

REPORT ON A RESISTIVITY SURVEY  
OF THE  
MONKTON KAOLIN DEPOSIT AND  
DRILL HOLE EXPLORATION

*By*  
JASON A. WARK

VERMONT GEOLOGICAL SURVEY  
CHARLES G. DOLL, *State Geologist*



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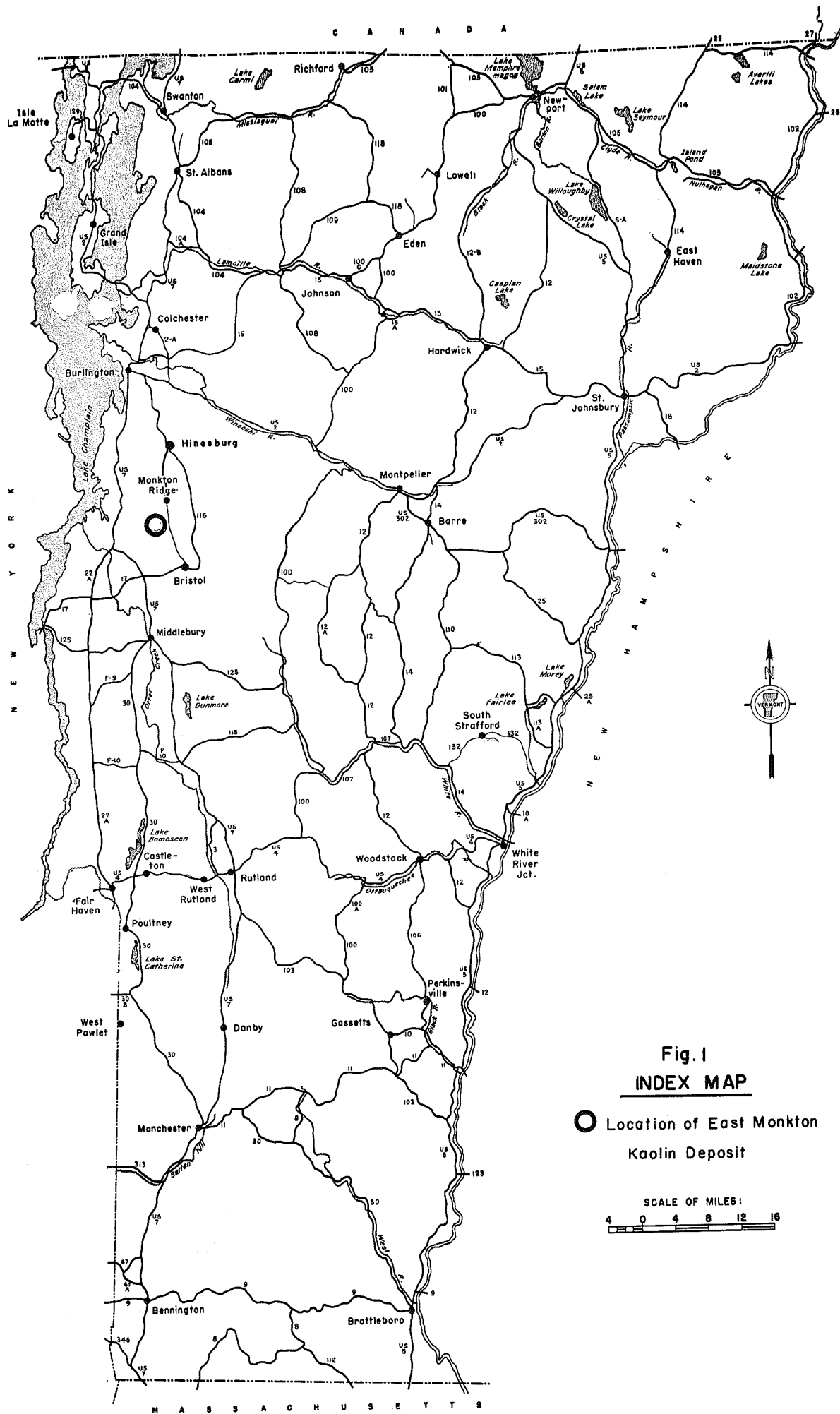


Fig. 1  
INDEX MAP

○ Location of East Monkton  
Kaolin Deposit

SCALE OF MILES:  
0 4 8 12 16

# REPORT ON A RESISTIVITY SURVEY OF THE MONKTON KAOLIN DEPOSIT AND DRILL HOLE EXPLORATION

By

JASON A. WARK

## INTRODUCTION

### *General Statement*

This survey was first initiated to establish the feasibility of using resistivity methods for the areal mapping and depth probing of a kaolin deposit. Field work toward this end was accomplished during the summer months of 1958 and 1959.

Work done during the early part of the survey was compared with the drilling data of the Vermont Kaolin Corporation, Bristol, Vermont, by means of cross-sections which were drawn from the two independent surveys and to establish resistivity values for kaolin.

Results of the two surveys were found to be nearly identical, and so the project was continued in an attempt to determine just how much farther the kaolin extends beyond its known location. Resistivity data indicate that this deposit of kaolin is much larger than was formerly believed, but the later phases of this survey have not as yet been corroborated with drilling.

### *Location of Area and Survey Base Points*

The area in which the survey was conducted is located in the lower central portion of the town of Monkton, in west-central Vermont (Fig. 1). On the U.S.G.S. topographic map it may be found in the north-central rectangle of the 15-minute Middlebury quadrangle.

Base points established during the survey are given below along with their locations.

Base point 00—found approximately 650 feet true west of Vermont Kaolin Corporation office building. It is the same base point used by the Corporation and was established as a permanent marker for its surveys. Taking its location from the Middlebury quadrangle, its position is longitude  $73^{\circ}07'33''$  west and latitude  $44^{\circ}10'27''$  north.

Base point 14—located 1400 feet north and 200 feet east of base point 00.

Base point 00'—1018 feet west on a line  $N78^{\circ}W$  from right front corner of school house at road junction one-half mile south of road junction 660.

Base point 0—in center at bend in road on 500-foot contour 0.3 mile south of road junction 514 in East Monkton.

Base point 0'—in center of road on 482-foot contour 0.4 mile north of road junction 482.

Base point 0''—longitude  $73^{\circ}06'07''$  west and latitude  $44^{\circ}11'21''$  north. In center of dirt road one-half mile northeast of road junction 482. Large Cheshire Quartzite outcrop is found beside the road just west of this base point.

These survey base points are shown on an aerial photograph (Pl. 1) and also on a topographic map of the area (Pl. 11 in pocket).

### *Previous Work*

Until the recent interest of the Vermont Kaolin Corporation, exploration of this deposit has not been very extensive. At different times during the past fifty years or more various interests have operated this deposit, but none on a scale to match the present one.

For the most part early exploration work was not planned or adequately recorded, so that it is of little or no value outside of the fact that it establishes the presence of kaolin in the area.

In 1954, E. F. Collins, Jr., working for the Vermont Geological Survey, spent part of the summer season in this area with a hand auger in an attempt to map the areal extent of this deposit. As Collins states in his report, the overburden presented quite a penetration problem and it was necessary, in many cases, to dig a hole through the coarser overlying materials before any adequate augering could be done. This report is on file in the State Geologist's office in Burlington.

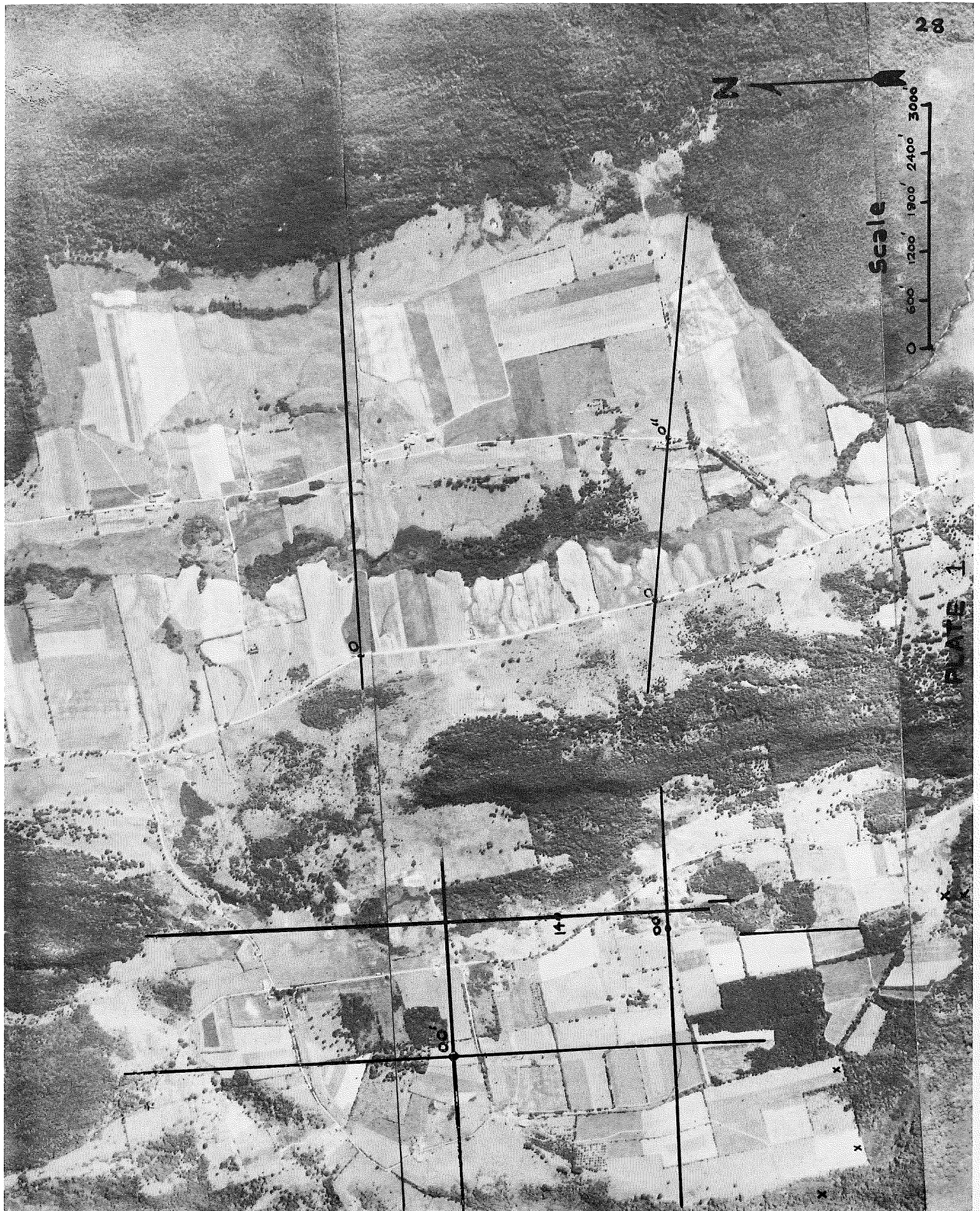
The Vermont Kaolin Corporation trenched, augered, and churn-drilled the area in and adjacent to former workings in the deposit. Logs were kept on all the work done, which were later used to draw cross-sections of the kaolin deposit and associated structures. It was these same cross-sections which were used for comparison with those of this resistivity survey.

### *Acknowledgments*

The writer is extremely grateful to Dr. Charles G. Doll, State Geologist, for the opportunity to gain experience in this field while still a student at the University of Vermont. In addition, thanks is given for his stimulating interest and advice during the course of the project. Mr. Willis P. Mould,\* Mining Engineer in charge of development at the Vermont Kaolin Corpora-

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\* Deceased



tion, gave appreciable aid and encouragement during all phases of the project and, in this connection, the writer wishes to express his thanks. Lance Meade and Frank Bryan III assisted ably and conscientiously in the field for two seasons.

## GEOLOGY

The anticlinal structures, which trend northerly in this area, are represented by extremely prominent ridges of Cheshire Quartzite. One of these wooded ridges is clearly seen in the aerial photograph (Pl. 1). This ridge, shown in the middle of the photograph, apparently marks the easternmost extent of the kaolin deposit, and the line of woods at the western margin of the photograph delineates, approximately, its western limit. Just beyond the western margin of this photograph, Cheshire Quartzite again outcrops in a ridge which forms part of the Champlain thrust fault.

It would seem from information available and work done by the Vermont Kaolin Corporation that the structures in the kaolin deposit itself are the result of folding and thrusting which have caused a separation in the body of kaolin into two parts with outcrops of Cheshire Quartzite between. This quartzite separation of the kaolin comes close to the surface at the top of the hill behind the Corporation's office, where the quartzite has an approximate dip of  $30^\circ$  to the east. As one continues westward across the level ground beyond this point, resistivity values indicate continuation of kaolin with a gradual increase in depth to bedrock. This would indicate that the point where the Cheshire Quartzite comes closest to the surface may be the apex of a fold in the bedrock or possibly the terminus of a thrust block of quartzite. In any event the following tends to explain the relationship of kaolin to bedrock.

In a Masters' Thesis on the origin of the kaolin deposit, D. G. Ogden has concluded that the formation of this deposit is due to hydrothermal replacement of the cementing material in the quartzite. Since there is an appreciable amount of silica sand present in the kaolin, Ogden has been presented with the problem of differential replacement of the silica cement only and not the quartz grains. He suggested that perhaps the cementing material was not silica and that replacement has taken place in a member of the Cheshire Quartzite which was different in composition.

## METHOD OF SURVEY

The electrical resistivity survey was conducted with the Wenner electrode arrangement of four equally spaced electrodes in a straight line (Fig. 2).

The principle behind this arrangement is that current introduced into the ground via the two outside electrodes  $C_1$  and  $C_2$  (Fig. 2) enables the operator to

measure the potential drop of the subsurface material at the inside electrodes  $P_1$  and  $P_2$ , to a depth ( $a$ ) which for field evaluation was taken as corresponding to the distance ( $a$ ) between the equally spaced electrodes (Fig. 2). By systematically increasing the distance between the electrodes it is theoretically possible to make measurements of potential to an increasingly greater depth.

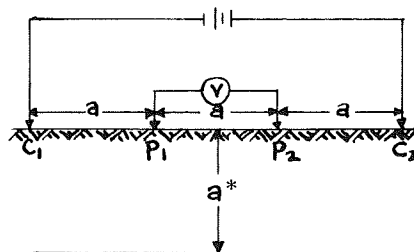


Fig. 2. Wenner electrode configuration.

The procedure of resistivity measurements was to increase the electrode separation by increments of 3 feet, as is done in the Barnes' method, until an electrode separation of 102 feet was reached. Each reading from the instrument for any given electrode placement is a measurement of the apparent conductivity, in *mhos*, of the total segment of ground encompassed by the induced electrical field. To determine the apparent conductivity of successive 3-foot layers it is simply a matter of subtracting the preceding instrument reading from the last, the difference between the two giving the desired apparent conductivity value for the 3-foot layer.

Since further discussion of this procedure would only be a repetition of material already in print, anyone wishing to review the Barnes' method in more detail is referred to "Electrical Subsurface Exploration Simplified" by H. E. Barnes. A copy of the paper may be obtained from Associated Research, Incorporated, Chicago, Illinois.

This principle sounds relatively simple and logical, but there are several factors which may interfere and it should be kept in mind that any measurements made usually give the "apparent resistivity" and not the "true resistivity," which is obtained only in homogeneous ground (Heiland, 1940, p. 28). This is especially true in an area as extensively glaciated as the one in which this survey was conducted. It was found that not only did the glacial cover vary vertically in relatively short distances, but also horizontally. This latter factor introduced a variable known as "inequal source and sink" (Spicer, 1957, p. 73-79), in which detection of vertical anomalies may be over-shadowed by changes

\* Not the same as "a" spacing; this was assumed for field estimation purposes.



in materials horizontally. These horizontal changes would result in unequal dispensation of current between the two outside or current electrodes, thus giving misleading potential readings. In some apparatus this condition may be compensated for by balancing the current electrodes, but with the instrument used in this survey, the only thing that could be done to try and maintain the symmetry of data recorded, was to reset the electrodes. Sometimes this was all that was necessary, but in all too many cases it did not produce the desired results. Also, as the electrode separation increased, the chances of correcting these phenomena decreased.

Another phenomenon which may lead to spurious potentials is known as the "saturation effect." When the condition exists in which one layer of material is more conductive than another there is a shift in the magnitude of the measured potential. For example, if the upper layer is 100 times as conductive as an underlying layer, there is a marked increase in the potential from its normal value. If the reverse is true, that is, the lower layer more conductive than the upper, then there is a decrease in the potential from the normal. For all intents and purposes, ratios of higher conductance of 1000 or 10,000 to 1 will give curves the same as those for the 100 to 1 ratio (Spicer, 1957, p. 96).

Another source of error in this survey was found to be directly attributable to the resistivity instrument used. This was due to the fact that there was a current reduction between scales on the instrument as adjustments were made for measurements at greater depths. As the instrument used was one of the early models (Pl. 2, Fig. 1) it must be stated in all fairness to the manufacturer that this error in design has since been reported corrected by the manufacturer.

How this reduction in current output influenced any measurements of the potential may be seen in the following excerpt from Spicer, 1957, p. 98.

"Because of the saturation effect and the tendency for the several layers to disturb and by-pass the normal distribution of current, it is necessary to increase continuously the amount of current introduced into the earth by the current electrodes so that these two effects are overcome.

Herein lies one of the primary defects of instruments used for earth resistivity measurements such as the megger and vibrator devices. These instruments cannot, under usual field conditions, accurately measure potentials at large separations, or, in other words, to relatively large depths, and should be confined to measurements of near-surface anomalies."

It was found time after time that when the depth probing had reached a level to require a change from the  $10^{-2}$  to the  $10^{-1}$  scale the potentiometer would not register any value for the potential, because of the re-

duction in current output between these two scales. It was extremely frustrating to have the instrument incapable of further accurate measurements when an exceptionally symmetrical sequence of resistivity values was being recorded up to the point of change.

This condition in several cases made the interpretation of data somewhat questionable as to whether the aforementioned condition existed or whether bedrock had been encountered. The writer's experience with the instrument leads him to believe that the instrument's reaction to these two conditions is not dissimilar.

It is also important to keep a constant check on the battery power supply because a smooth apparent resistivity curve may suddenly become erratic as the batteries lose their charge.

## EQUIPMENT

The instrument used for resistivity measurements was the Model 274M Michimho Vibroground manufactured by Associated Research, Incorporated, Chicago, Illinois.

This instrument is powered by two 1.5 volt General Radio A Batteries, dry cells, wired in series. The instrument has a synchronous vibrator, multiple potentiometers, hand-calibrated 13-inch scale in terms of conductance instead of resistance, and a reported overall accuracy of  $\pm 1\%$  of full scale (Pl. 2, Fig. 1).

Accessory equipment used with this instrument is listed as follows:

<i>No. of Items</i>	
2	160-foot lengths of insulated electrical cable.
2	55-foot lengths of insulated electrical cable.
4	Copper weld steel electrodes.
4	Solid copper 300 ampere battery clamps.
2	2-pound hammers for driving electrodes.
2	Machetes for clearing brush.
4	100-foot measuring tapes.
1	Camp stool on which to set the instrument.
3	Metal pins for anchoring measuring tapes.

These metal pins are rather hard to keep track of, as the field assistants seem prone to leave them behind when moving to another station.

The insulated electrical cable did not appear to contribute to spurious potentials under extremely high moisture conditions, such as after a heavy rain or when taking readings in a swampy area. This possible source of error has been mentioned by Spicer (1957) and was found on investigation attributable to breaks in the cables' insulation. Periodic examination of the insulated cover is therefore recommended to insure detection of such a source of false potentials.

In connection with this moisture problem care should be exercised to see that the electrodes do not come in



Figure 1. Model 274M Michimho Vibroground.

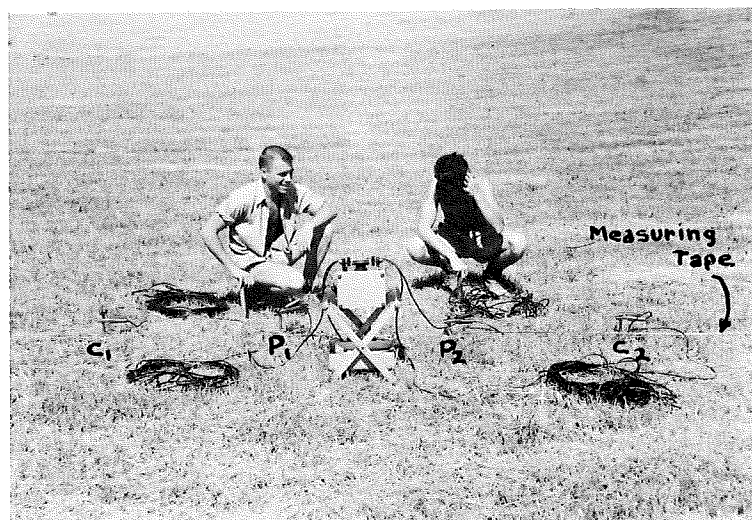


Figure 2. Field arrangement of resistivity equipment.

contact with the measuring tapes when they are damp, as it may result in a multiple distribution of current beyond the desired four electrode contacts with the ground. Also, if the tapes do become wet they should not be subjected to any undue stress as they may become permanently elongated, thus contributing to inaccurate placement of electrodes. Shrinkage is also a possibility, therefore it is recommended that the cloth tapes be checked for accuracy from time to time by comparing them with a steel tape.

A typical arrangement of the aforementioned equipment set up for the first shot may be seen in (Pl. 2, Fig. 2).

A Brunton Compass was used to lay out the lines along which resistivity measurements were made at 100-foot intervals. The Brunton was mounted on a tripod with a ball-bearing mount. Pl. 3, Figs. 1 & 2, illustrates this and shows the equipment set up on the Cheshire Quartzite outcrop just west of survey base-point 0'' (Pl. 1).

In an attempt to correlate resistivity data against that acquired by augering, a McIntosh hand auger was used. This set of tools is comprised of the following: a hammer or driving head, an auger handle, a lifting tool, 12 four-foot sections with couplings, 2 wrenches, a 1-inch diameter auger, two core samplers, and two bullet-shaped heads used for driving in hard ground.

Parts of this equipment are shown in operation in Pl. 4, Figs. 1 & 2.

A maximum penetration of 50 feet was possible with this equipment, but with one exception it was never reached. Most of the augering never penetrated to a depth substantial enough to prove or disprove the presence of kaolin, as indicated by the resistivity instrument. Because of the small size of the auger, pea-size stones were sufficient to make further penetration impossible. However, comparison of auger data with resistivity values to a depth at which penetration was possible reveals that there are inhomogeneous materials in the overburden which possess resistivity values identical to those established for kaolin. In light of this there is the possibility that the interface between kaolin and this type of overburden cannot be detected by resistivity methods, so that the overburden may become much more substantial in some areas and be misinterpreted as kaolin-bearing material. Proof of this possibility will come only with subsequent core sampling at greater depth with more appropriate equipment.

A Paulin altimeter was used to establish the elevations at different points along the survey lines, to facilitate the accurate representation of surface contours when representing the subsurface kaolin-bearing areas. A Fahrenheit thermometer was included with this instrument to record changes in temperature which would

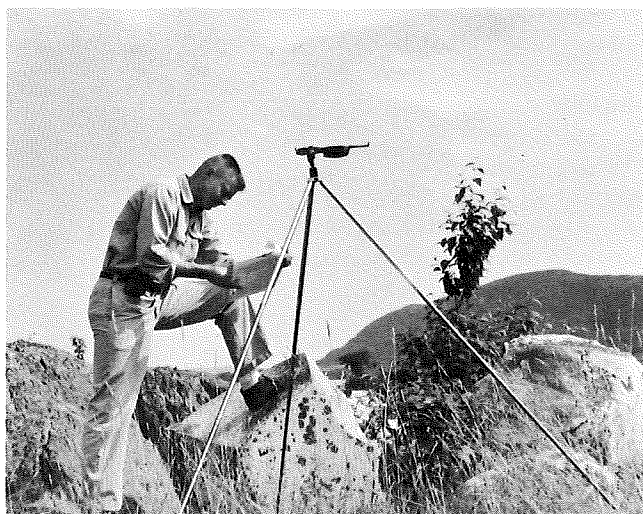


Figure 1

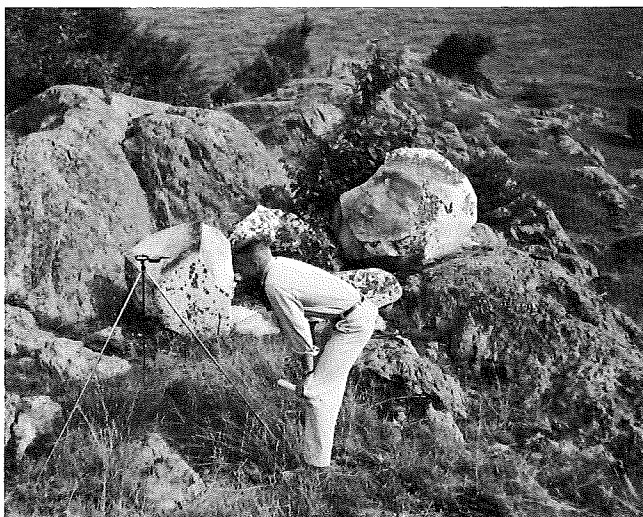


Figure 2

### PLATE 3

Figures 1 & 2. Brunton Compass mounted on tripod.

then be used to make calculated corrections in elevation. Also taken into account were changes in barometric pressure between the time the instrument was adjusted at a base point of known elevation and a return to this same point after having established points of elevation along a survey line.

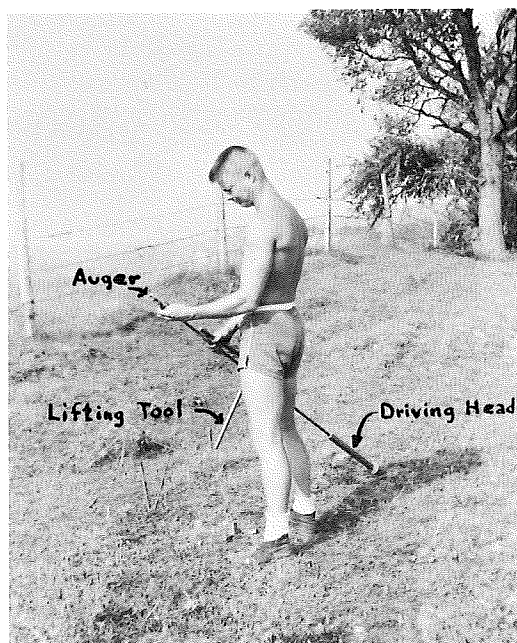


Figure 1

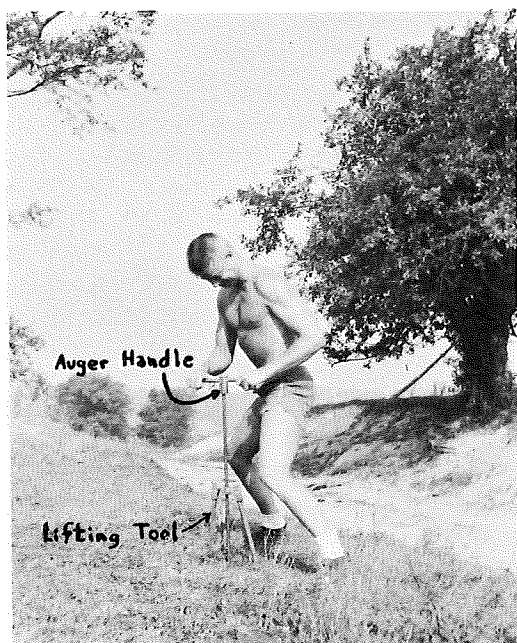


Figure 2

#### PLATE 4

Figures 1 & 2. McIntosh hand auger.

## EXTENT OF SURVEY

Eight separate survey lines and six base points represent an approximate total of 38,000 linear feet covered along the ground surface. The normal pattern was to make resistivity electrode separations to a depth of 102 feet at 100-foot intervals along these lines, which would give a similar figure of 38,000 for total readings, but because of departures from the aforementioned general plan, there is only a total of approximately 35,000.

As noted previously, these survey lines and base points have been located on an aerial photograph (Plate 1) and on a topographic map (Pl. 11, in pocket).

A different photographic perspective of these points may be seen in Plate 5. This composite is made up of three pictures taken from an outcrop near the top of Hogback Mountain looking in a westerly direction toward Lake Champlain. Using these illustrations, there should be no confusion as to the location of the survey lines and their reference to survey base points.

Some 600 pages of data were recorded in the field, including graphs of data at each survey station, auger records, and altimeter readings, which are on file in the Office of the State Geologist in Burlington. They are available to anyone with a knowledge of resistivity methods wishing more detail than is contained in this report.

## CORRELATION OF DATA

As previously mentioned, resistivity values for kaolin were determined by comparing profiles drawn from resistivity data with those made by the Vermont Kaolin Corporation from data acquired by trenching, augering, and churn drilling.

Initially, two lines were laid out on the property of the Vermont Kaolin Corporation by Mr. Willis P. Mould. The East-West line of this survey passed through their 00 point, terminating 900 feet to the west and 1700 feet to the east. The North-South line passed through station 00 + 200 feet east, terminating 1300 feet north and 600 feet south of this station. Resistivity "soundings" to 102 feet were made along these lines on the average of every 100 feet. In a few places the interval was shortened to pin-point what appeared to be faults.

Prior to drawing profiles from the data recorded along these lines, the instrument was set up near the edge of an exposed pit of kaolin, in two proximal locations, to record values for this material. The results may be seen in Figure 3.

From this data, a range of values for kaolin was determined and profiles drawn (Pl. 6). Subsequent comparison of these profiles with those of the Vermont Kaolin Corporation revealed that the range for kaolin was somewhat greater than that determined from these



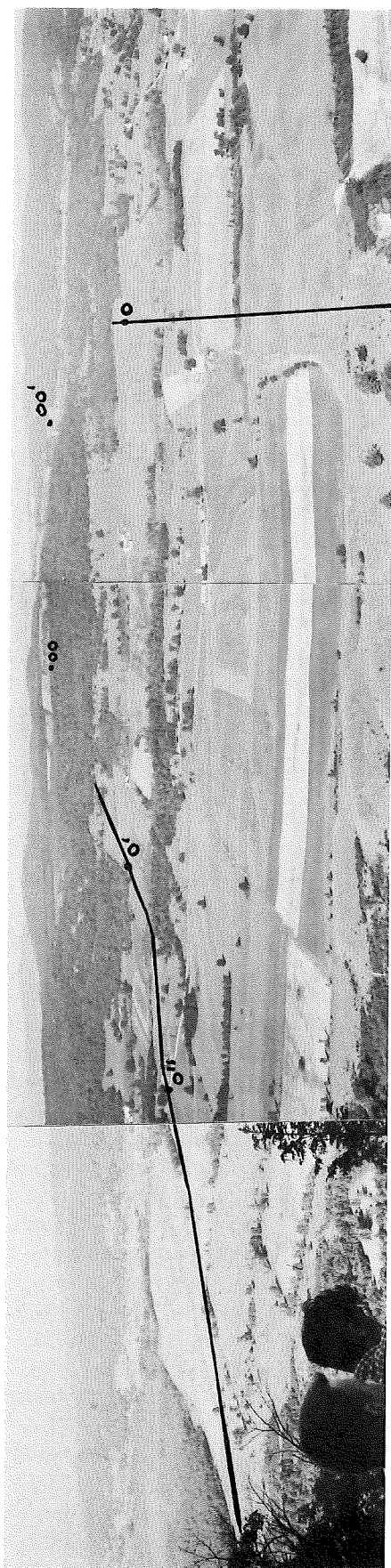


PLATE 5

Westward view from Hogback Mountains.

two resistivity "soundings." The resulting range of resistivity values established was between 16,000 and 140,000 ohm cm., with some variations depending upon curve characteristics. Reading the conductance curve, the values for kaolin, as read from the resistivity instrument, are those portions of the curve which fall between  $40-350 \times 10^{-4}$  mhos.

In addition to comparing the results of these two independent profiles, comparison of resistivity values at individual stations was made with the data of auger and churn drill holes in the immediate vicinity. An example of the close correlation of resistivity instrument readings with the data from one of the churn drill holes may be seen by examining Figures 4, 5, 6. Figure 4 represents a log of C. D. H. #6 and is located 67 feet north of 00 + 458 feet east. As can be seen in Figures 5 and 6, the 3-foot layer of quartzite rock between 25 feet and 28 feet in Figure 4 appears as a sharp increase in the resistivity curves. Again, the same thing occurs for the 4-foot layer of sand rock found between 96 feet and 100 feet in Figure 4.

The apparent differences in depth below ground surface level of these highly resistive layers is partially due to differences in elevation between these three locations and certainly some change in relationship of the subsurface stratigraphy is to be expected in an area as highly deformed as this one.

The irregular nature of the curves and the wide range of resistivity values for kaolin just mentioned are undoubtedly due to the change in composition of the kaolin-bearing material, which is known to possess variable amounts of silica sand. In addition, many of these irregularities in the curves drawn from data taken in the vicinity of the Corporation's office may be attributed to the fact that much of the area covered for purposes of correlation is far from being undisturbed ground, and it was sometimes impossible to keep the electrodes in a straight horizontal line. Indeed, a side view of the terrain, in some cases, would look much like a corrugated roof on a larger scale.

In only two instances did the McIntosh hand auger reach a depth great enough to definitely substantiate the presence of kaolin as indicated by the resistivity instrument. These two cases are illustrated in Figures 7 and 8, in which the auger data have been superimposed upon the resistivity and conductivity curves.

The end result of accumulating and plotting data is represented in Plates 6, 7, 8, 9 and 10, which are profiles illustrating kaolin-bearing ground at individual stations. No attempt was made at classifying resistivity data outside of the range for kaolin, because it was proved to be extremely variable due to changing percentages of materials and water content. As already mentioned, this variability in percentages of materials raises the question as to whether or not the interface



NAME \_\_\_\_\_ NO. \_\_\_\_\_

DATE: 7/17/58

BY: WARK

STA. Top of kaolin Pit Bank OFFSET \_\_\_\_\_ LT. \_\_\_\_\_ RT. \_\_\_\_\_

—•— Resistivity: Kilohm-cm  
 —<— Conductance: Mhos - as read from instrument  $\times 10^{-4}$

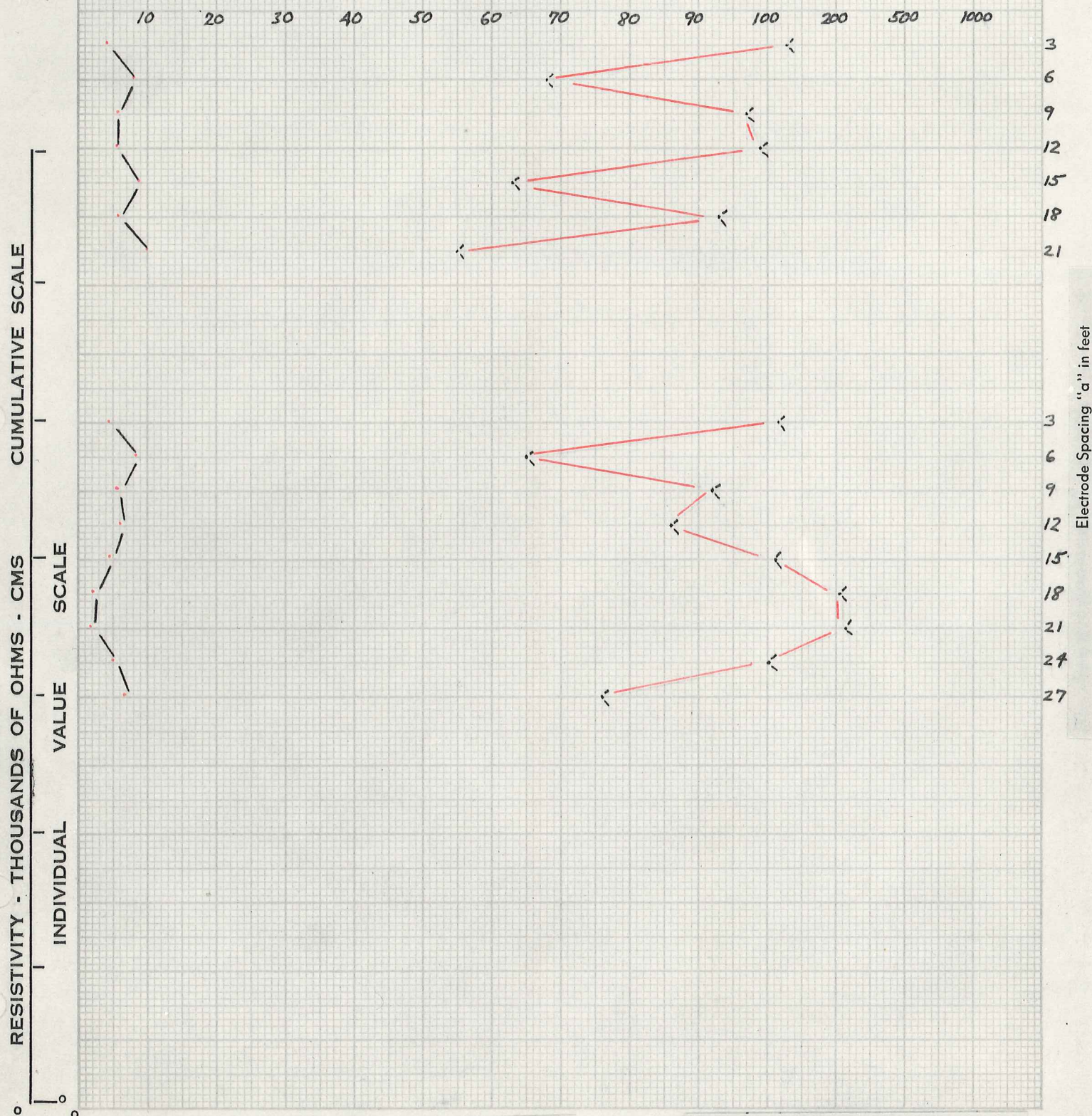


Fig. 3



NAME \_\_\_\_\_ NO. \_\_\_\_\_

DATE: \_\_\_\_\_

BY: \_\_\_\_\_

67' N. of 00+458'E

STA. C.D. H. # 5

OFFSET \_\_\_\_\_

LT. \_\_\_\_\_

RT. \_\_\_\_\_

Ground Surface

1' Glacial Till

16' Rock

17'

8' Rusty Clay Sand  
+ Clay Rock

25'

28'

3' Quartzite Rock

7' Clay Rock

35'

37'

2' White Clay

9' Clay, a little Rock

46'

7' White Clay

53'

8' White Clay

61'

35' White Clay

96'

100'

4' Sand Rock

25' White Clay to 125' then 10' Hard  
Quartzite to 135'

CUMULATIVE SCALE

RESISTIVITY - THOUSANDS OF OHMS - CMS

SCALE

VALUE

INDIVIDUAL

PL = 3 FEET

Fig. 4

SOIL RESISTIVITY GRAPH

VERMONT GEOLOGICAL SURVEY



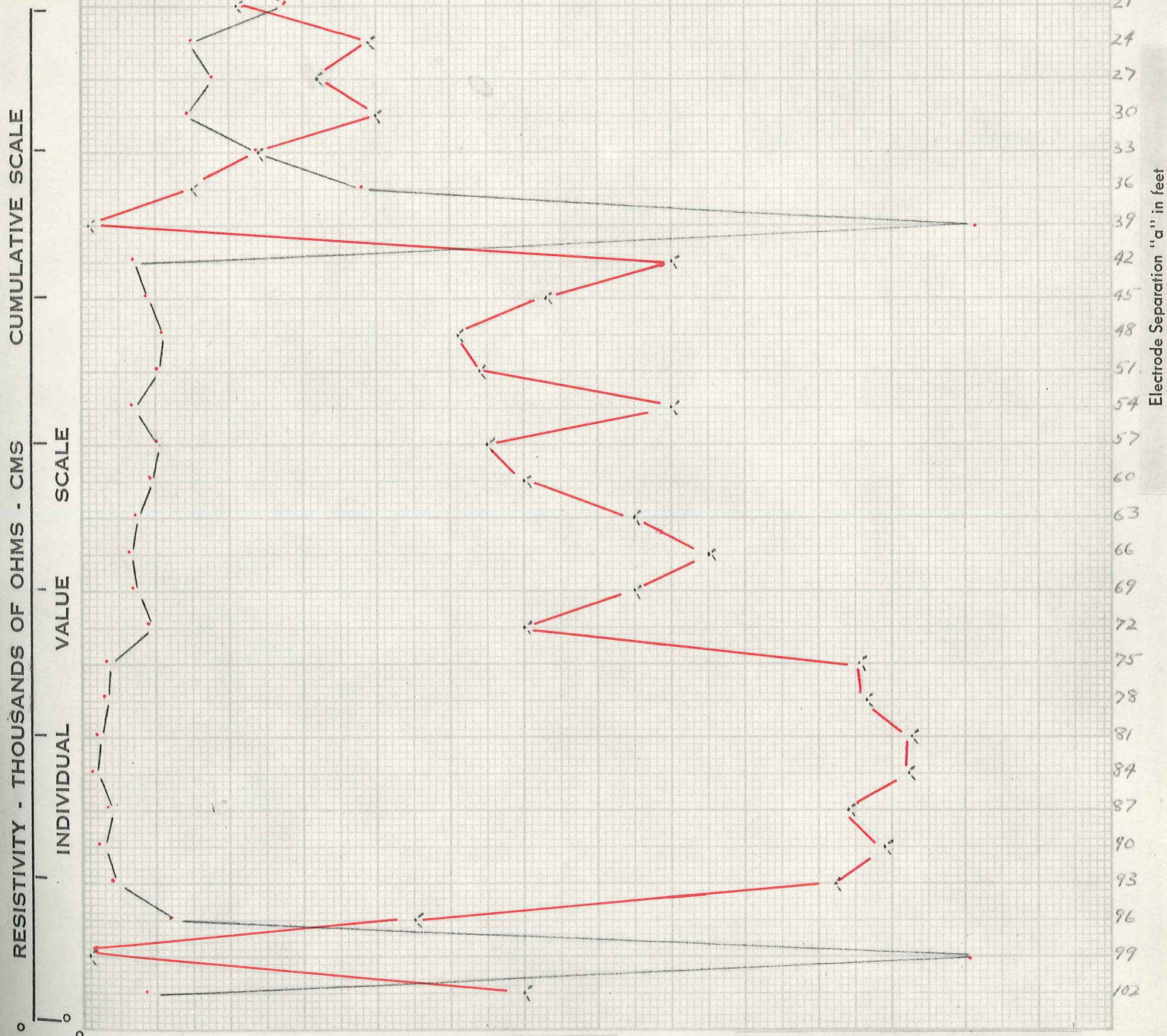
NAME \_\_\_\_\_ NO. \_\_\_\_\_

DATE: 7/10/58

BY: WARK

STA. 00+400'E OFFSET \_\_\_\_\_ LT. \_\_\_\_\_ RT. \_\_\_\_\_

10 20 30 40 50 60 70 80 90 100 200 500 1000



PL = 3 FEET

Fig. 5



NAME \_\_\_\_\_ NO. \_\_\_\_\_

DATE: 7/10/58

BY: WARK

STA. 00+500'E

OFFSET

LT.  
RT.

10 20 30 40 50 60 70 80 90 100 200 500 1000

RESISTIVITY - THOUSANDS OF OHMS - CMS  
CUMULATIVE SCALE  
SCALE  
VALUE  
INDIVIDUAL

Electrode Separation "a" in feet

3  
6  
9  
12  
15  
18  
21  
24  
27  
30  
33  
36  
39  
42  
45  
48  
51  
54  
57  
60  
63  
66  
69  
72  
75  
78  
81  
84  
87  
90  
93  
96  
99  
102

PL = 3 FEET

Fig. 6



NAME \_\_\_\_\_ NO. \_\_\_\_\_

DATE: 7/1/59

BY: WARK

STA. 00 + 330' E      OFFSET 900' S      LT. \_\_\_\_\_  
RT. \_\_\_\_\_

10   20   30   40   50   60   70   80   90   100   200   500   1000   2000

Ground Surface

5' Clayey Sand

10' Moist Kaolin

Refusal in kaolin  
Cemented Silica Sand

0  
3  
6  
9  
12  
15  
18  
21  
24  
27  
30  
33  
36  
39  
42  
45  
48  
51  
54  
57  
60  
63  
66  
69  
72  
75  
78  
81  
84  
87  
90  
93  
96  
99  
102

Electrode Separation "a" in feet

CUMULATIVE SCALE

RESISTIVITY - THOUSANDS OF OHMS - CMS

SCALE

VALUE

INDIVIDUAL

No Registration on Meter  
Regardless of Scale

BED ROCK

PL = 3 FEET

Fig. 7



NAME \_\_\_\_\_ NO. \_\_\_\_\_

DATE: 6/19/59

BY: WARK

STA. 00'+31 S

OFFSET

LT.  
RT.

10 20 30 40 50 60 70 80 90 100 200 500 1000

Ground Surface

8' Damp Sandy Clay

- Refusal in kaolin Cemented silica sand

CUMULATIVE SCALE

RESISTIVITY - THOUSANDS OF OHMS - CMS

SCALE

VALUE

INDIVIDUAL

Electrode Separation "a" in feet

0  
3  
6  
9  
12  
15  
18  
21  
24  
27  
30  
33  
36  
39  
42  
45  
48  
51  
54  
57  
60  
63  
66  
69  
72  
75  
78  
81  
84  
87  
90  
93  
96  
99  
102

PL = 3 FEET

Fig. 8

SOIL RESISTIVITY GRAPH  
VERMONT GEOLOGICAL SURVEY

between the overburden and kaolin can be detected by resistivity methods in this area. Profiles indicating kaolin some distance from the known ore bodies should be substantiated with additional drilling.

Work done from the three base points 0, 0', and 0'' are not represented in profile because the writer is of the opinion that this portion of the survey was conducted over non-kaolin bearing ground. This conclusion is drawn from the appearance of the resistivity data and the fact that hand augering, as far as it was possible to penetrate, showed no kaolin where the resistivity data indicated its possible presence.

### CONCLUSIONS

The results of this survey indicate that resistivity methods definitely have their place as a geophysical prospecting tool for kaolin, but with the type of overburden present in this area (variable amounts of clay, sand, gravel and water) the information derived therefrom is by no means conclusive enough to be taken at face value without substantiation by drilling.

Because the area in which resistivity data was accumulated for purposes of correlation has been disturbed by past intermittent working of the kaolin beds, it is further concluded that the resistivity values estab-

lished for kaolin and the overburden may prove to need some revision when additional drilling has been done in undisturbed ground.

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## APPENDIX A\*

### *"Smoothed" Field Curves*

For the purposes of the field investigation the author and investigator took the electrode separation as equal to the depth penetration. This is very seldom true.

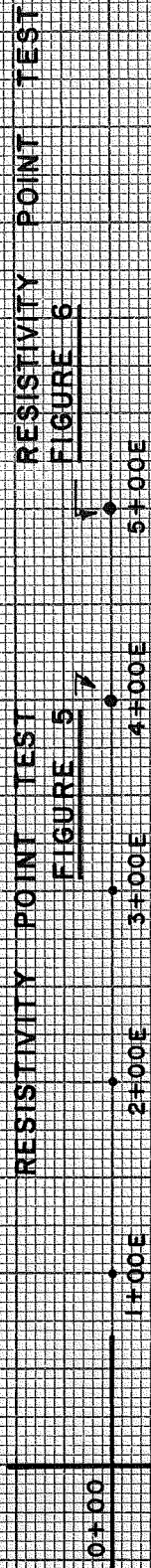
It is almost always necessary to smooth the field curves and to match them to a simulated mathematical model which does not always represent a unique geologic environment.

Two "smoothed" field curves are shown in Figure 10 and Figure 11 which correspond respectively to the "field" plots of Figures 5 and 6. A plan is shown in Figure 9.

\* Contribution by Mr. Richard J. Holt, President, Weston Geophysical Research, Inc.

# PLAN MAP OF RESISTIVITY POINTS SCALE 1"=100'

C.D.H. # 5



NOTE: WENNER SPACINGS EXPANDED  
IN EAST--WEST DIRECTION

FIGURE 9

# RESISTIVITY POINT TEST (SEE FIGURE 5) 0 + 400' E

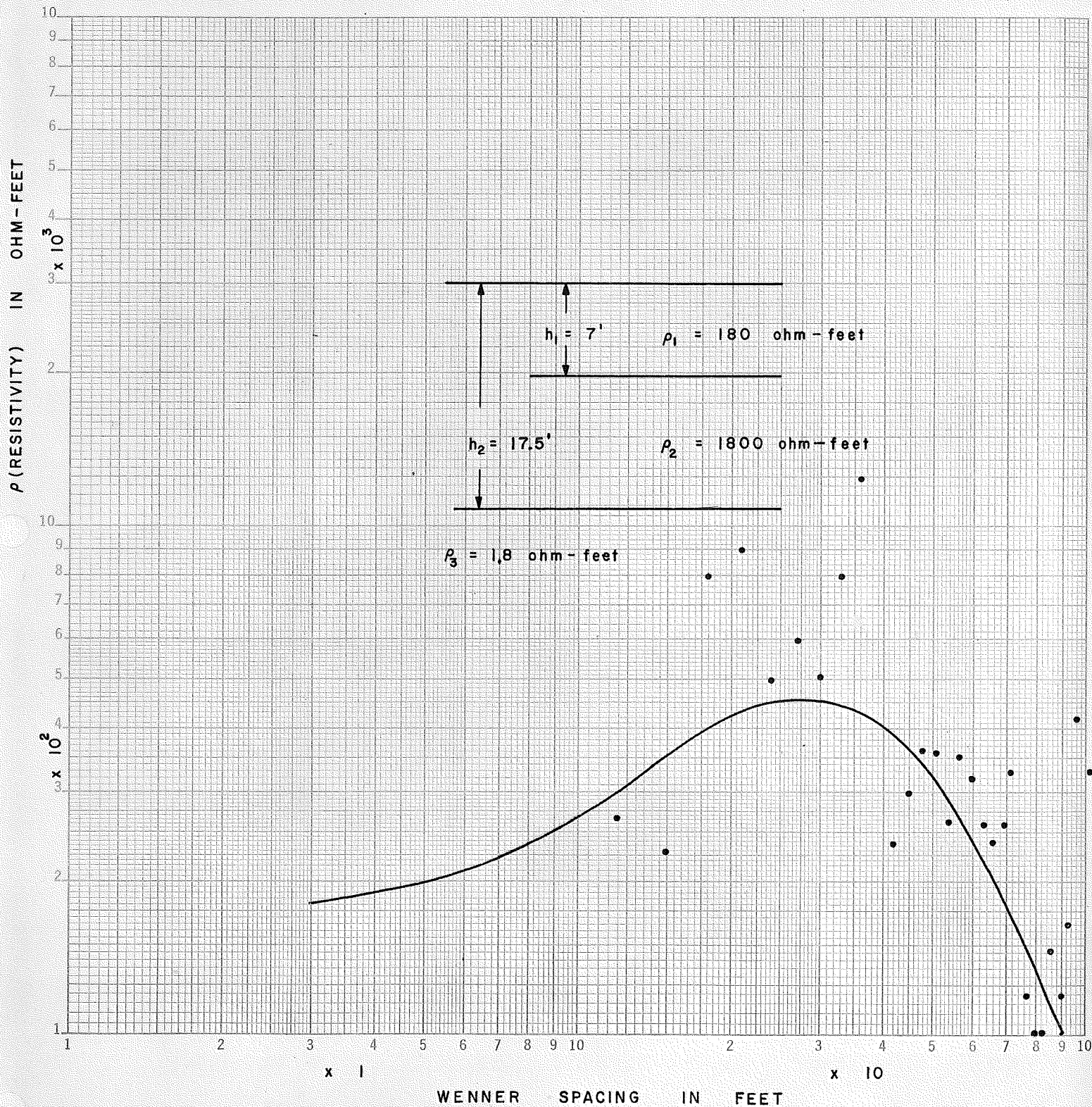


FIGURE 10



RESISTIVITY POINT TEST (SEE FIGURE 6)  
00 + 500' E

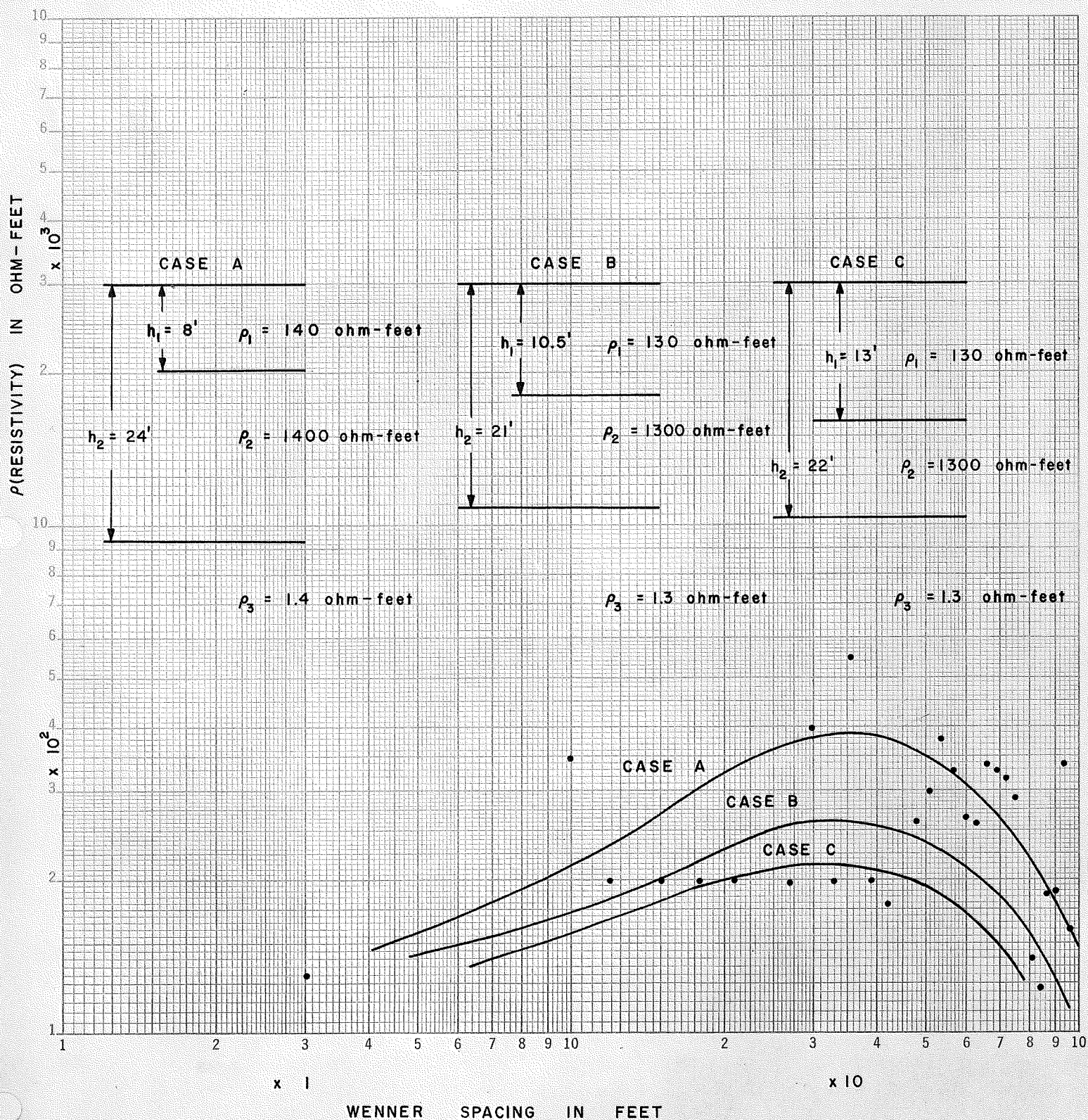


FIGURE II

## APPENDIX B\*

### *Vermont Kaolin Corporation Drill Hole Exploration 1960 and 1961*

\* Courtesy Vermont Kaolin Corporation  
Jason A. Wark, Geologist

# SUMMARY OF EXPLORATION WORK IN 1960

## Trenching

Backhoe penetration to friable quartzite on the LaFountain property revealed negligible amounts of ore at six sites. These are located between the south end of the old worked-out pit and a point at the height of land approximately 1000 feet N 70° W.

Although the bedrock exposed is in the Cheshire Formation, it is not a true quartzite. The original rock

is now a poorly cemented silica sand with friable quartzitic members and finger-width layers of kaolin. Despite this marked alteration, the original sedimentary structures are preserved, indicating an average strike of N 20° E and dip of 50° SE.

The overburden, glacial till, is made up of cobbly, clayey-sand, 2 to 7 feet thick. Auger drill (130 recorded holes):

Area	Total Footage	Total Overburden	Overburden in holes showing kaolin	White Kaolin	Yellow Kaolin	Total Kaolin
Blanchard	471.0	220.0	142.5	142.5	108.5	251.0
Jewell	2943.5	1114.5	834.0	1448.5	380.5	1829.0
Jewell & Blanchard	3414.5	1334.5	976.5	1591.0	489.0	2080.0
LaFountain	2031.0	698.5	325.0	97.5	1235.0	1332.5
Total:	5445.5	2033.0	1301.5	1688.5	1724.0	3412.5

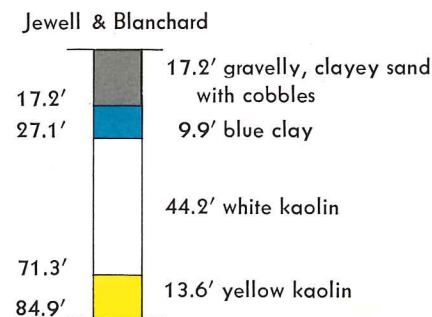
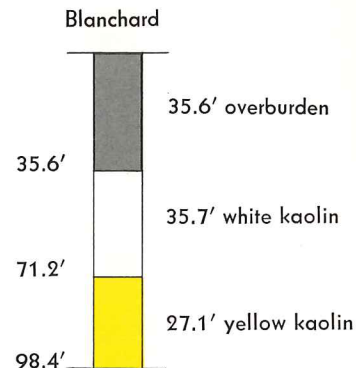
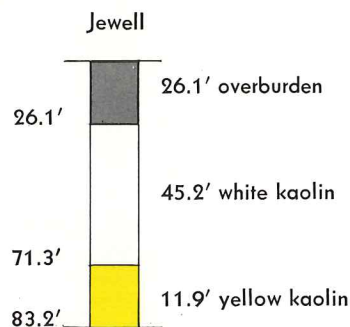
Total number of holes drilled on respective properties:

Blanchard—8; Jewell—50; Jewell & Blanchard—58; LaFountain—72.

Holes drilled on respective properties, penetrating to kaolin:

	No. of Holes	Footage
Blanchard	4	393.5
Jewell	32	2663.0
Jewell & Blanchard	36	3056.5
LaFountain	40	1657.5
Total	76	4714.0

Average of productive\* holes on Jewell and Blanchard properties:



\* Only the holes penetrating to kaolin are considered in these calculations, but there is reason to believe that kaolin also underlies those holes not penetrating the overburden in this area.

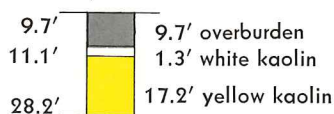


Exploration drilling on the Jewell and Blanchard properties north of the road between the schoolhouse and Barnum's (coordinates W800'-W2400' and N2300'-N4900') covered 4,160,000 sq. ft. (91.3 acres).

Taking into consideration the amount of overburden in this area (10'-50'), the depth to which kaolin was found, (Max. 177'), and the apparent lack of any major structural division of this clay body into two or more parts, it seems reasonable to assume an average thickness of 58' for the kaolin-bearing ground underlying this area. With this knowledge of the third dimension, we can calculate 241,280,000 cu. ft. of ore in place. Using a factor of 15.4 cu. ft. = 1 ton, (derived from direct weighing of a 6-inch cube carved from a representative block of ore in place), this gives 15,652,000 wet tons, or minus 20% water, 12,491,600 dry tons. Subtract 1/3 for included quartzite, clay left in pit banks, clay loss in stripping and pit operation, there remains an estimated recoverable reserve of 8,318,000 dry tons of ore in place for this area.

Of this figure, approximately 1,331,000 dry tons are unsuitable for processing in the present plant facilities because of an  $\text{Fe}_2\text{O}_3$  content.

Average of Auger Drill Holes on LaFountain Property:



Both productive and non-productive holes are considered on this property, as most of those not penetrating to kaolin bottomed in Cheshire Quartzite. The drilling to date indicates a substantially large portion of this area as non-kaolin bearing, which must be considered if a realistic average of potential is to be construed and applied toward an estimate of ore reserves on this property. Any estimate of reserves will, however, be partly conjecture, until more extensive exploration drilling is completed.

Approximately 175 acres, or 8 million square feet of the LaFountain property were scantily explored. Using 18.5 feet of kaolin for an average, as represented above, we would have 148 million cubic feet of ore. Applying the same factors as in the preceding section on the Jewell-Blanchard properties, we are left with 5,116,000 dry tons of recoverable ore in place, nearly all of which is too discolored by  $\text{Fe}_2\text{O}_3$  to be dry milled if a white product is desired.

None of the colored clay sampled to date has a high enough  $\text{Fe}_2\text{O}_3$  content to be considered an ocher. Analysis of the deepest stained sample collected showed 3.9703% Fe. If all the Fe is in combination as  $\text{Fe}_2\text{O}_3$ , it gives a calculated  $\text{Fe}_2\text{O}_3$  percentage of 5.677, which is less than the required 15% to 80% necessary for inclusion in this mineralogical classification.

Total estimated ore reserves, including colored clays, in the areas explored may be enumerated as follows:

Eastern ore body	1,095,700 dry tons
Western ore body	1,500,000 dry tons
Jewell-Blanchard property	8,318,000 dry tons
LaFountain property	5,116,000 dry tons
Total:	16,029,700 dry tons

Considering the original estimated crude ore feed to the mill of 64,000 dry tons per year, and just the ore suitable for dry milling, (9,582,700 dry tons) these reserves should last for 150 years.

## GEOLOGY

The East Monkton kaolin is associated with Cheshire Quartzite which predominates in this area. This hard and resistant Lower Cambrian formation, dating back some 500 million years, outcrops as pronounced ridges representing differentially eroded remnants of the north-south trending Starksboro syncline, Hogback anticline, and Monkton thrust. These structures are included in the Monkton cross anticline—from which the Middlebury synclinorium plunges southward, and the Hinesburg synclinorium plunges northward.

Tectonic forces involved in producing the foregoing structures were also responsible for extensive joint and fracture systems found in some members of the Cheshire Quartzite. This fracturing and jointing is exhibited in the quartzite layers which remain as relatively unaltered members of the ore body and were the avenues through which hydrothermal alteration of more porous members took place.

As for the agent necessary for addition of alumina to the secondary silica of the quartzite, the assumption is made that its origin is related to the igneous activity of Triassic time, as evidenced by the regional geologic relationships of the Champlain Valley dikes (camp-tonite) and the Barber Hill syenitic intrusion in Charlotte.

Nearly all past reports on the geology of this deposit mention the presence of megascopic feldspar in hand specimens, but a search of the area revealed none in evidence. However, microscopic feldspar (microcline) is found in the quartzite, but not in quantities large enough to warrant the previous theory that this deposit resulted from weathering of feldspar in place. Indeed, the characteristics exhibited in exposed portions of this deposit leave little room for postulating an origin other than hydrothermal.

The foregoing is taken from an abstract of a Master's thesis at the University of Vermont written by Duncan G. Ogden, entitled "Geology and Origin of the Kaolin at East Monkton, Vermont."

In the vicinity of the Vermont Kaolin Corporation office, where sufficient drilling and trenching have been carried out, two ore bodies have been mapped, which are separated by approximately 500 feet of relatively non-kaolin bearing, friable Cheshire Quartzite. They have been referred to as the eastern and western ore bodies, generally paralleling each other, dipping to the east, and striking in a northeasterly direction. The western ore body is located near the top of the ore-bearing ridge, but its easterly dip places it stratigraphically below the eastern ore body.

The eastern ore body is limited on the east by a north-south fault paralleling the road in front of the Vermont Kaolin Corporation office, and on the west by friable Cheshire Quartzite separating the two bodies. To the north, the northeasterly striking footwall bears to the east, intercepting the north-south fault, thus terminating the ore body in this direction, while to the south, it seems to gradually pinch out. An estimate of 1,095,700 dry tons of white clay in place and available for treatment has been made for this ore body.

The western ore body has not been completely delineated because non-ownership of the property and

mineral rights prohibited exploration in that direction. However, an estimate of 1,500,000 tons of white, pink, purple and lavender clay has been made for this ore body.

An additional 130 auger drill holes were logged in 1960 to extend the area of exploration over approximately 300 more acres. A total of 5572.5 feet was drilled, 3437 of this in kaolin. Of this latter figure, approximately 50% was in kaolin containing enough  $\text{Fe}_2\text{O}_3$  to make it unsuitable for processing in the present plant. In none of the samples taken, is the  $\text{Fe}_2\text{O}_3$  content high enough to classify the material as an ochre.

Considering the areal extent covered in this phase of exploration, the depth to which kaolin was found (max. 177'), the amount of overburden (10'-50'), and the uncertainty of any structures which may be inferred from this type of drilling operation, a reasonable estimate of recoverable wet ore in place, would be 5 million tons. This would bring the total of known, probable, and estimated ore reserves to approximately 6.5 million dry tons of ore in place, 2.5 million tons of which are unsuitable because of their  $\text{Fe}_2\text{O}_3$  content.

#### WEIGHT DETERMINATIONS OF KAOLIN AND ASSOCIATED MATERIALS

	<i>Weight</i>	<i>Volume</i>	<i>lbs./cu. ft.</i>	<i>cu. ft./ton</i>
Quartzite (Dense-Vitreous)	210.05 g .46316025 lb.	80 ml. .0026248 cu. ft.	176.46	11.3
Quartzite (Dense-Sandy)	77.82 g .1715931 lb.	31 ml. .00109491 cu. ft.	156.7	12.8
Quartzite (Sandy-porous)	210.32 g .4637556 lb.	101 ml. .0035631 cu. ft.	130.04	15.4
Quartzite (Sandy-soft)	261.72 g .5770926 lb.	130 ml. .00459030 cu. ft.	125.7	15.9
Vein Quartz (Gray to milky)	135.05 g .29788525 lb.	52 ml. .00183612 cu. ft.	162.23	12.3
Kaolin Frozen raw ore from s. face of operating pit 100' from footwall	106.9 g .2357145 lb.	62 ml. .00218922 cu. ft.	107.67	18.6
Kaolin Frozen raw ore from Bushey Pit below Quartzite layer	883.1 g 1.9472355 lbs.	370 ml. 0133647 cu. ft.	questionable, as air escaped from sample during volume determination 145.8	13.7
*Kaolin Raw ore from s.e. corner of operating pit.	16 1/8 lbs.	6 cu. in.	129.0	15.4

\* This weight determination for wet raw ore is probably the most valid, as the calculations were made from a 6" cube carved from a block of ore in place. Dry weight was 13 lbs. giving a moisture content of 20% for ore in place.

Calculated from its specific gravity (2.63), kaolinite has a weight of 164.0328 lbs/cu. ft. or 12.2 cu. ft./ton.

1 g = .002205 lb.

1 cc = .00003531 cu. ft.



# STRATIGRAPHIC COLUMN OF MONKTON AND VICINITY\*

Upper Cambrian Series	Danby Formation	Protruding, differentially weathered beds of gray quartzite 1 or 2 feet thick separated by varying thicknesses of dolomite.	400-800' thick
	Winooski dolomite	Pink to buff or even gray beds of dolomite 4 inches to 1 foot thick separated by thin siliceous partings which protrude as dark, slightly undulating ridges.	100-800' thick
	Monkton quartzite	Decidedly reddish color varying from reddish-brown through brick red and purple to light shades of red, pink, buff and white quartzite in layers from a few inches up to 3 feet thick separated by beds of pink to gray dolomite.	0-800' thick
Lower Cambrian Series	Dunham dolomite	Siliceous buff-weathering dolomite containing well-rounded sand grains irregularly distributed; it is pink and cream mottled or buff to gray on the fresh surface.	1700-2000' thick
	Cheshire quartzite	Pure massive white, gray and blue quartzite; lower portion less massive appearing and weathers brown.	1000' $\pm$ thick
	Mendon formation	Conglomerate, albite-quartz-chlorite-muscovite schist. Forestdale member in middle: buff to white dolomite, Moosalamoo member at top; graphitic quartz—muscovite schist.	800-1800' thick
Unconformity			
Pre-Cambrian	Mount Holly	Gneiss, schist, quartzite (tourmaline-bearing pegmatites).	? thick

\*After W. M. Cady, Bull. Geol. Soc. Am., Vol. 56, 1945, p. 525.

## EXPLORATION DRILLING IN 1961

Drilling was confined to the LaFountain property, and the few holes (16 in number) drilled just east of the old county road and south of the bordering Barnum property revealed no changes in estimated ore reserves as predicted from data accumulated in 1960. This area, bounded by coordinates W900-W2000 and S100-S1000 (22.7 acres), has a fairly rich body of ore but it is all yellow-brown in color. It was from this sector that colored clay feeding from the drill holes was processed by Mr. Fred Tupper in the pilot mill and distributed to independent ceramists in the Burlington area for firing.

Similarly, colored clay was found in a few holes scattered to 2200 feet south of this location, but they are too widely separated to say positively that they indicate an uninterrupted continuation of this ore body.

This deposit of colored kaolin is west of the so-called "upper" or "western" ore body and is an entity in itself. A series of holes drilled on a line running westerly of the "western ore body" encountered mixed strata of sandy brown, friable Cheshire Quartzite with little or no kaolin and a relatively firm non-iron bearing member of the same formation. This is the footwall of the

western ore body and it continues for approximately 400-500 feet before encountering the body of colored clay. There are a few kaolin-bearing members in this footwall, but they are quite sandy and not very thick. Actually, neither is the ore body under discussion (approx 100'), but it appears to be of good quality as it feeds up the augers and may be of some value in the future.

Continuing in a westerly direction to the old county road bordering the Barnum property, a distance of about 250 feet, we again encounter very sandy, friable, brown Cheshire Quartzite with little or no kaolin.

As far as is known, the structural geology in this area conforms to that of the region; namely, a northeasterly strike and southeasterly dip. These structures have been exposed in only one place. A backhoe exposure was made next to ADH 60-111, located in the southwest corner of the T-shaped field on top of the hill west of the office, which showed a strike of N 12° E and dip of 60° E. Also exhibited was the suggestion of a minor fold which could be indicative of an anticline as postulated for this ridge by Ogden in his thesis "Geology and Origin of the Kaolin at East Monkton, Vermont." If this anticline could be demonstrated to

be a fact, the chances are reasonably good for the presence of white kaolin on the western limits of the Barnum property which borders the Cheshire Quartzite escarpments forming the Monkton break thrust.

In support of this possibility is the fact that as one crosses the kaolin deposits as a whole from east to west, he invariably passes from white to colored clay. If the ridge in question is an anticline, then one would be crossing from the upper to the lower members of the Cheshire Formation in the anticline's east limb, and since the lower members are characteristically rusty brown in color this would help explain why some of the clay is stained with Fe.

A series of holes drilled across Barnum's fields to their western limits on this ridge would aid a great deal in answering some of the foregoing questions. Company property borders these fields to the south, but the presence of woods and a ravine would make it difficult, time consuming and expensive to carry out a drilling program there.

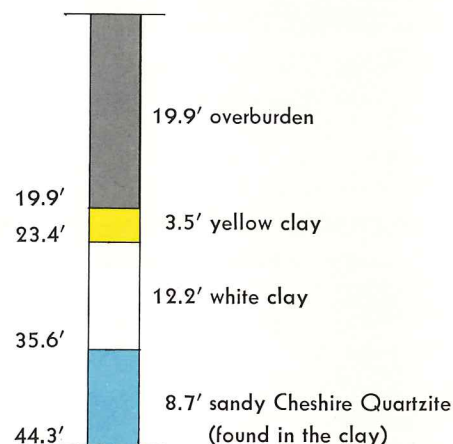
The remainder of exploration drilling in 1961 was carried out on the southern limits of the LaFountain property along the now unused county road which runs from the old Monkton iron ore bed up the ridge to Estey's.

The geology of this area is far from understood and the 34 holes drilled have seemed to do nothing but confuse the issue. No visible pattern of ore trends can be drawn from the drilling data in these holes as yet, but one valuable bit of information gained from them is the discovery of an unsuspected deposit of white kaolin, some of which seems richer than any encountered in the past two years of drilling.

The deposit appears to be a small one, judging from the scanty information available, and may be a small pocket of white clay similar to that in the old pit at the south end of the runway. In mentioning this old pit it should be pointed out that next to nothing is known about it. It has always been assumed that the ore gave out and was therefore abandoned. This is a reasonable assumption but not conclusive. It is just possible that the body of ore continues to dip to the east and that operations were abandoned because the owners chose not to go underground, being satisfied to glean what they could by open pit operation. It was Mr. Mould's wish to take the drill rig to the bottom of this pit and probe deeper. In addition it was planned to drill holes at an angle into the east wall near its bottom to determine if the ore does continue in that direction. Cheshire Quartzite outcrops along the top of this east wall give the impression of dipping to the east, in which case it would be the hanging wall to any remaining ore. The quartzite is fractured and would present a definite hazard to any underground mining and this may be one reason that work was terminated in the past.

This newly discovered white clay just north of Estey's may be more extensive than meets the eye. Many of the holes drilled were difficult and met refusal in sandy brown, friable Cheshire Quartzite, but those that did not meet refusal penetrated to as much as 124 feet, showing 87 feet of white kaolin. The average thickness of white clay is approximately 40 feet as revealed by the holes that did penetrate to white clay.

Shown below is an average drill log computed from data collected in this area.



Using the same line of reasoning and factors considered in the 1960 report on exploration drilling, an estimate of 228,162 recoverable dry tons of white kaolin can be mined from this deposit. At planned plant consumption this is about a 4 year's supply.

There is also a small amount of colored clay adjoining the above deposit which is estimated at 66,454 recoverable dry tons.

This area has an overburden averaging 26 feet, from as little as 10 feet to as much as 43 feet. It is made up predominantly of clayey sand with cobbles and pebbles, and a few minor layers of hard pan. Also included in this overburden is a cap rock of brown sandy, friable Cheshire Quartzite which does not exceed a thickness of 5 feet in the holes encountering white clay. It rests directly upon the clay and it may be that some of those holes which met refusal in this same material might have encountered kaolin had it been possible to drill to a greater depth. This has been a bad point in the whole exploratory drilling program. Every hole drilled should have been carried to a depth commensurate with the information desired, regardless of whether it was in productive ground or not. It could be argued that anything that cannot be penetrated

with auger drilling is not worth investigating anyway because it would be too expensive to remove in mining; but if one follows this line of reasoning he suffers under the handicap of not knowing conclusively the geologic structural relationship between kaolin-bearing ground and non-kaolin bearing ground. Consequently, any estimate of ore reserves are empirical at best. Worse yet, one cannot plan a valid mining program for removal of the ore.

One interesting fact about this deposit is the presence of pure white sugary silica sand occurring in layers as much as 10 feet thick and having little or no kaolin mixed with it. Layers of white sugary sand have been mentioned in some of the old descriptions of the ore body near the office when it was first discovered and mined, but this is the first time that such material has been collected from any of the holes drilled over the past two years. This may be a good sign as the old mines had this material associated with the clay.

There is one further aspect of the exploration program needing attention which will undoubtedly be as time consuming as the drilling itself, and that is the analysis of all samples recovered from the exploratory drill holes. Information sought should include a mineralogical analysis with respective percentages and particle size distribution. Of course, there are many additional specific tests required by the various industries, but it would be to some advantage to have a knowledge of the mineralogy of these samples for the following reason.

It is known that clay deposits are notorious for their variability with regard to mineralogy, the degree and extent of which may be influenced by the origin of the clay deposit. In some cases a marked change can be noted in just a few feet.

Since some difficulty already has been experienced in not having the clay mineral desired (example: ceramics—too much K, presumably illite), it would be desirable to know if there are portions of the deposits which do have the characteristics required by various potential users. Eventually it might be possible (and necessary) to establish a selective mining program to meet the increasingly specialized requirements of industry. It would be a distinct advantage to be able to provide the mill at any given time with material more closely allied to the requirements of a specific industry. Certainly it will not be possible to find clay with only one clay mineral present, but there will be portions of the various clay bodies which will have a higher percentage of one kind than of another. With this knowledge it might then be possible to establish just such a mining program.

Included in this report is a map (scale 1" = 300') covering those properties upon which the company has mineral rights as well as land owned outright (Pl. 12). The locations of all auger drill holes completed in 1960 and 1961 are recorded on this map. Anyone desiring more specific information than is included in this report is advised to use the aforementioned map in conjunction with the drill log data on file under separate cover.

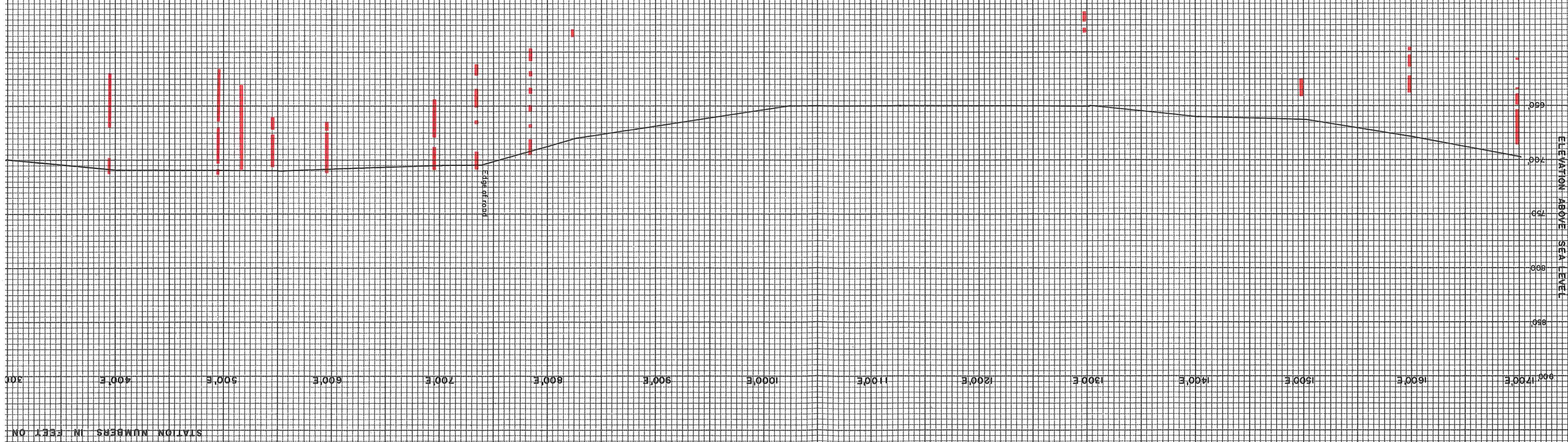
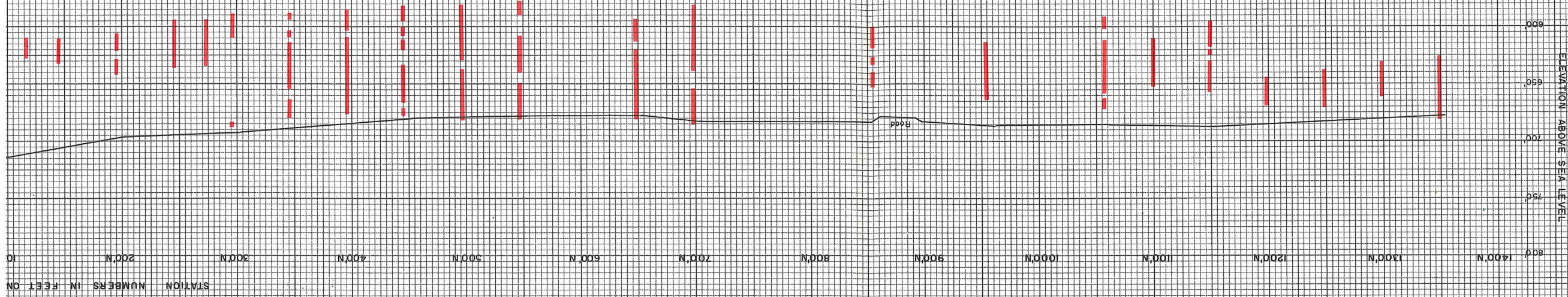
## SUMMARY OF EXPLORATION WORK IN 1961

*Table of Auger Drill Hole Data (50 recorded holes)*

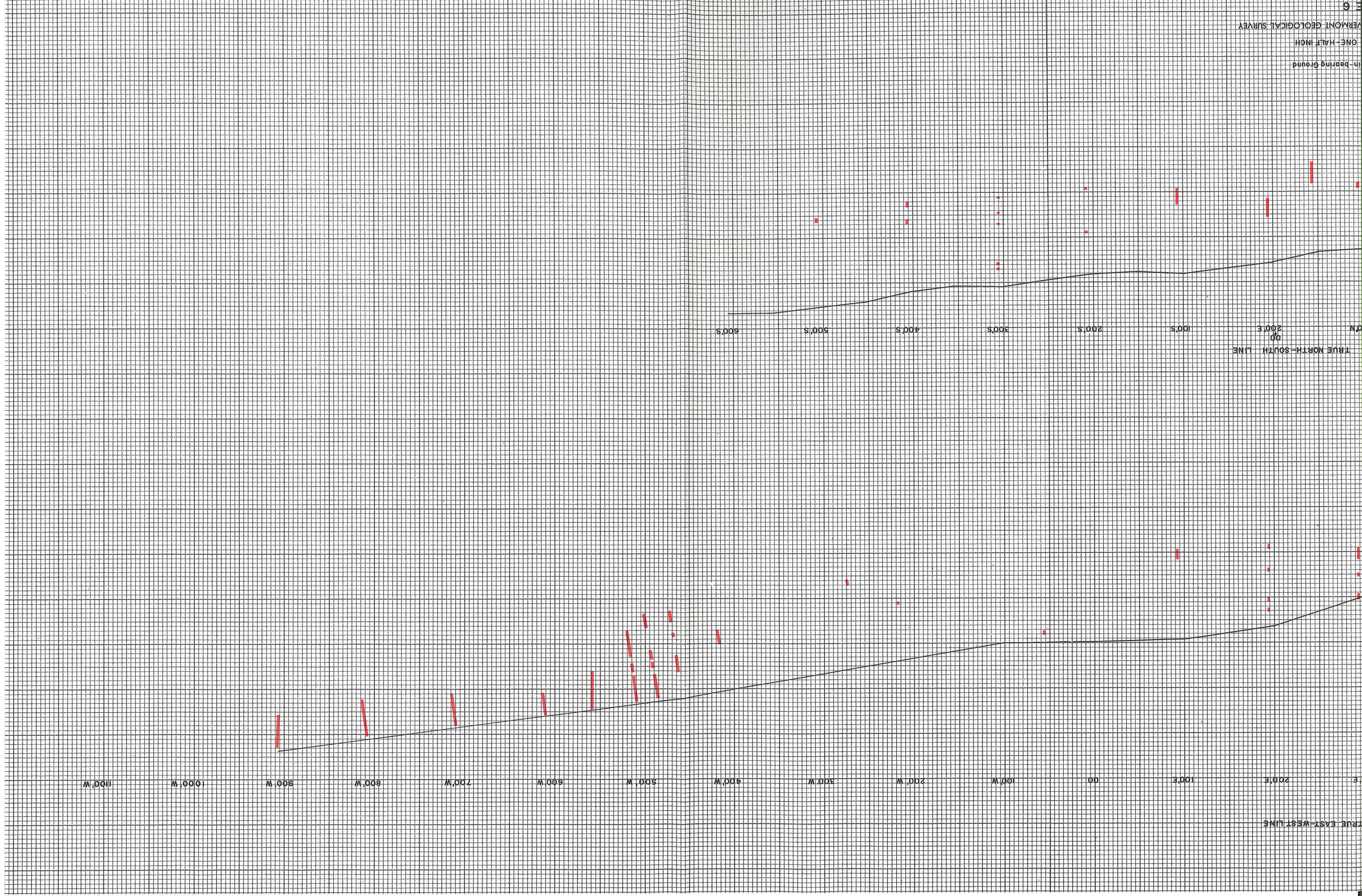
Area	No. of Holes	Total Footage	Total Overburden	Overburden in holes showing Kaolin	White Kaolin	Yellow Kaolin	Total Kaolin
LaFountain (T-shaped field)	16	743.5	142.0	42.0	None	322.5	322.5
LaFountain (just north of Estey)	34	1473.5	666.5	320.5	404.0	115.5	519.5
Total:	50	2217.0	808.5	362.5	404.0	438.0	842.0



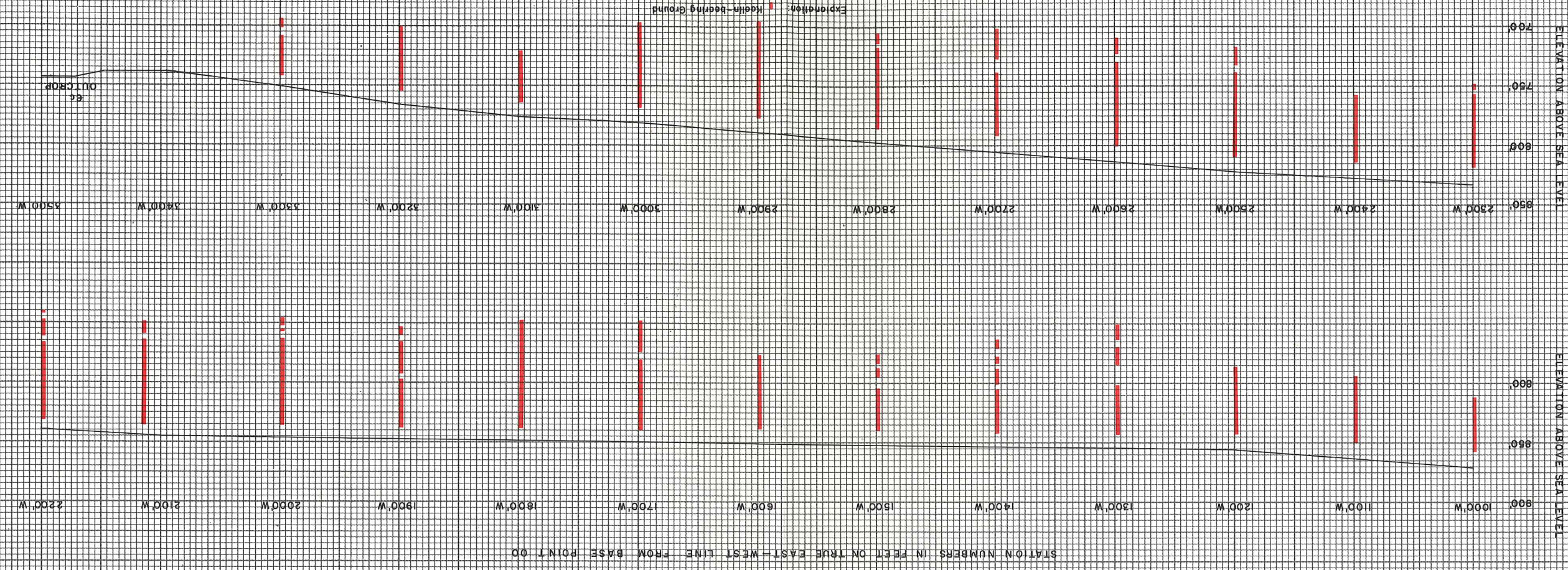
PLAT  
ECONOMIC GEOLOGY NO. 2  
SCALE: 50 FEET/  
Explanation: ■ Koo







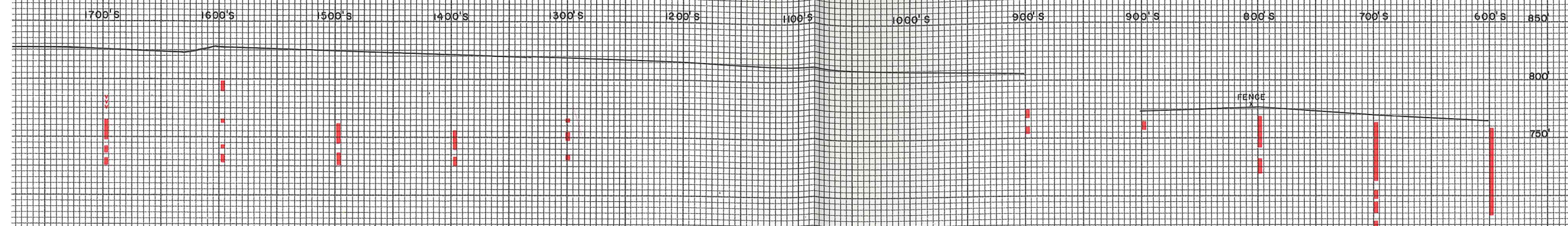




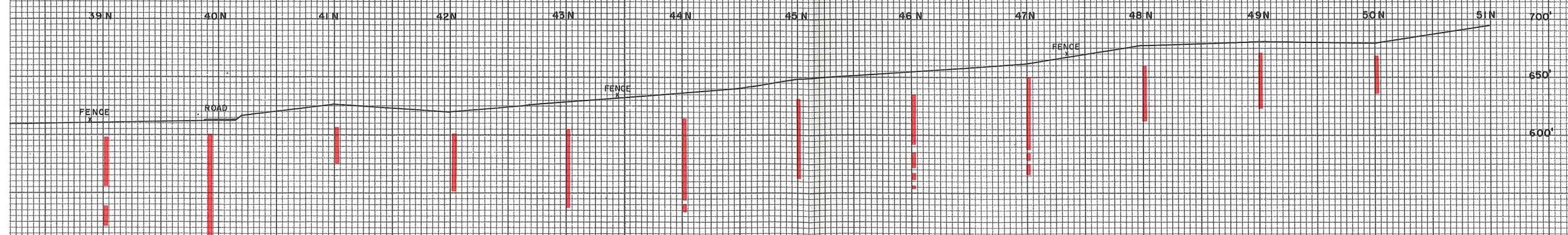
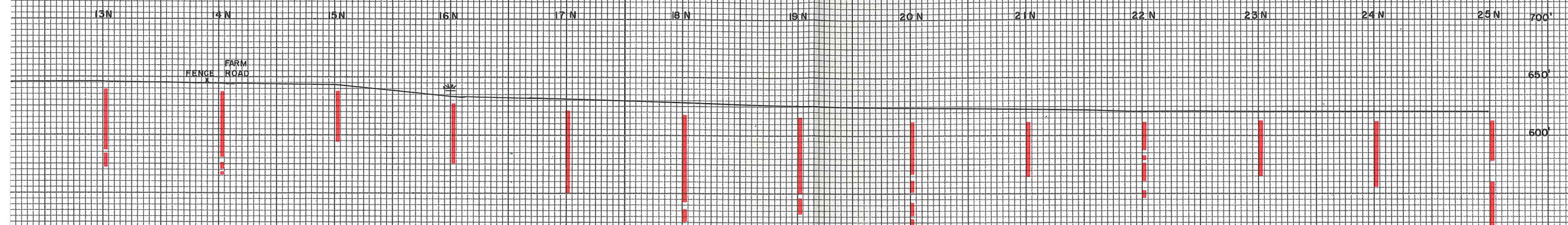


FEET ON TRUE NORTH-SOUTH LINE FROM BASE POINT 00+100'W

BASE POINT 00+330'E



FEET ON TRUE NORTH-SOUTH LINE FROM BASE POINT 14  
(14 IS 1400' NORTH OF 00+200'E)



on: ■ Kaolin-bearing Ground

50 FEET/ ONE HALF INCH  
NO. 2 VERMONT GEOLOGICAL SURVEY  
PLATE 8



STATION NUMBERS (N

ELEVATION ABOVE SEA LEVEL

850' 2400's 2300's 2200's 2100's 2000's 900's 1800's

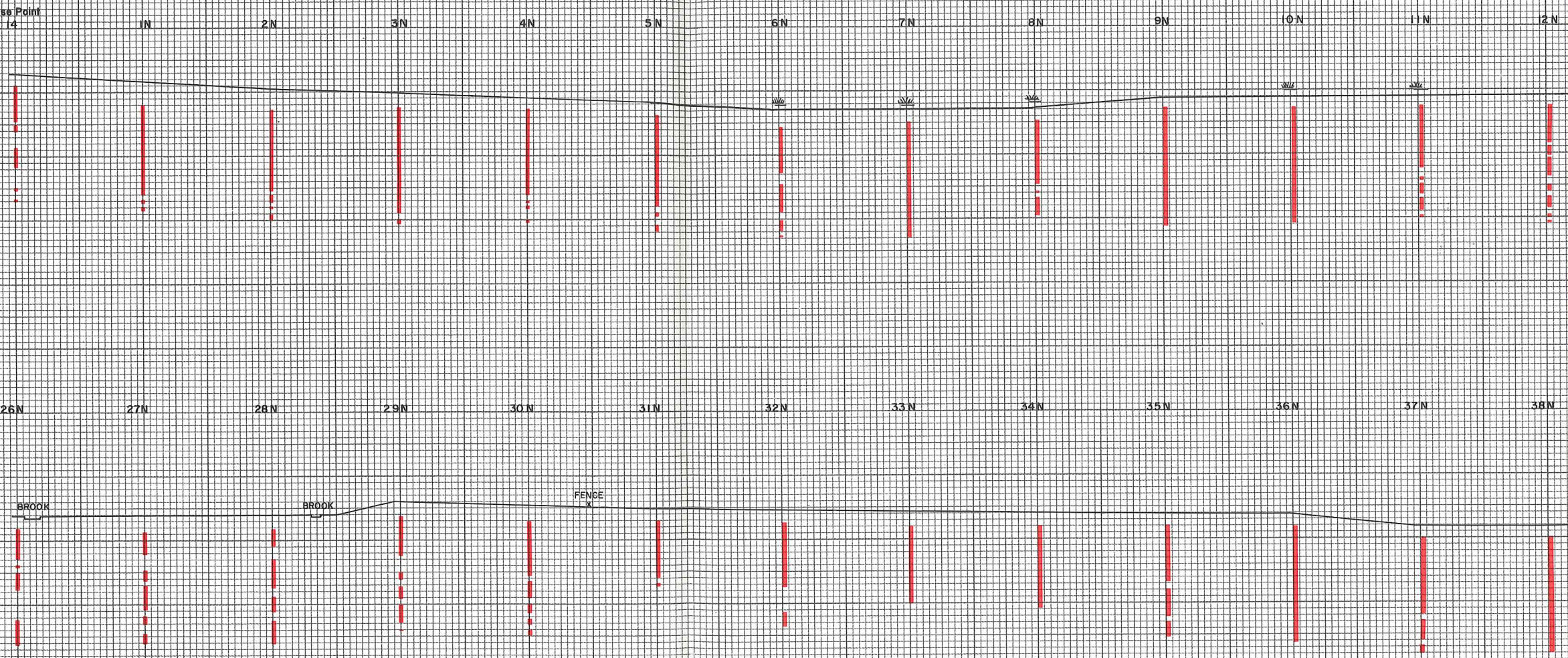
STATION NUMBERS IN HUNDREDS OF FEET  
(BASE POINT

ELEVATION ABOVE SEA LEVEL

700' Base Point 14 1N 2N 3N 4N 5N 6N 7N 8N 9N 10N 11N 12N

ELEVATION ABOVE SEA LEVEL

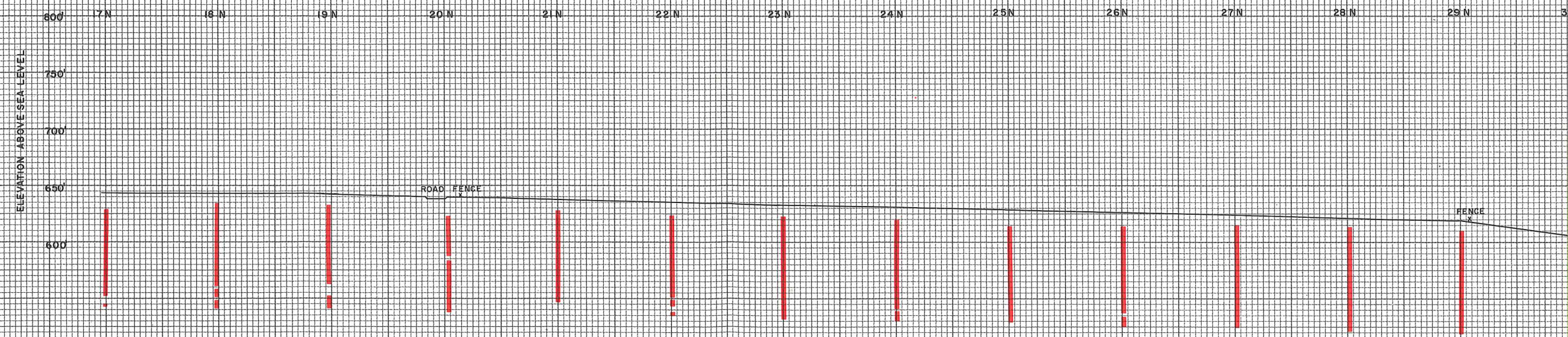
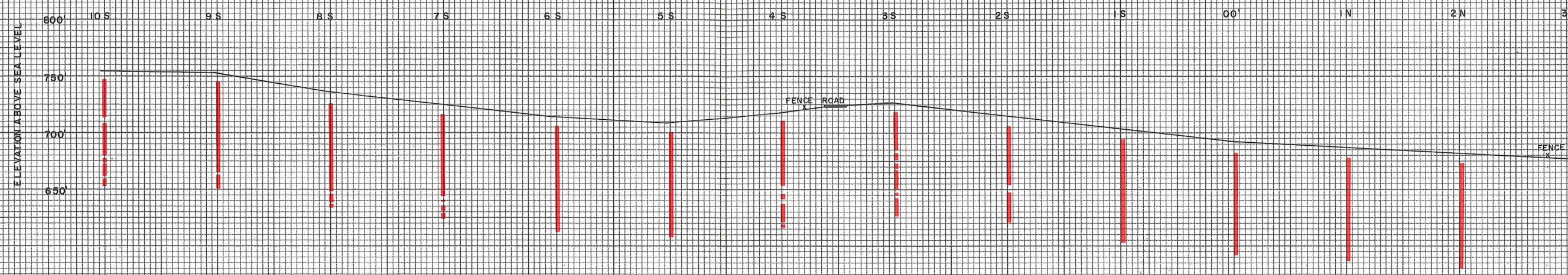
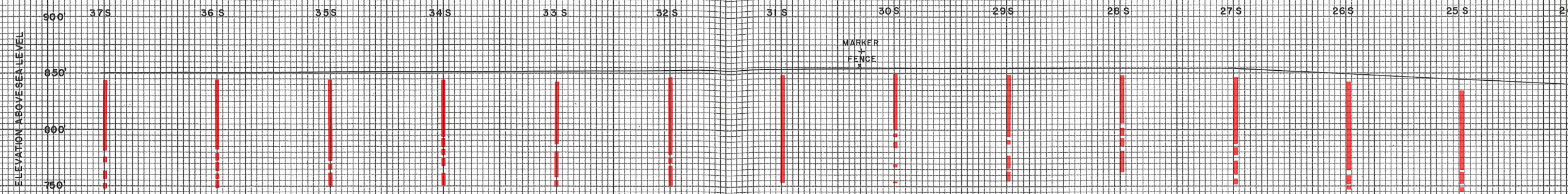
700' 26N 27N 28N 29N 30N 31N 32N 33N 34N 35N 36N 37N 38N



Explorati

SCALE:  
ECONOMIC GEOLOGY







ITH LINE FROM BASE POINT 00

4 S 23 S 22 S 21 S 20 S 19 S 18 S 17 S 16 S 15 S 14 S 13 S 12 S 11 S 900'

850'

800'

750'

N 4 N 5 N 6 N 7 N 8 N 9 N 10 N 11 N 12 N 13 N 14 N 15 N 16 N 900'

750'

700'

650'

0 N 31 N 32 N 33 N 34 N 35 N 36 N 37 N 38 N 39 N 40 N 41 N 600'

750'

700'

650'

600'

FENCE  
A

FENCE  
A

FENCE  
A

FENCE FENCE  
A A

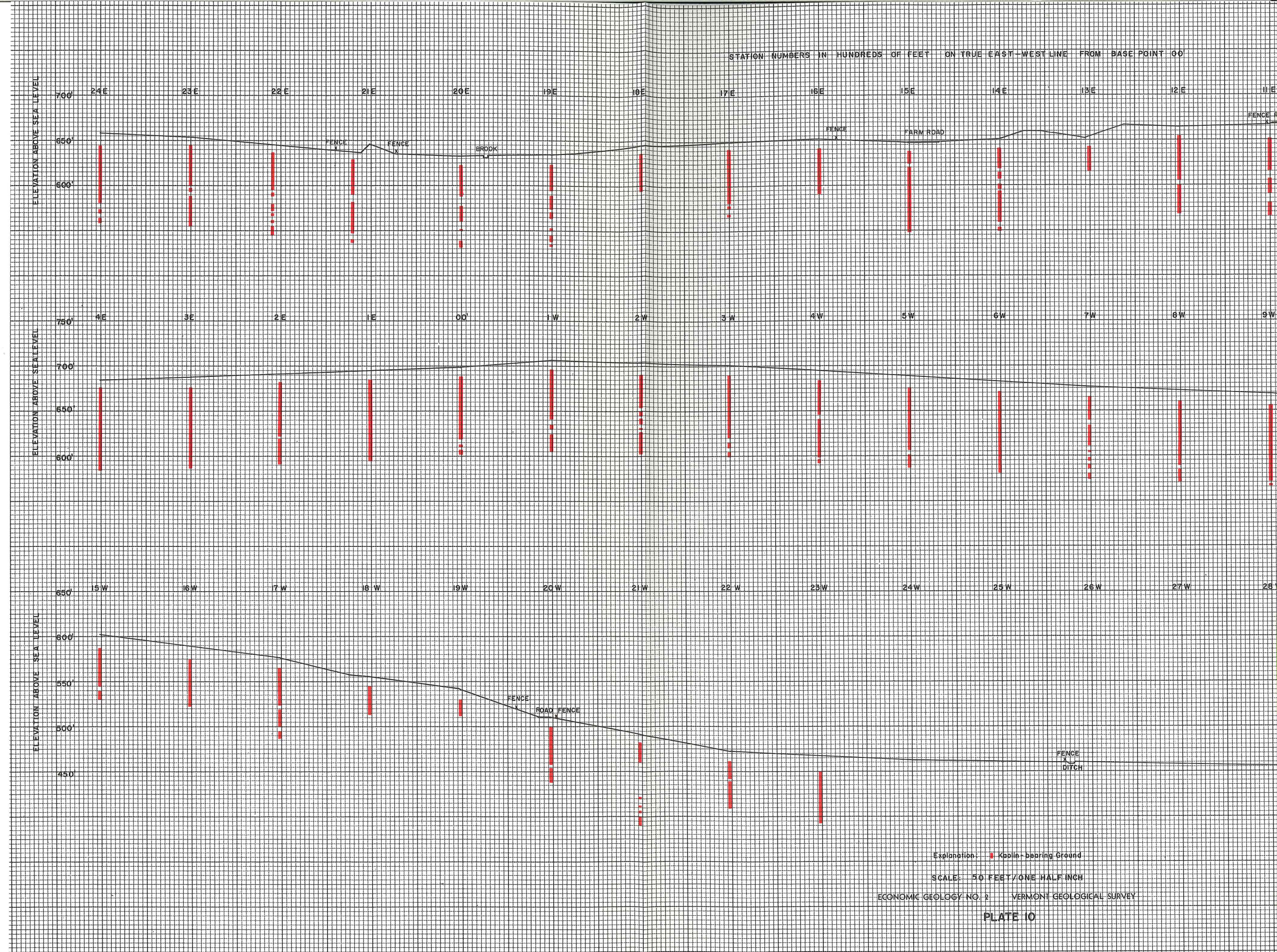
BROOK

FENCE ROAD FENCE  
A A

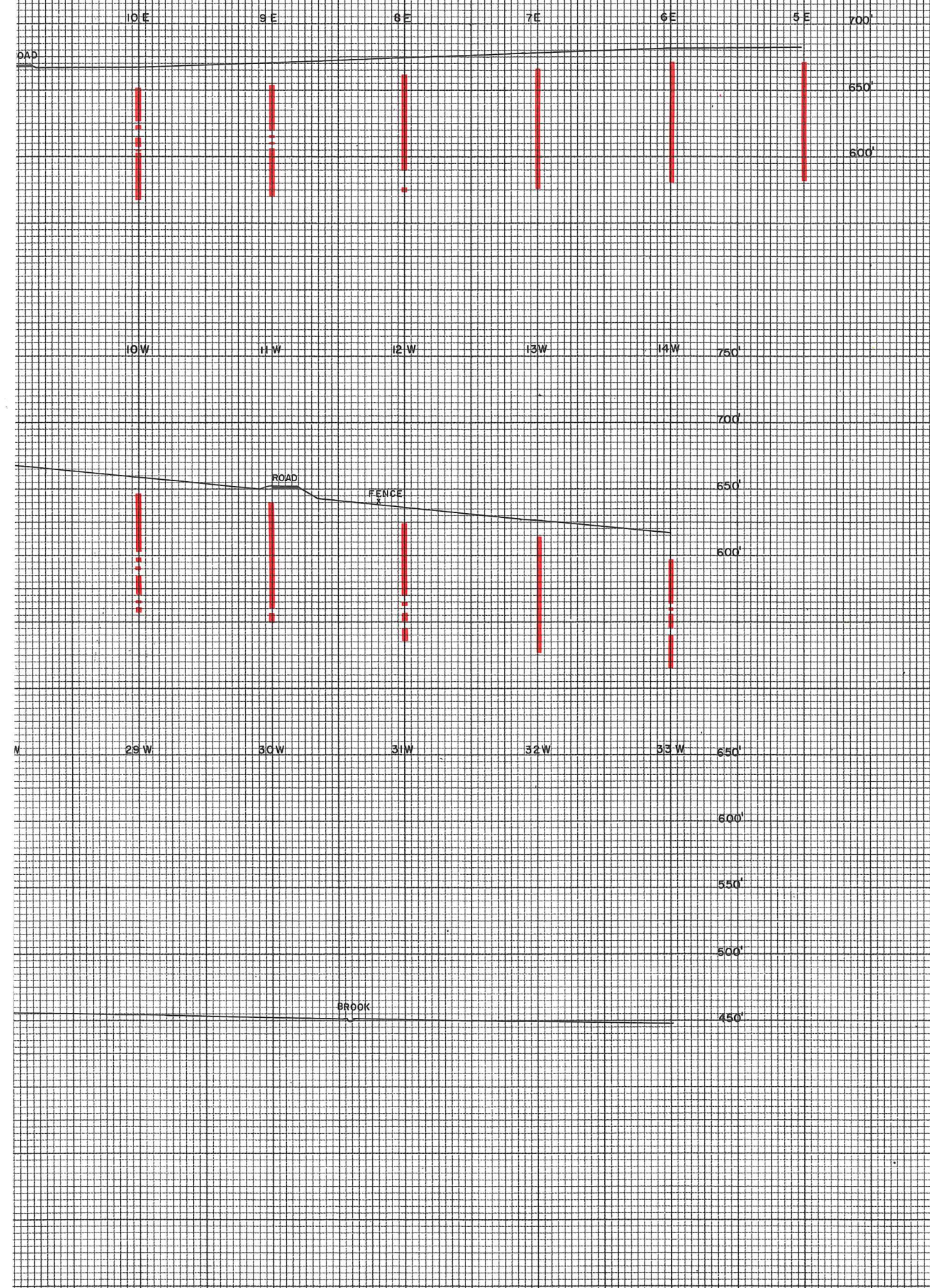
bearing Ground

ONE HALF INCH  
MONT. GEOLOGICAL SURVEY

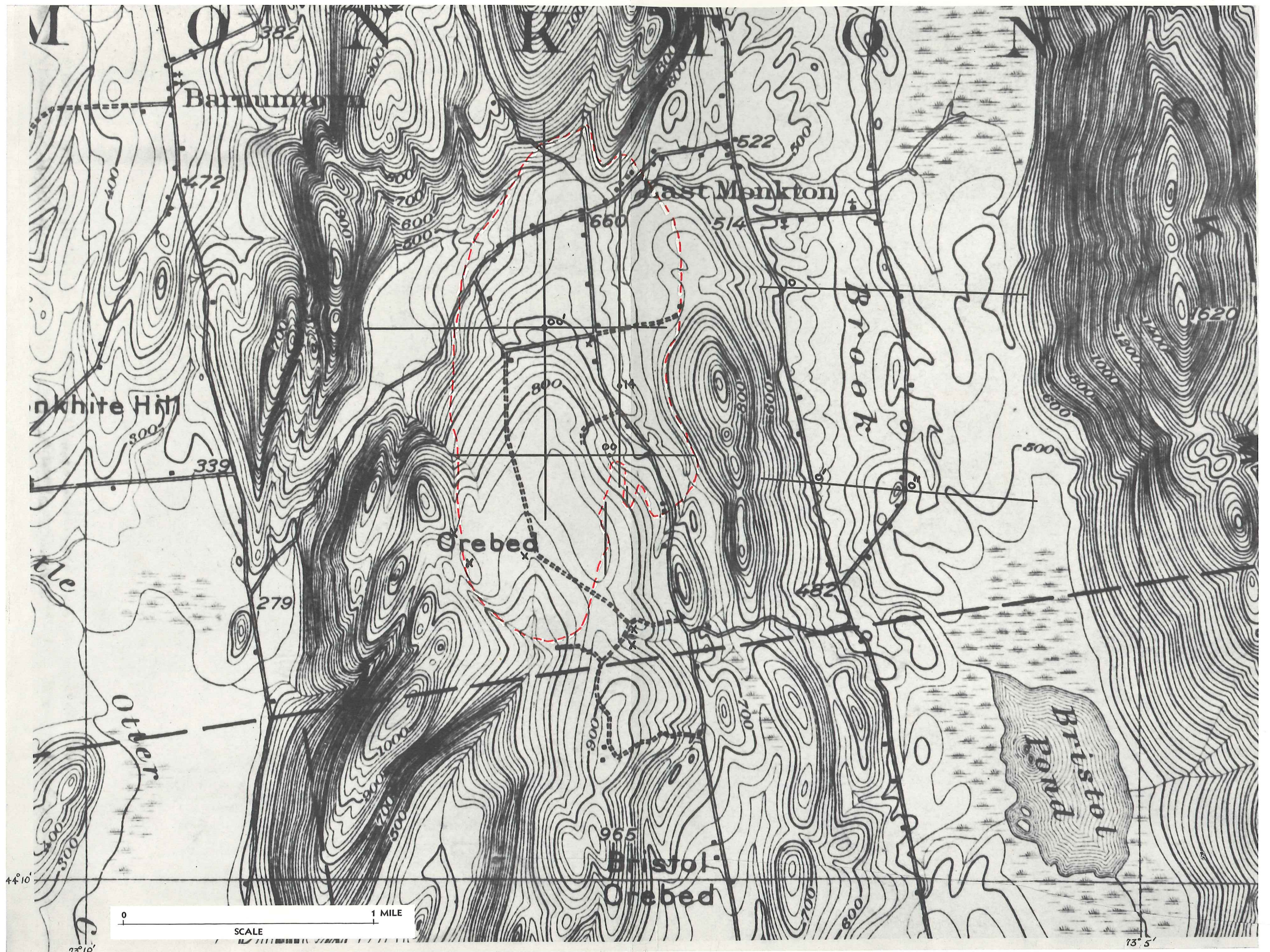












--- Approx. Boundary of Kaolin-bearing Area X = Off-Trace Stations



