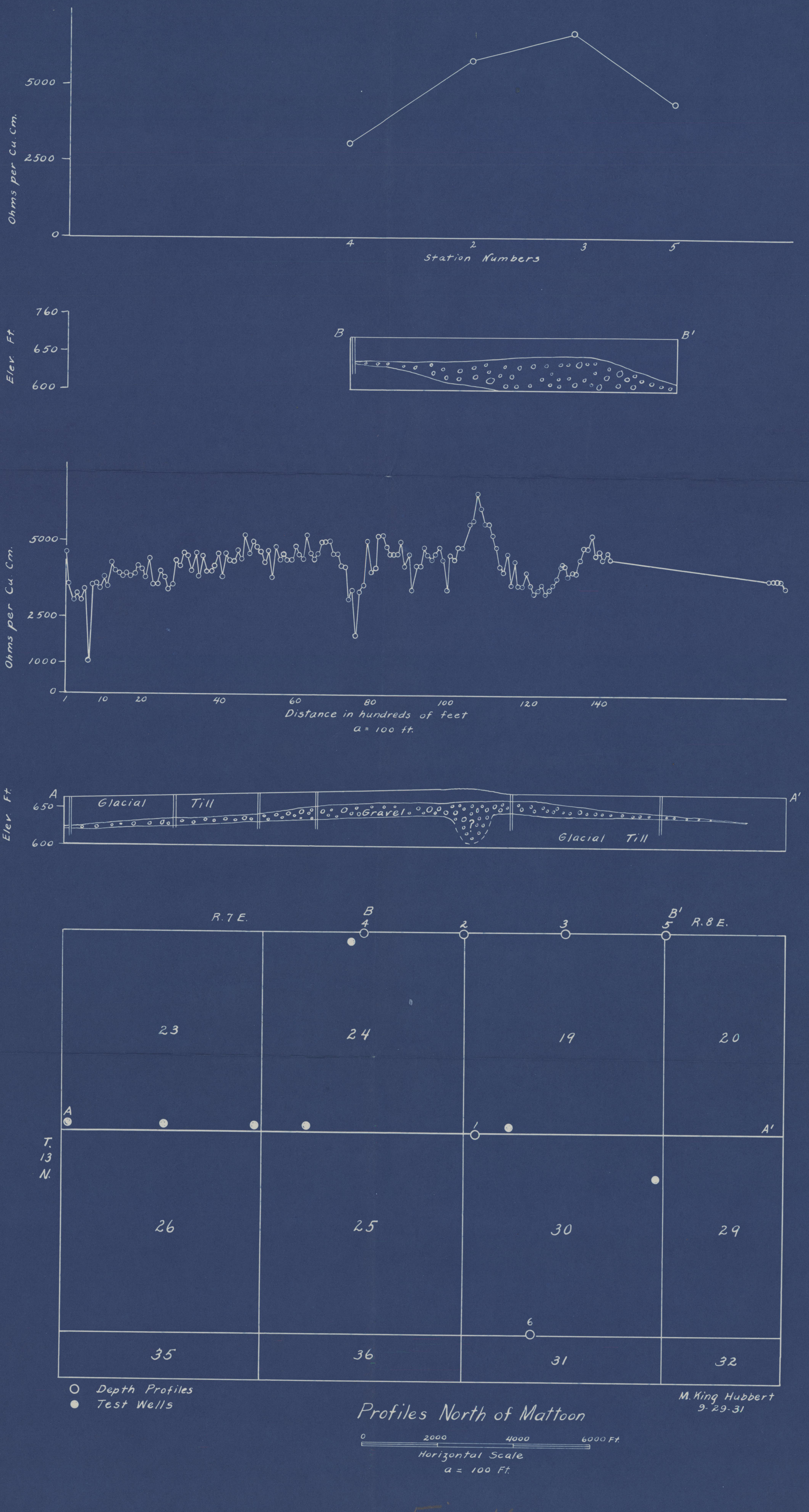
a = 100 Ft.

Fig. 15



Sullivan Section and Control Wells

Fig. 14



Profiles North of Mattoon

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Fig. 16

PROFILE ACROSS LA SALLE ANTICLINE AT

0 1000 2000 3000 4000 5000 FT

HORIZONTAL SCALE

a = 200 FT.