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A technique for correcting landslides using a chemical treatment is discussed. Treatment of a specific landslide using the technique is described. The results of a monitoring program to determine the effectiveness of the treatment are presented and analyzed.

The technique appears to be theoretically sound. Treatment of the landslide was simple and relatively inexpensive. The slide now appears stable, but this condition cannot be clearly attributed to the chemical treatment. Future use of the technique is recommended.

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Final Report
M&R No. 632116
D-5-38

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is our research report titled:

EVALUATION OF THE ION EXCHANGE LANDSLIDE

CORRECTION TECHNIQUE

Raymond A. Forsyth
Principle Investigator

Ronald Mearns and Robert Carney
Co-Investigators

Paul Salinas
Technical Assistance

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

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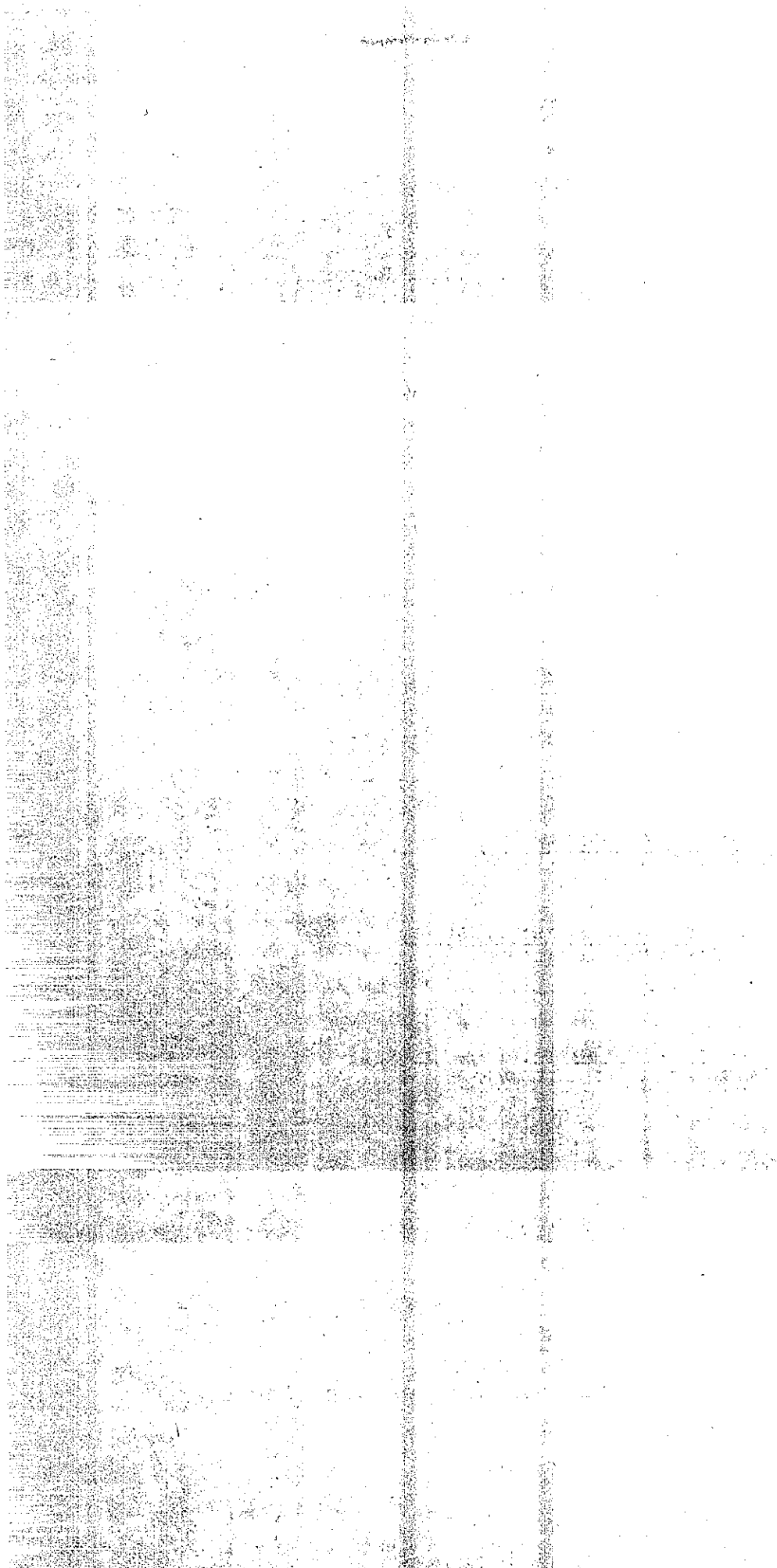

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Special thanks are extended to Mr. Ed Graf, President of Ion Tech Inc., for the time and effort he personally expended in completing the preliminary work and treatment within our time schedule.

The contents of this report reflect the views of the authors who are responsible for the accuracy of the data presented herein. They do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard specification or regulation.

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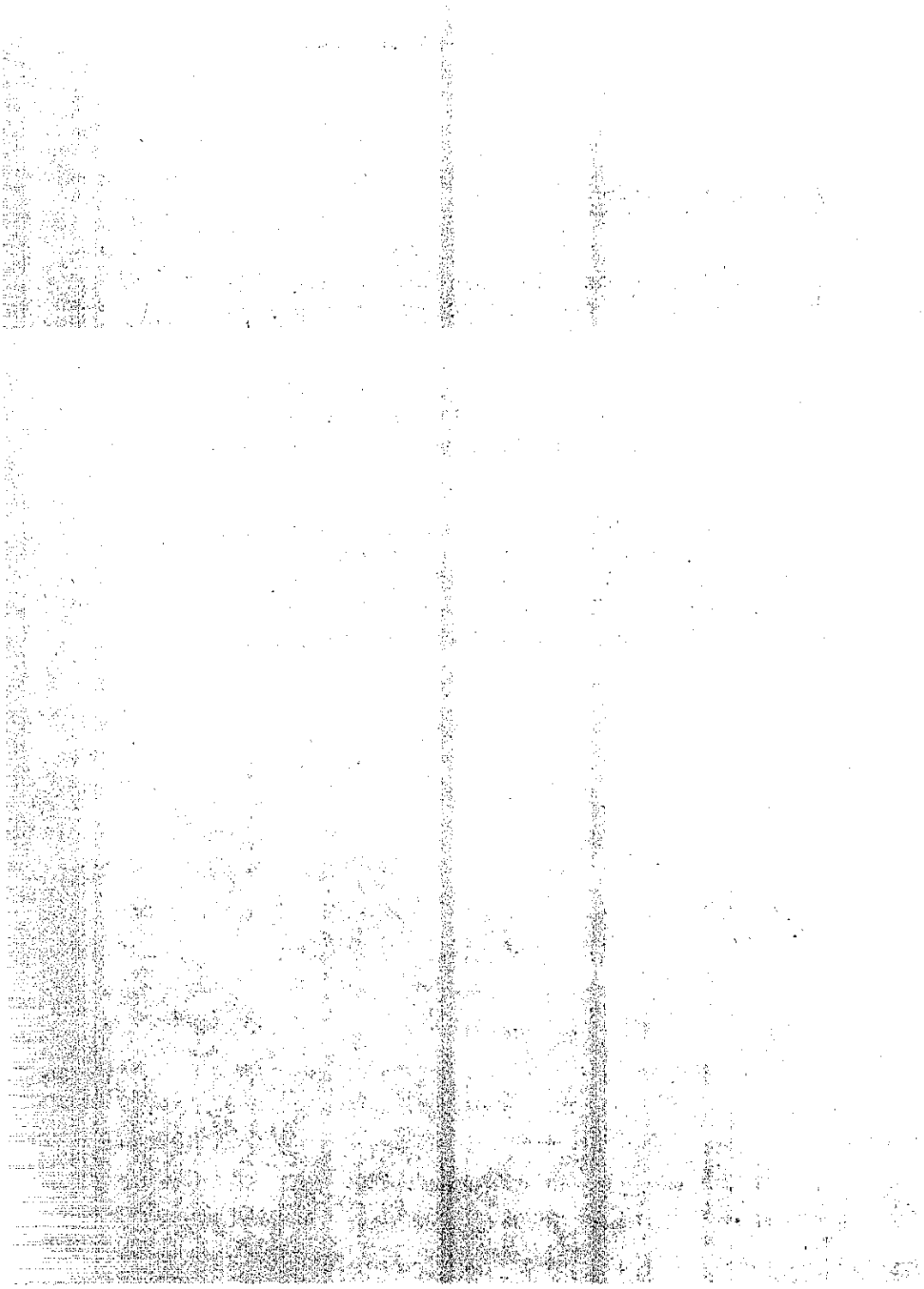

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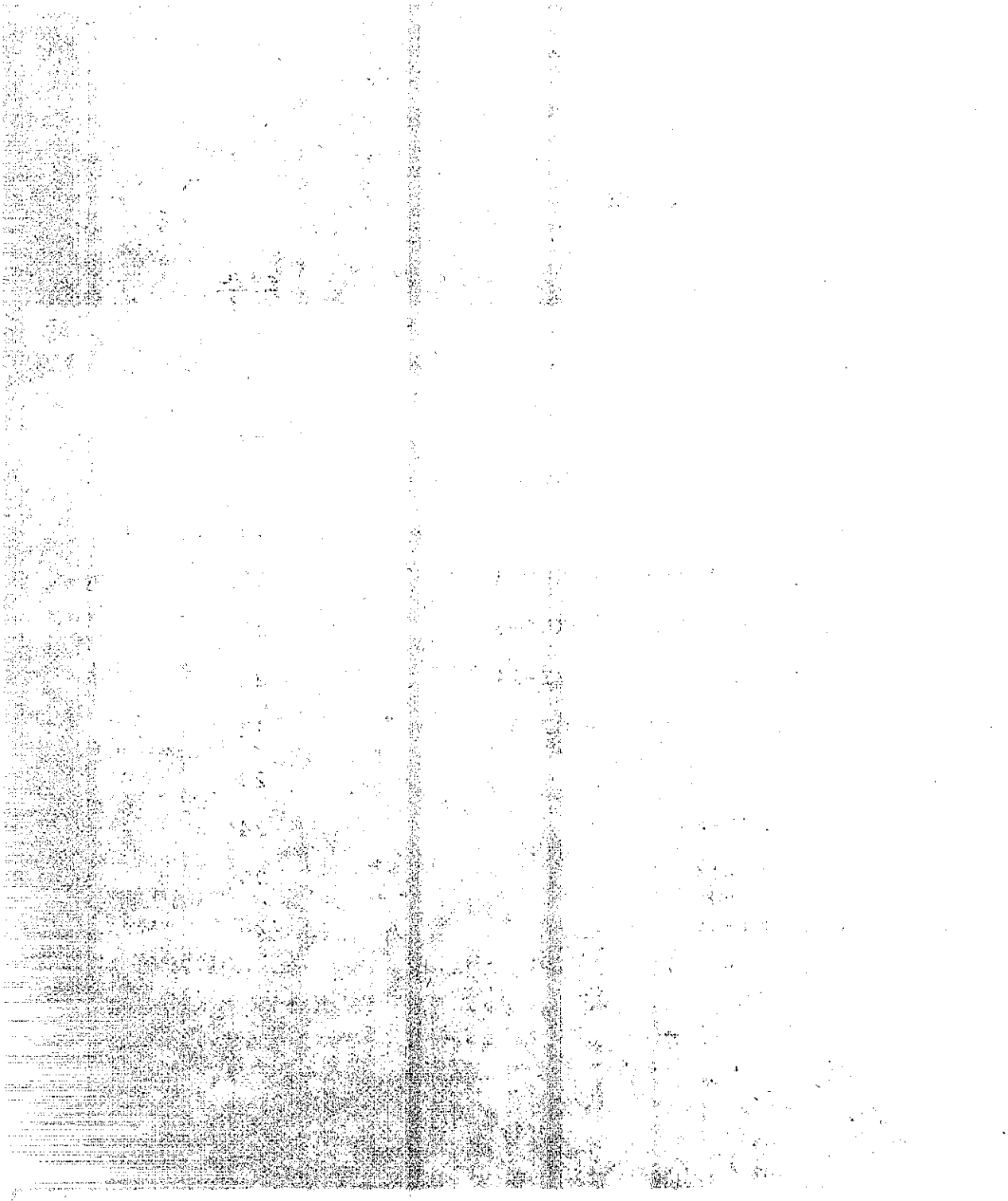

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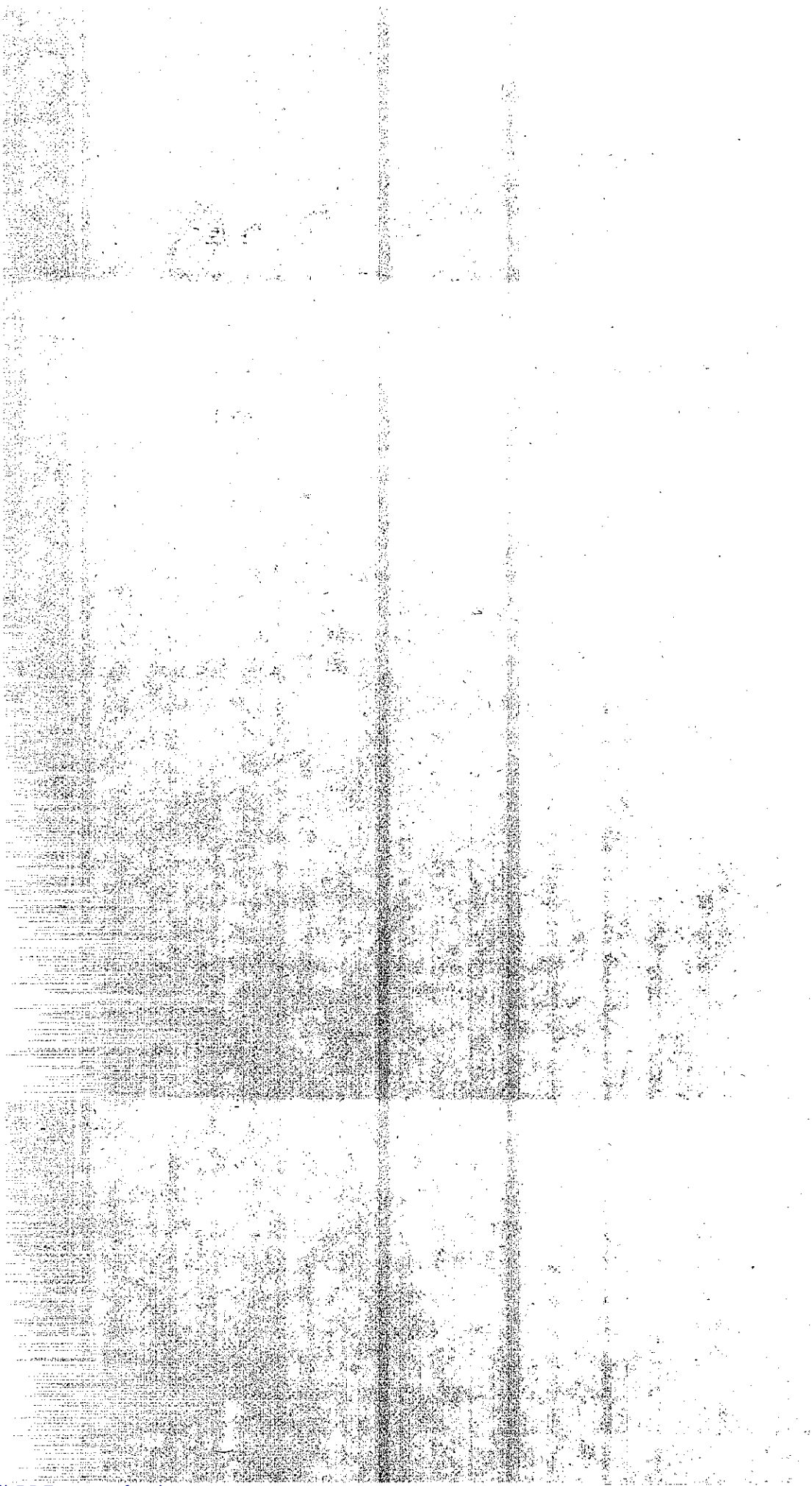

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Introduction

The ion exchange landslide correction technique, described in the Appendix, is a promising new method of stabilizing landslides chemically. It is relatively inexpensive, quick, convenient to use and provides the additional benefit of a reduced environmental impact when compared to normal landslide correction techniques such as resloping or construction of buttresses.

These potential advantages led to a decision by District 02 of the California Division of Highways to undertake ion exchange stabilization of a landslide on Road 02-Sha-5 PM 65.2. Because of the new and unproven nature of the technique, this Department initiated a monitoring program to evaluate the effectiveness of the treatment. The results of this monitoring program are discussed in this report along with a description of the treatment and the conditions under which it was used.

Summary

Treatment of a landslide using the ion exchange landslide correction technique was undertaken by the California Division of Highways during April, 1971. The landslide was monitored during the winter before treatment and for one year following treatment in order to determine the effectiveness of the treatment.

The conditions monitored include rainfall, groundwater, the position of survey stakes, subaudible rock noise (SARN), slope indicator data and clay strength.

Results of the monitoring are not conclusive except in the case of clay strength. All monitoring suggests that the landslide has stabilized. The strength of the clay in the zone of movement exhibits marked increases. However, the results are clouded by the fact that in the winter following treatment only about 65% of normal rainfall occurred which could have had a direct effect on the level of slide activity. The present stable condition of the landslide, therefore, cannot be clearly attributed to the chemical treatment.

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Recommendations

Because of the apparent success of this project and the tremendous benefits to be derived from chemical landslide correction, it is recommended that this technique be tried again as soon as a suitable test site becomes available.

Test Site

Numerous landslides were initiated or reactivated by the heavy rains of the winter of 1968-69. Engineering Geologists from this Department were asked to recommend corrective measures for a number of these landslides at various points along Interstate 5 in the Sacramento River Canyon.

One of the landslides appeared to meet the criteria for correction by the ion exchange technique and which was recommended as an alternate solution to resloping. The criteria referred to above are: (1) an identifiable clay zone in which the movement was occurring; (2) saturated condition within the landslide material; and (3) very slow movement suggesting near stable conditions.

The District elected to try the chemical treatment at the recommended site to reduce correction costs and to reduce the environmental impact in a sensitive area. The opportunity to evaluate a potentially useful technique was also a significant factor.

The test site is located on Road 02-Sha-5, Post Mile 65.2, approximately three miles south of Dunsmuir. See Figure 1 for the location map.

The slide which is pictured on Plates 1 and 2, is approximately 900 feet long and 400 feet wide with a maximum thickness of 100 feet. Figure 2 shows the topography at the time of this correction. It appears to be a very old landslide that was reactivated by construction of the highway cut in 1959. Correction work completed during construction consisted of slope flattening and the installation of horizontal drains. Although actual measurements have not been taken subsequent to construction, the movement appears to have continued since that time. The wet winters of 1964-65 and 1968-69 appear to have resulted in particularly large movements and the destruction of the horizontal drains installed during construction.

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Material in the slide mass is a mixture of several types of soil and rock. The soils all contain significant percentages of clay minerals which, until the time of treatment, appeared to remain saturated even during very dry years. The few rocks visible on the surface of the slide have been metamorphosed to some extent and are fractured and weathered.

The movement appears to be occurring primarily on an interface between the slide mass itself and the stable but fractured underlying bedrock. The clay layer that has formed on the plane of movement is apparently impermeable which has resulted in impounding of water in the slide mass, thereby keeping the clays saturated.

The movement was slow but perceptible as shown in Plate 3. The trees had, in one year, moved downhill enough to deflect the telephone cable. Plate 4 shows the cable after the trees were pruned by the phone company.

Chemical Treatment

The treatment was accomplished using state personnel and equipment. Mr. Ed Graf of Ion Tech Inc. provided technical direction and assisted in completing the project.

The treatment was accomplished on April 22 and 23, and April 28 and 29, 1971. All injection points were treated twice, with a week between treatments. Five points on the north side of the slide received a third treatment one day after the second treatment.

Ion exchange company personnel declined to identify the chemicals that were used in the treatment. It was known, however, that one of the chemicals was a very strong acid requiring special precautions in handling.

A total of 3000 pounds of dry chemicals and 660 gallons of acid were used in the treatment. On the first day of chemical treatment the following proportions were used:

75 pounds of dry chemicals

15 gallons of acid

40 gallons of water

This mixture was injected into cracks at the rate of 16 gallons per injection point and was injected into borings at the rate of 15 gallons per boring.

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The mixture was changed for the remainder of the treatment days as follows:

50 pounds of dry chemicals

10 gallons of acid

45 gallons of water

This mixture was applied to cracks at the rate of 18 to 20 gallons per injection point and to borings at a rate of 10 gallons per boring.

The chemicals were combined in 50-gallon drums and a mechanical agitator was used to maintain a uniform solution. This solution was delivered to the injection points and borings using an air-driven pump. Although it required a number of vehicles to move equipment and supplies up the hill and considerable manual labor to complete the chemical treatments, the work was accomplished in an efficient and relatively trouble-free manner.

A total of 31 borings were used for injecting chemicals into the slide. The locations of these borings are shown on Figure 3. Twenty-two of the borings were drilled specifically for chemical treatment at locations specified by Ion Tech, Inc. Nine previously drilled sample borings were also used to provide wider chemical distribution.

Fifty-five injection points in cracks were utilized. These injection points are shown in Figure 4 and were selected in the field under Mr. Graf's direction.

Research

The decision by District 02 to use ion exchange provided an ideal opportunity to evaluate the technique. This Department and District 02 evolved a schedule and division of responsibility to assure maximum usefulness of the data that would be acquired. The research provided monitoring of the slide stability through one winter prior to the application of the chemicals, through the time of chemical treatment, and also through the following winter. Horizontal drains were to be installed after the second winter of monitoring (Installed May and June, 1972). All monitoring was to be terminated when the horizontal drains were installed because of the problem of differentiating between the effects of the chemical treatment and the effect of the dewatering.

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The monitoring at intervals ranging from days to weeks was performed by personnel of the Materials and Research Department, the District 02 Materials laboratory and the District 02 Surveying Department. The monitoring methods included in this research were rainfall data, groundwater depth, ground surface surveys, subaudible rock noise, slope indicator, and clay strength values. Each of these methods is described and the results are discussed in this section.

The data developed by the monitoring program appears adequate in terms of quality and quantity. However, the very dry year following the treatment renders analysis of the data difficult and decreases the reliability of the resulting interpretation.

Rainfall

The relationship between landslide activity and the presence of water is well known. For this reason monitoring of the rainfall and groundwater levels was necessary to evaluate the effectiveness of the chemical treatment.

Data from the Dunsmuir Ranger Station, which is located about four miles north northeast of the landslides was used to complete the following table. It is believed that rainfall at the test site is substantially the same. The total rainfall for each month of the study period is included in the table.

	1970	1971	1972
January		9.20	7.39
February		.34	7.28
March		8.60	4.62
April		2.32	
May		3.44	
June		.72	
July		.02	
August		.16	
September		.57	
October	4.30	2.08	
November	18.29	7.03	
December	15.39	8.27	

The rainy season in the Dunsmuir area generally extends from the beginning of October through the end of March. The average annual precipitation is approximately 60 inches. As indicated in the above table, 56.12 inches fell during the winter of 1970-71 while only 36.67 inches fell during the winter of 1971-72.

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The effects of the generally mild winter cannot be separated from those of the chemical treatment which tends to mark out a clear cut evaluation of the beneficiating effect of the chemical treatment alone.

Groundwater

The depth of groundwater was monitored between October 1970 and March 1972 in borings KBR-4, KBR-6 and SI-14. The location of these borings is shown in Figure 3. Borings KBR-4 and KBR-6 were dry throughout the study period with the exception of the early spring when about one foot of water in the bottom of each hole was observed. It is believed that this water was due to surface runoff from melting snow that entered the borings faster than it could be absorbed into the surrounding material. Boring SI-14 is high on the slide and in the most active area. The water depth in this boring ranged from 54 to 12 feet between October 1970 and April 1971 and for the same time period the next year ranged from 46 to 23 feet. Since the second year was relatively dry, it was anticipated the water level would not rise as high as it had the previous year.

During April of 1971 a number of borings were made in the upper part of the slide to be used as chemical injection points. Some of these borings, the locations of which are shown on Figure 3, were monitored for water level through the rest of the study period. These included borings KBR-5, 15, 17 through 34, 37, 38, 39, and SI-35. Subsequent observation showed the water level in the landslide area dropped gradually between April 1971 and January 1972 and then climbed until March at which time it began to gradually drop again. At no time has the water returned to the levels of the same month during the year prior to treatment.

Another observation during this period was totally unexpected and cannot be explained satisfactorily at this time. Of the 24 borings being monitored, 16 showed abrupt changes in water level at the time of chemical treatment. Four borings showed a rising water level, which could be expected since the chemicals were being added in a water solution. The maximum increase in water level was 11 feet. Twelve borings, however, dropped in water level from 1 to 9 feet. Some of these water levels rapidly returned to the pre-treatment levels while others remained as permanent changes.

Since the treatment chemicals were highly acidic and could be harmful to both plants and animals, the ground water pH was monitored daily for a week following the final treatment. All known springs and seeps on the ridge between the top of the landslide and the Sacramento River several hundred feet away from the

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landslide were checked. No change in groundwater pH was ever detected. Laboratory tests of water samples taken before and after the treatment at various springs verified that the chemicals were not leaching away.

Ground Surface Surveys

A row of points were established across the landslide on a line and the elevation of each point was established. Each end of the line was tied into a bench mark and a reference point. These points are all included on Figure 5 and are labeled A, B, C, D, E, BM#1, BM#2, RP PtA and RP PtE. This line was established and located in July of 1970 and was checked for changes in horizontal alignment and elevation in February of 1971, prior to treatment, and in March of 1972, nearly one year after treatment.

The results of this survey are tabulated below. The changes shown are the total changes in feet as of the date indicated.

Point	Vertical Changes		Horizontal Change	
	2-25-71	3-27-72	2-25-71	3-27-72
A	+.04	+.05	0	0
B	-.01	-.01	.17	.21
C	-.04	-.06	.11	.10
D	0	-.01	.01	0
E	-.01	-.02	0	.04

The apparent increase in elevation of Point A may reflect a surveying error. Another possible explanation is that since the main mass of the landslide is resting against the ridge on which Point A is located, it may be squeezing it up. Points B and C show significant horizontal movements in the uphill direction. Apparently the block of landslide material on which these points are located is dropping and rotating back toward the hill.

The greatest movement both horizontally and vertically occurred during the winter prior to treatment. The difference may be explained by an effective chemical correction, by the occurrence of a dry winter, or a combination of the two.

Subaudible Rock Noise (SARN)

Subaudible rock noises are naturally occurring audio frequency sounds generated in stressed soil and rock. These sounds are

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the results of both shearing and interparticle movements. The Materials and Research Department has developed the equipment and techniques required to detect, record and analyze these sounds. The number of sounds and their distribution in time can be related to the stability of the area being monitored. The borings used for this monitoring were KBR-4, KBR-6, SI-14 and SI-35. The locations of these borings are included on Figure 5. SARN monitoring extended through the entire study period except for SI-35 which was not drilled until April of 1971.

It was performed several times just before and during the period of chemical treatment. There was concern that the addition of fluids to the cracks and onto the slide plane through borings might trigger a more rapid movement. No such effect was observed, however.

The results of SARN monitoring are included in the following table. The number under each boring represents the number of noise events per minute for the date indicated.

Date	KBR-4	KBR-6	SI-14	SI-35
10-1-70	0.4	0.2	-	-
11-9-70	0.3	2.7	2.3	-
2-9-71	0.3	0.4	0.6	-
4-5-71	3.3	2.5	1.0	-
4-12-71	5.7	-	-	-
4-13-71	1.3	-	2.5	-
4-20-71	-	-	2.5	4.5
4-21-71	3.1	1.0	0.0	0.7
4-22-71*	0.0	0.0	0.6	6.5
4-23-71*	0.0	-	-	4.7
4-27-71	0.0	0.3	0.6	4.5
4-28-71*	0.3	-	-	8.0
4-29-71*	0.0	0.0	1.0	7.4
5-4-71	0.0	0.0	2.0	5.0
5-5-71	0.0	0.0	1.0	6.5
5-6-71	0.0	0.0	2.0	5.1
5-26-71	-	-	-	29.5
5-27-71	0.0	0.3	1.3	10.8
7-22-71	9.0	2.5	2.7	0.7
9-20-71	-	-	5.7	11.2
9-21-71	1.0	0.7	-	-
11-8-71	0.9	0.6	2.0	3.0
12-13-71	0.7	0.2	6.9	1.2
1-10-72	0.6	0.5	4.0	9.2
2-16-72	0.3	0.5	1.0	4.1
3-7-72	0.0	0.1	1.3	0.2
3-27-72	1.0	2.0	1.8	1.6

* - Chemical Treatment

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The tabulated data has been plotted in Figures 6 through 9. Inspection of Figures 6 and 7 show that the noise rate for borings KBR-4 and KBR-6 apparently declined and stabilized after the chemical treatment. However, the noise rates of SI-14 and SI-35, located about 15 feet apart, were found to be higher and more erratic subsequent to chemical treatment as shown on Figures 8 and 9.

Our interpretation of these results, in the absence of any indication of renewed sliding, is that the slide mass is either settling or adjusting internally as the hill becomes more stable. Based on SARN observations on other landslides, the noise rates on this slide are not high enough to suggest active movement. This was true of the year before chemical treatment as well as the year after.

Slope Indicators

The slope indicator is a device used to accurately measure the depth and magnitude of lateral movement, in a special casing installed in a boring, over a period of time. The principles of operation of this equipment can be obtained from the Slope Indicator Co. of Seattle, Washington.

The slope indicators were installed to define the plane of movement and to provide the basis for comparing movement rates before and after the chemical treatment. Three borings, KBR-4, KBR-6 and SI-14, were selected for monitoring. These borings (40, 50 and 63 feet deep respectively) are located at different elevations up the center of the slide.

Erratic readings and failure to indicate a distinct slide plane during the winter before chemical treatment suggested that the borings may not have been deep enough. To assure sufficient depth, monitoring was started on SI-35 which is 104 feet deep and located near SI-14.

The locations of these borings are shown in Figure 5. The first three borings were monitored between October 1970 and March 1972 and the last between April 1971 and March 1972.

The results of the slope indicator monitoring are plotted in Figures 10 through 13. The data used in preparing these figures were arbitrarily selected from all of the slope indicator data obtained. For borings KBR-4, KBR-6 and SI-14 the three curves represent the beginning of monitoring (Oct. 2, 1970), just before the chemical treatment (April 21, 1971), and the completion of monitoring (March 27, 1972). For SI-35, only the before treatment and completion of monitoring data is available.

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A clearly defined plane or zone of movement did not develop during the life of this project. Only very small movements occurred between consecutive readings and most of that was near the ground surface. In general, the same magnitude of movement occurred before and after the chemical treatment. Since the ground surface survey data did not indicate any evidence of significant movement down slope, the slope indicator data was interpreted as indicating internal adjustment and settlement within the slide mass.

Clay Strength

Samples of clay were submitted to Ion Tech, Inc., for determination of the chemical treatment which would be most effective. These samples were obtained at surface exposures as well as from two borings made expressly for this purpose. The sample borings are located near KBR-15 and KBR-20 as shown on Figure 3.

Undisturbed samples obtained from these same borings were tested in the soil mechanics laboratory of the California Division of Highways, Materials and Research Department. The samples were 40 to 55% clay. Using differential thermal and X-ray diffraction techniques, the clay minerals were identified as halloysite, a vermiculite-chlorite complex and kaolinite. Unconfined compression tests were run, then the sample was remolded and tested in the vane shear apparatus.

One year after the chemical treatment, the locations of the original sample borings were reestablished and two sample borings two feet away from the original and on opposite sides of it were drilled. Undisturbed samples were taken at the same depths as the samples that had been tested from the original borings. These samples were then subjected to the same testing procedure used on the original samples.

Data from these tests are included in the following table. The boring with a single number is the original sample boring while those with an A or B suffix are the corresponding new borings. The horizontal lines represent either no recovery or a sample that was not acceptable for unconfined compressive strength testing. On the following table, q is the unconfined compressive, and v is the vane shear strength in tons per square foot.

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Depth	D-1		D-1A		D-1B	
	q	v	q	v	q	v
8'8" - 9'0"	-	1.43	1.57	1.58	-	-
12'0" - 12'4"	-	1.60	2.12	1.30	2.38	1.55
14'8" - 15'0"	-	1.60	1.80	1.23	-	-
15'0" - 15'4"	-	1.60	1.80	1.23	1.49	1.60
17'8" - 18'0"	2.03	1.59	2.62	1.33	-	-
18'0" - 18'4"	3.32	1.60	-	-	.60	.99
21'0" - 21'4"	1.72	1.33	2.81	1.45	.86	1.59
27'0" - 27'4"	.35	1.38	.67	1.58	.95	1.60
49'0" - 49'4"	.60	1.28	.38	1.60	-	-
	D-2		D-2A		D-2B	
	q	v	q	v	q	v
6'4" - 6'8"	-	.68	1.04	.95	.50	1.60
10'6" - 10'10"	.69	.96	1.41	1.60	1.49	1.28
16'6" - 16'10"	.44	.51	.43	1.53	.64	1.60

The amount of rotation of the vane is mechanically limited on the apparatus used for these tests. Consequently, it is not possible to measure strength values greater than 1.60 tons per square foot.

Of the samples tested from Borings D-1, D-1A and D-1B, there are as many with strength decreases as increases. However, all samples below a depth of 20 feet showed strength increases in the vane shear tests. Since the chemicals were simply poured into the hole, the greatest effect is presumed to occur towards the bottom where the chemicals would have the longest time to react.

Borings D-2, D-2A, and D-2B were much shallower and all vane shear tests showed strength gains after treatment. Only one unconfined compressive strength test did not show a strength gain.

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The apparently consistent vane shear strength gain can be taken as an indication that the chemical treatment did indeed affect the physical properties of the clay.

It must be emphasized that this is a subjective interpretation and that the data are very limited. The fact that the unconfined compressive strengths are not as clear an indicator of improved strengths as the vane shear results also suggests a need for caution in evaluating these results.

It was found that the water content of the samples was generally less in the samples obtained after treatment than in those obtained before. This difference, which ranged between 1 percent and 12 percent of the sample weight, could be a factor in the strength differences measured. The generally lower moisture contents noted after treatment could be the result of increased permeability due to chemical reaction, a mild winter, or both.

Horizontal Drains

Horizontal drains were used as part of the correction of the landslide that occurred during construction. The apparent stability of the hill for the previous 10 years was probably due, at least in part, to the original horizontal drains. Local maintenance personnel indicated that a year round flow of water was maintained by the drains which continued until the drains were finally destroyed upon reactivation of the landslide in the winter of 1968-69.

Since the presence of water in the slide mass is a prime contributing factor to instability, it was decided that the installation of horizontal drains would be necessary for any form of correction to be successful. However, in order to better evaluate the effectiveness of the ion exchange correction technique, the horizontal drains planned for this landslide were not installed until a year after the chemical treatment.

A total of 21 drains were installed, eight from a point slightly above the toe and on the south side of the main slide mass and another 13 from a point about half way up the slide and in the center. This work was completed during May and June of 1972.

The drains at the lower level ranged in depth from 160 to 405 feet. Only three of the borings intercepted water, and the total initial flow was 7100 gallons per day. The drains at the upper

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level ranged in depth from 290 to 327 feet. Only two of these borings intercepted water, and they produced a total initial flow of 18,000 gallons per day. By September 1, 1972, all of the drains were dry.

Construction of access roads and work pads for the horizontal drill have resulted in the destruction of many of the groundwater level observation wells. The water levels in the other observation wells is definitely lowered, but this lowering corresponds to the normal seasonal lowering and follows an unusually dry winter.

Because of the difficulty of separating the effects of the chemical treatment and the dewatering, all monitoring has now been terminated.

Cost Analysis

All of the costs accrued as a result of performing the landslide correction at this location are included in the following table:

Ion Tech, Inc.	$ 7,650
District 02	6,450
Research	18,900
Horizontal Drains	22,500
TOTAL	$55,500

These figures have been rounded to the nearest 50 dollars for simplicity. The cost of the traditional resloping correction was estimated by the District 02 Design Department to be $150,000, which also included the horizontal drains.

If the slide remains in its present stable condition, the Division of Highways will have saved $94,500. Savings could be considered greater if the research costs were not included.

In addition to the actual cash savings, the Division was able to avoid the necessity of obtaining additional right-of-way, the large bare slope resulting from a resloping correction, and the problem of a site for disposing of the excavation.

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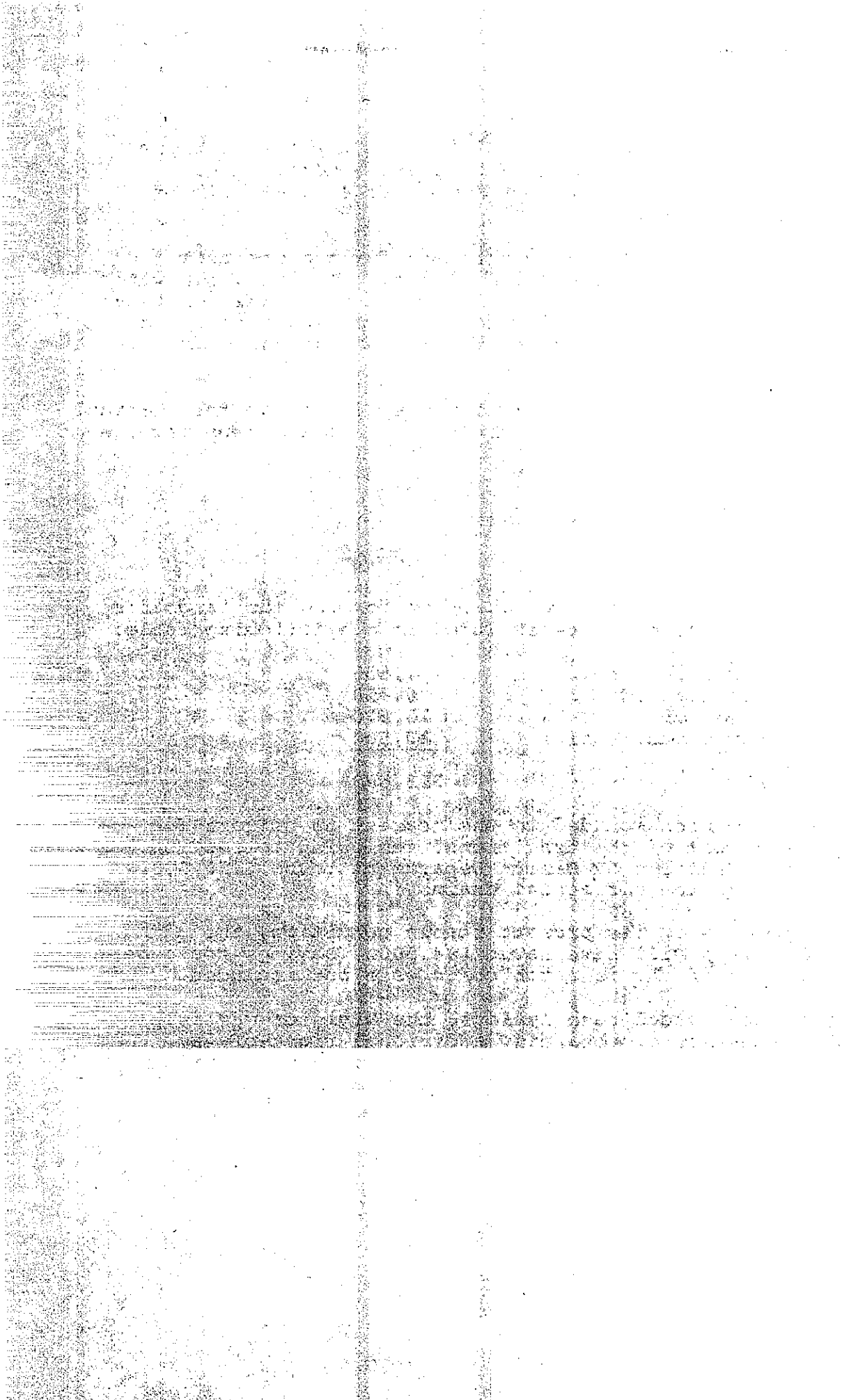

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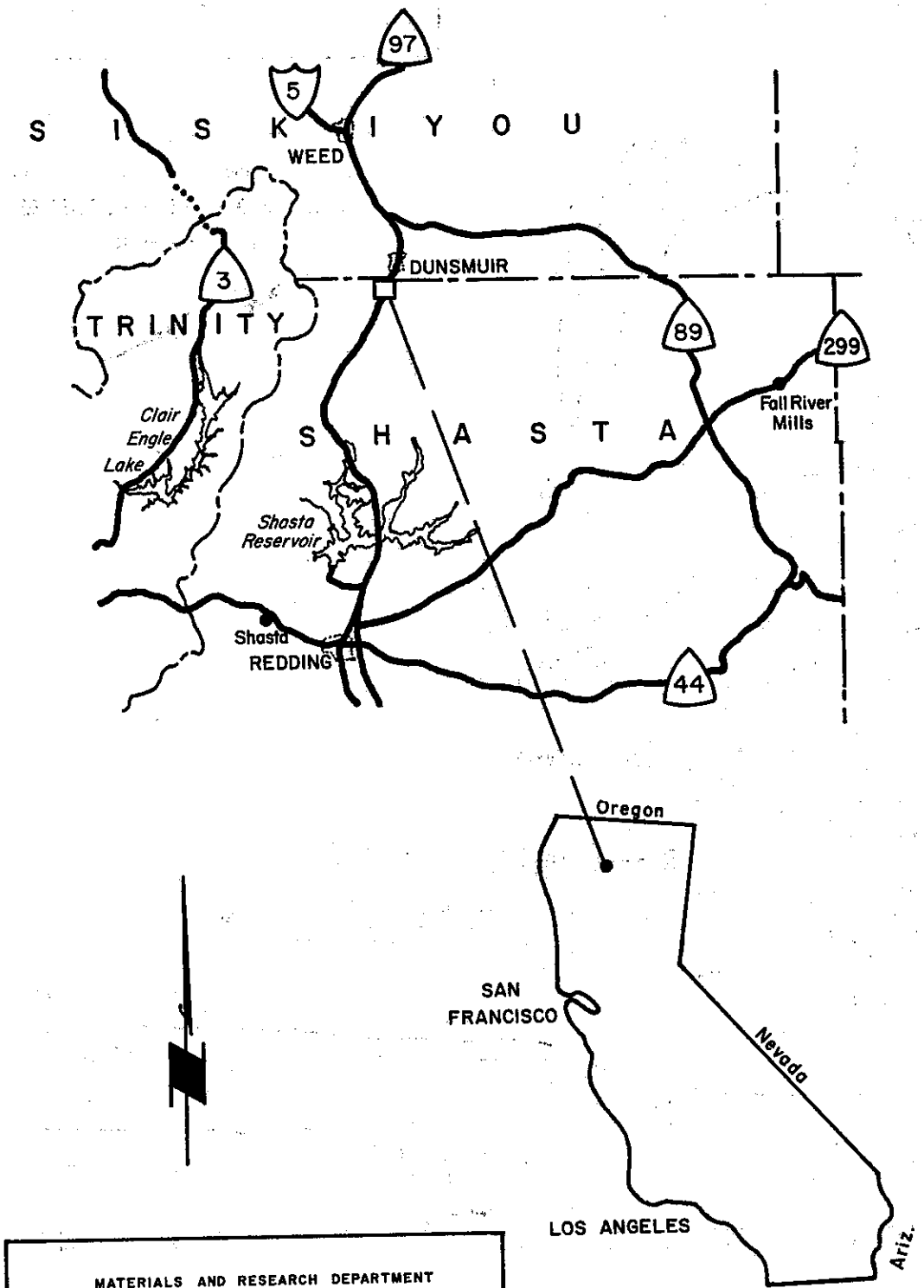
Figure 1



MATERIALS AND RESEARCH DEPARTMENT

ION EXCHANGE LANDSLIDE CORRECTION

ROAD 02-Sha-5 PM 65.2

LOCATION MAP

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Figure 2

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ION EXCHANGE LANDSLIDE CORRECTION

ROAD 02-Sha-5 PM 65.2

PLAN

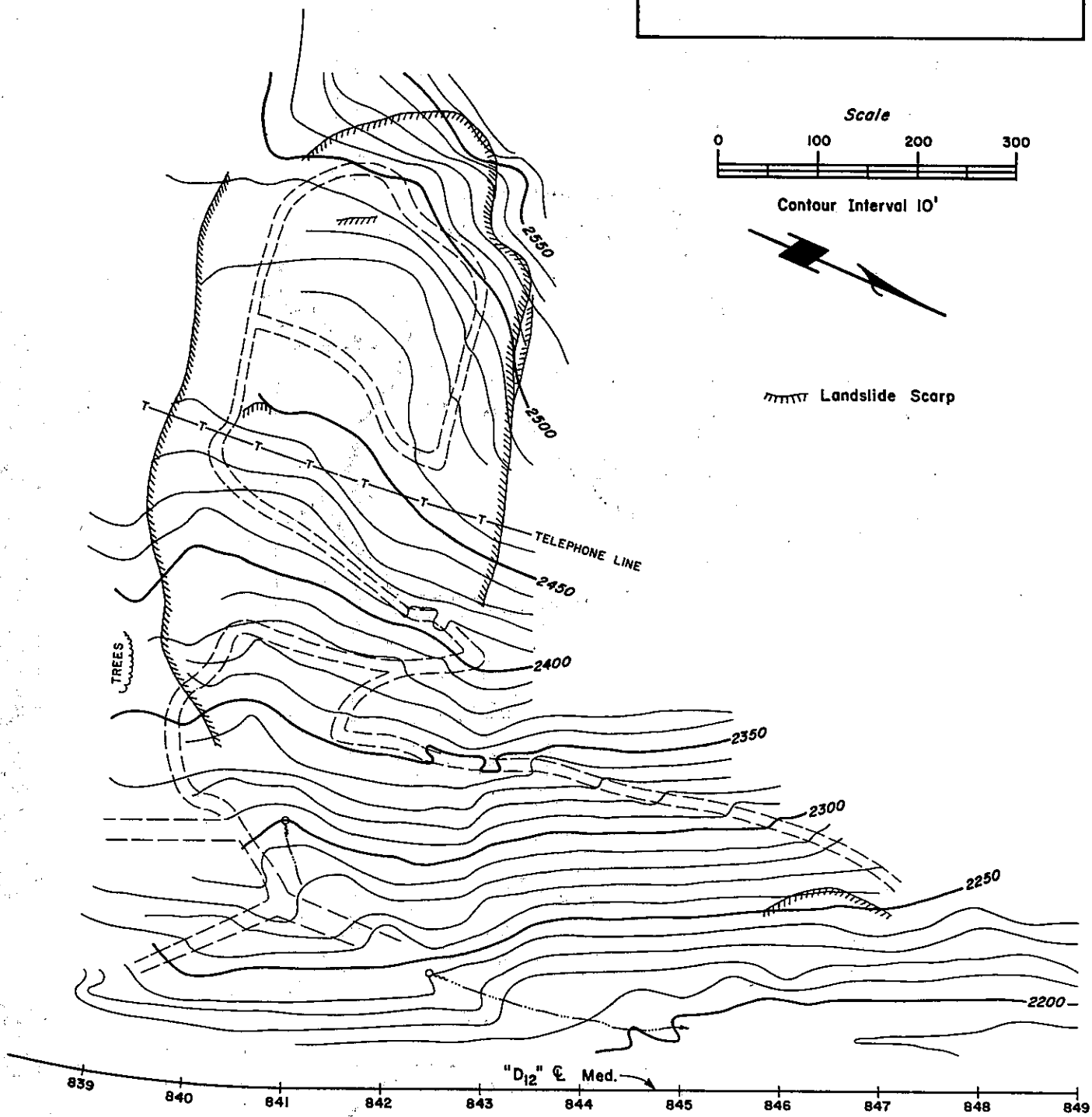

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Figure 3

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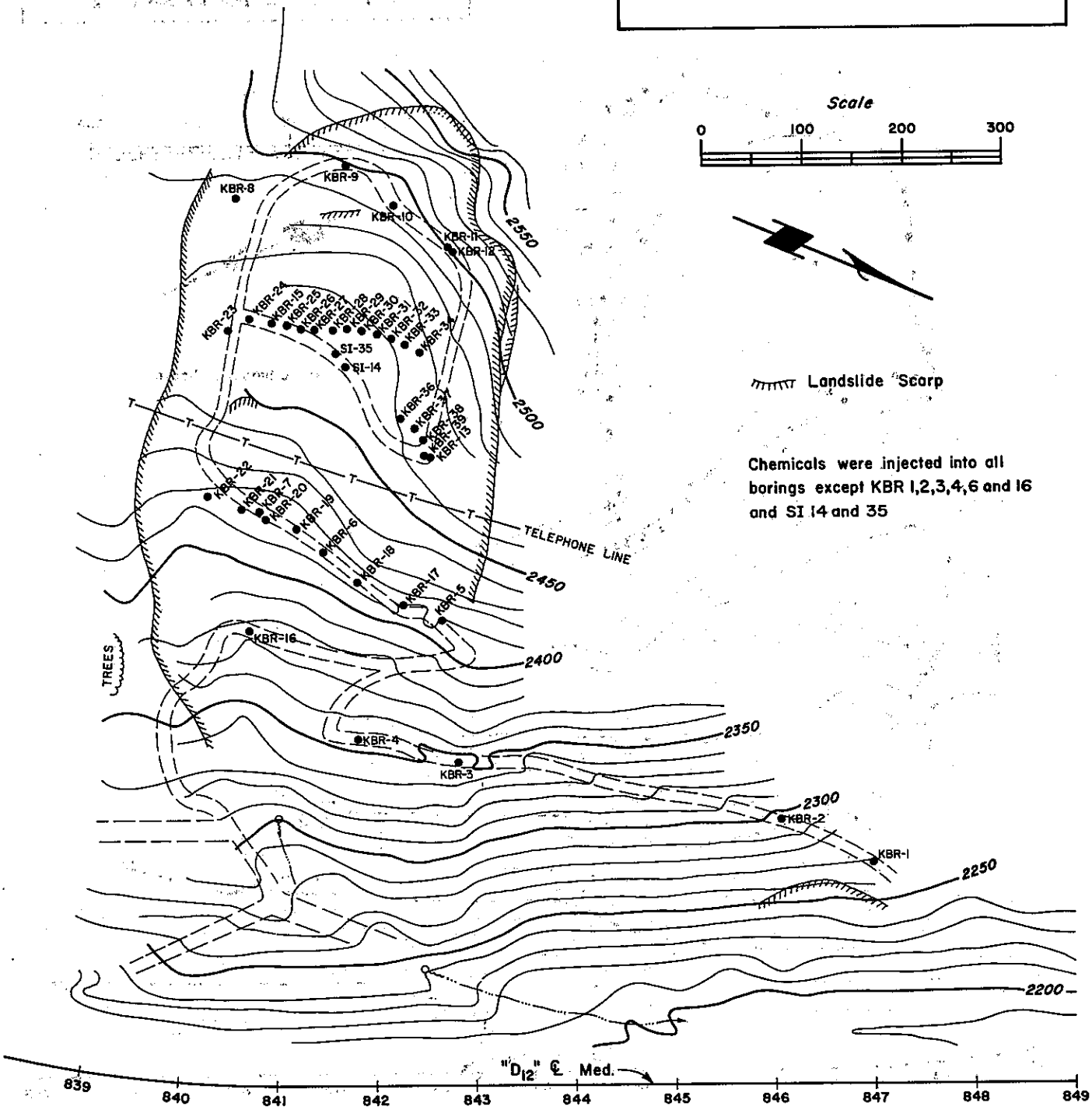
ION EXCHANGE LANDSLIDE CORRECTION

ROAD 02-Sha-5 PM 65.2

Plan of Boring Locations



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ION EXCHANGE LANDSLIDE CORRECTION

ROAD 02-Sha-5 PM 65.2

PLAN

Points of Chemical Injection into Cracks

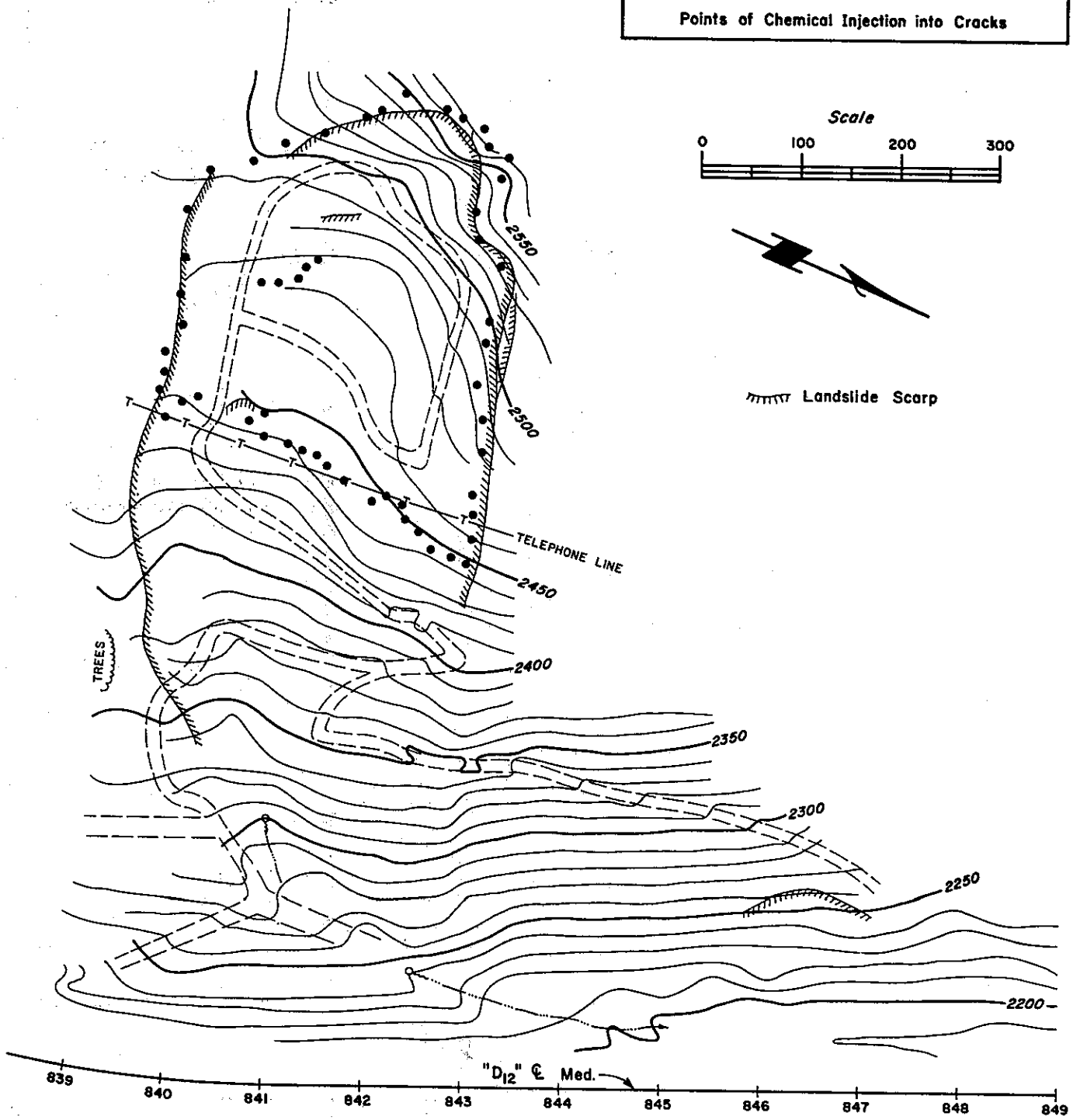

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Figure 5

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ION EXCHANGE LANDSLIDE CORRECTION

ROAD 02-Sha-5 PM 65.2

PLAN

Monitoring Locations

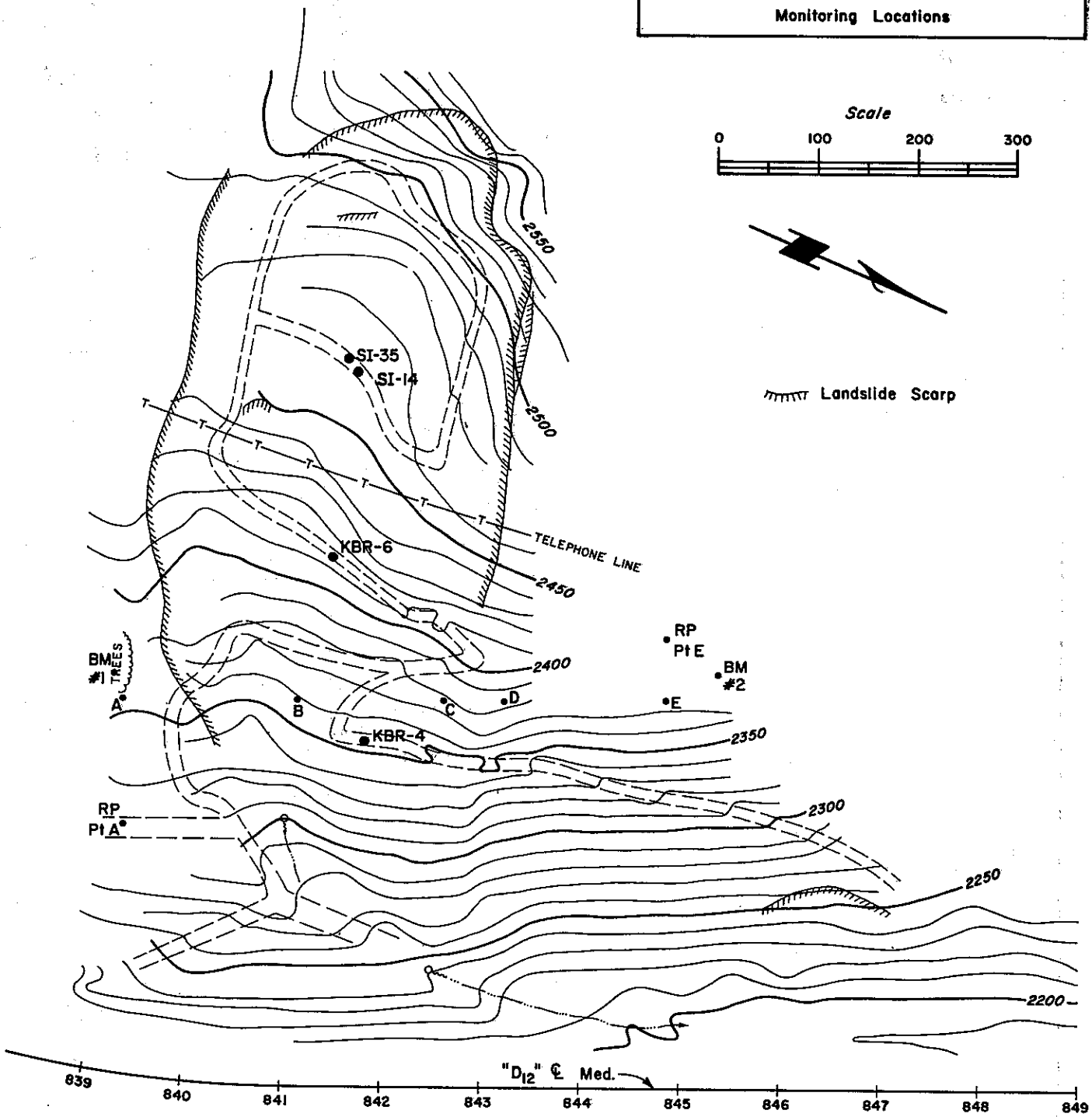

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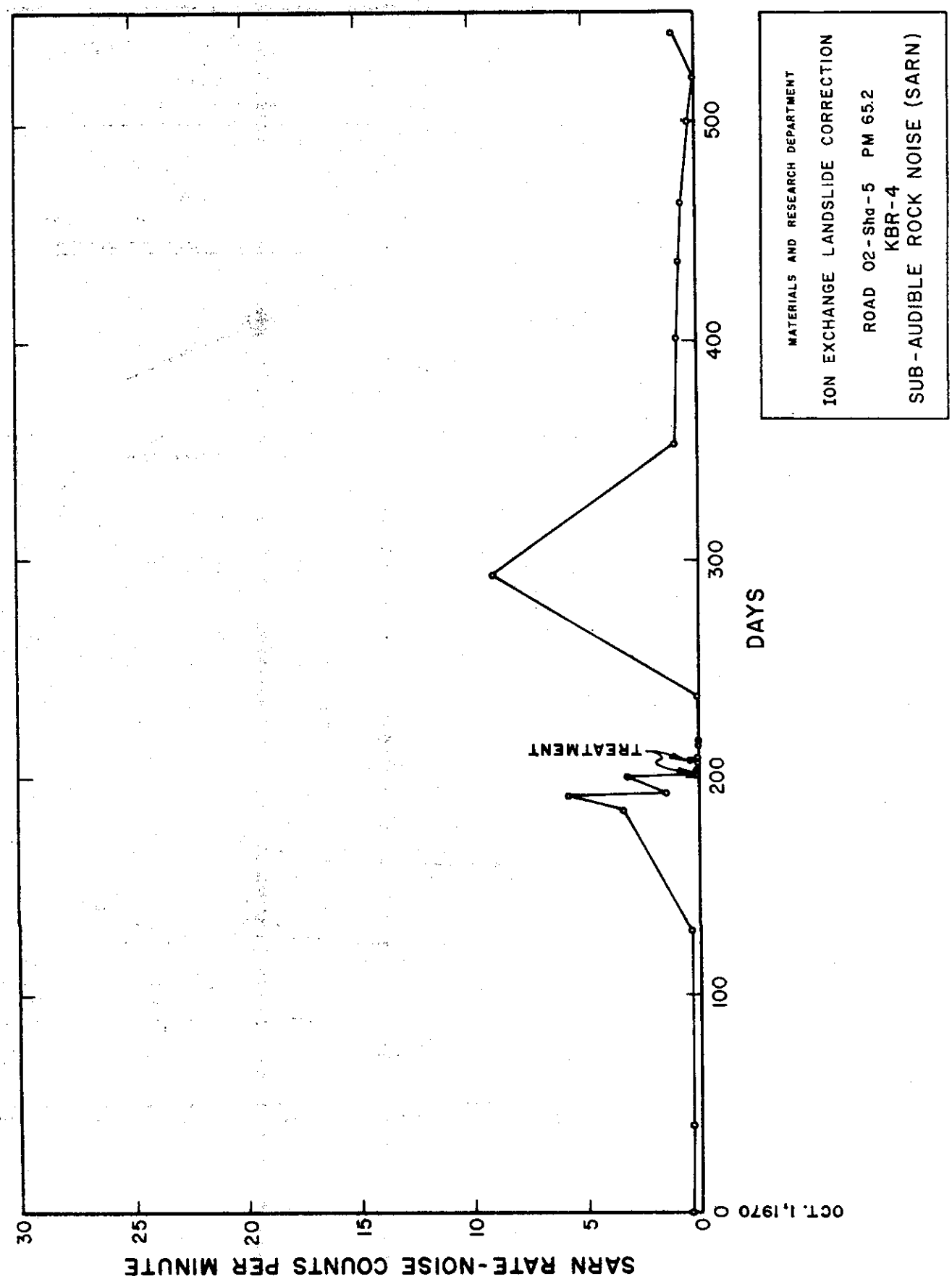
Figure 6



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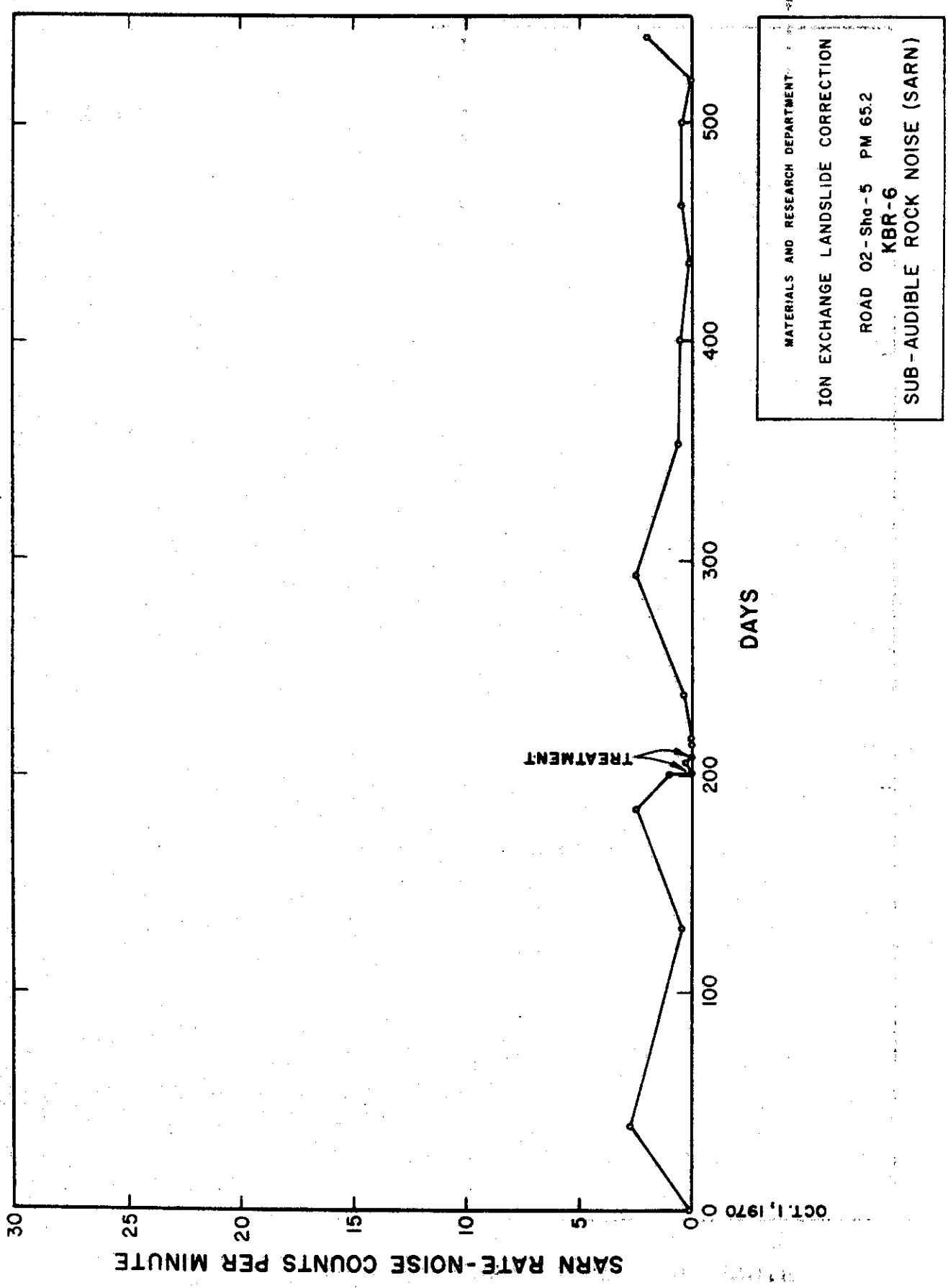

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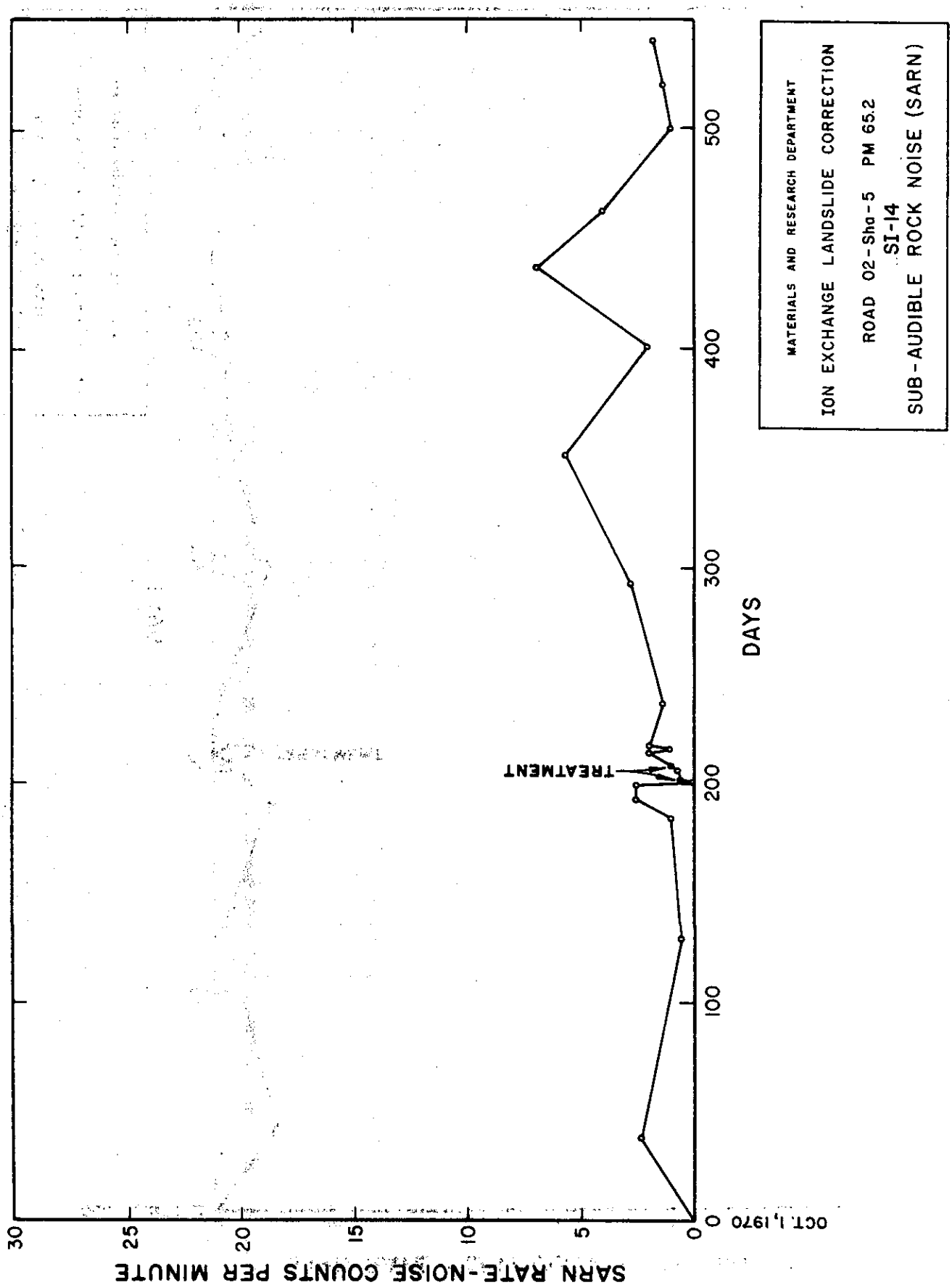

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Figure 9

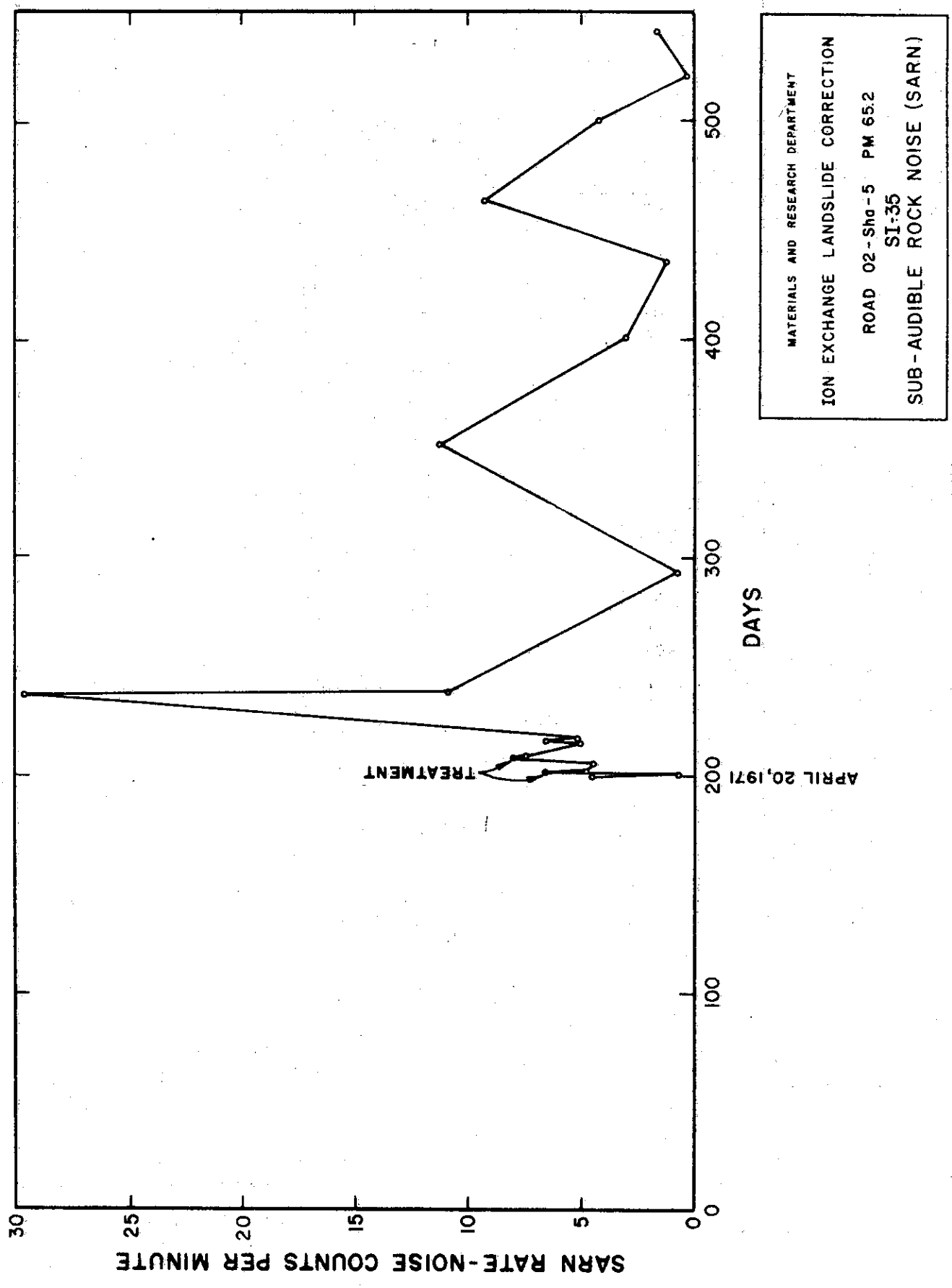

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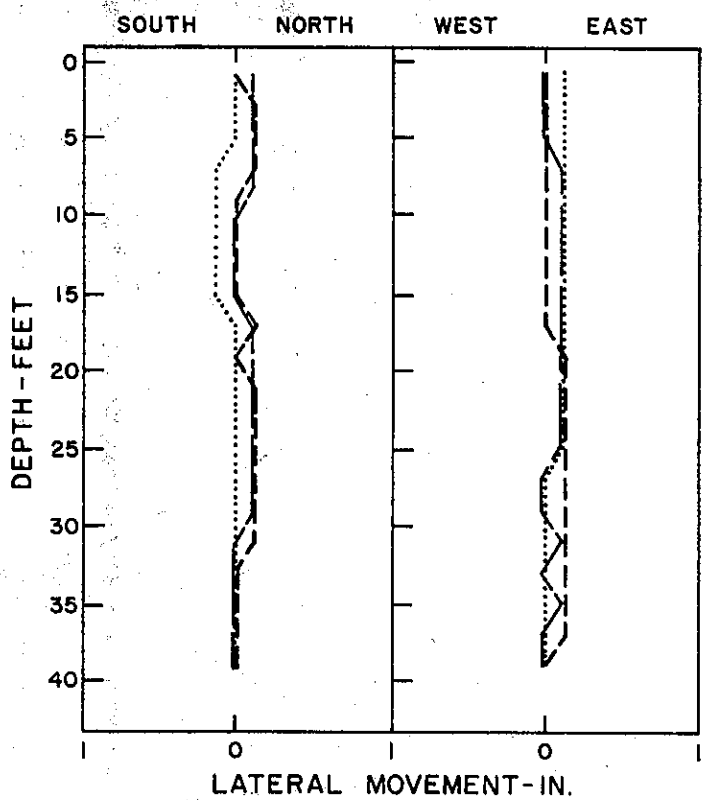
Figure 10



LEGEND

..... OCT. 2, 1970

— — — — APR. 21, 1971

——— MAR. 27, 1972

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ION EXCHANGE LANDSLIDE CORRECTION
ROAD 02-Sha-5 PM 65.2
SLOPE INDICATOR KBR-4

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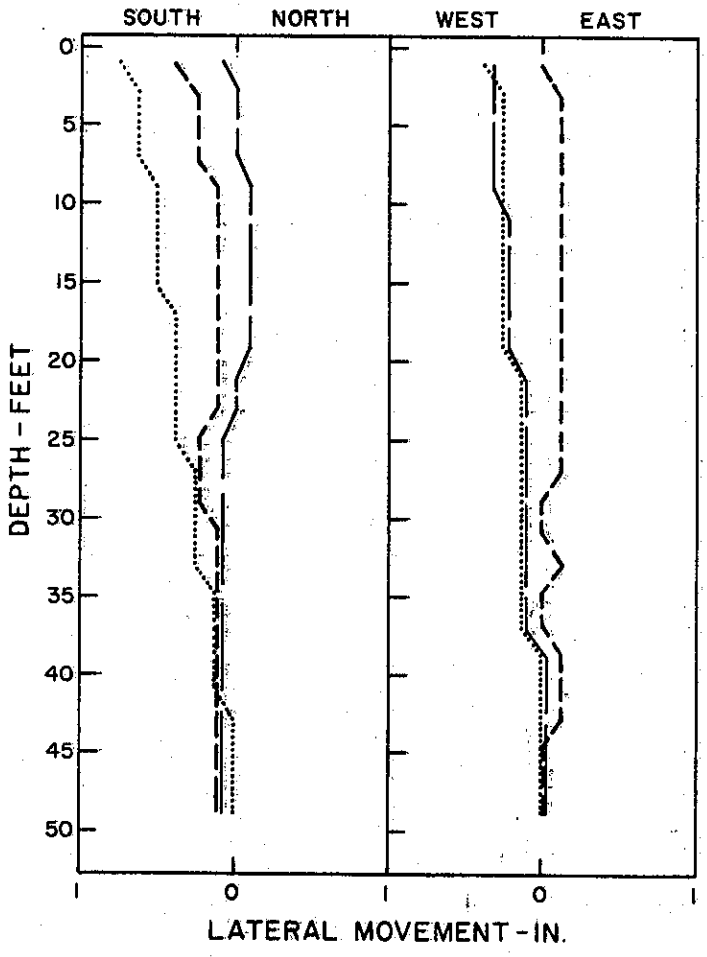
Figure 11



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ROAD 02-Sha-5 PM 65.2
SLOPE INDICATOR KBR-6

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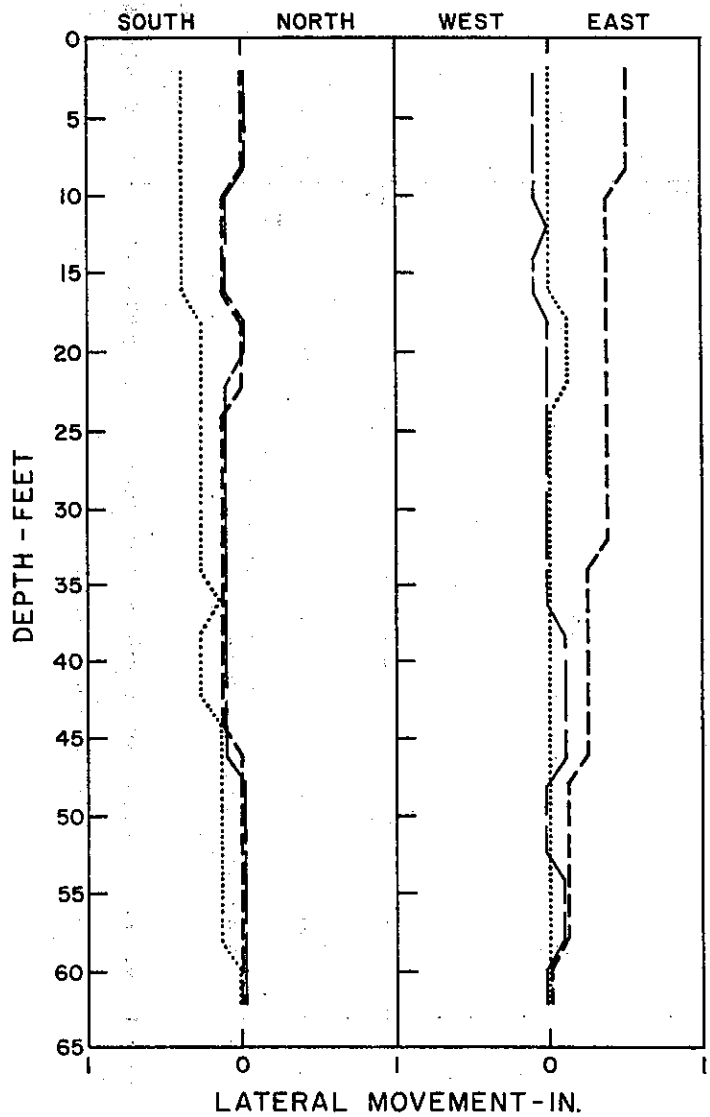
Figure 12



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—— —— MAR. 27, 1972

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ION EXCHANGE LANDSLIDE CORRECTION
ROAD 02-Sha-5 PM 65.2
SLOPE INDICATOR SI-14

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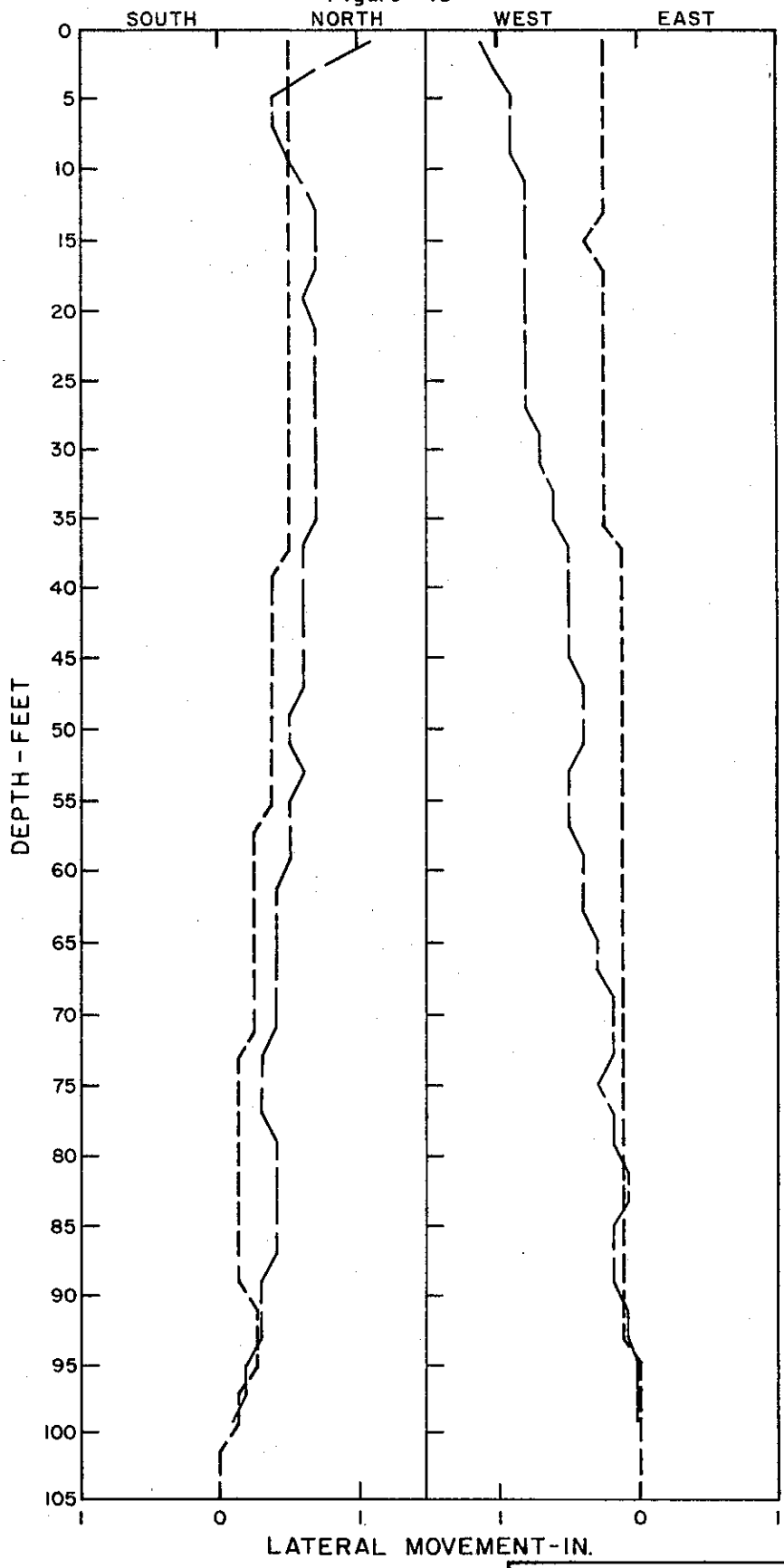
Figure 13



LEGEND

APR. 20, 1971

MAR. 27, 1972

MATERIALS AND RESEARCH DEPARTMENT

ION EXCHANGE LANDSLIDE CORRECTION
ROAD 02-Sha-5 PM 65.2
SLOPE INDICATOR SI-35

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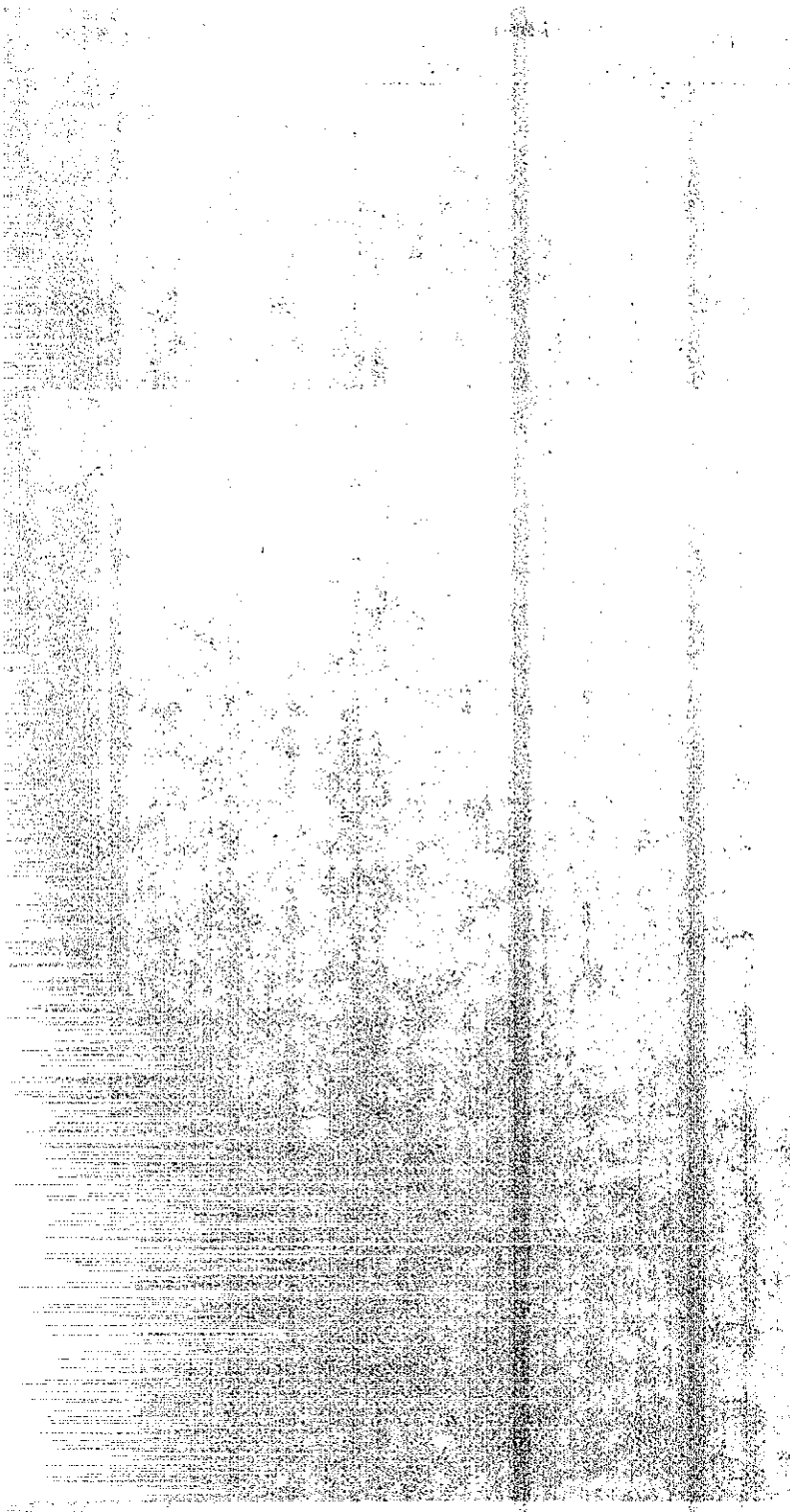

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APPENDIX

The Ion Exchange Method

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The Ion Exchange Method

The ion exchange landslide correction technique consists of treating the clay minerals along the plane of movement with a concentrated chemical solution. The chemical solution required for effective treatment is determined by the clay mineralogy and the groundwater conditions for each landslide.

The success of this technique is based on the replacement of some cations in the clay minerals with different cations introduced in the chemical solution. In a liquid medium, cations can migrate to any place within the medium independent of the movement of the medium itself. This means that, in a saturated clay, cations can and in fact do migrate at a much greater rate than the water can permeate through the soil structure. By taking advantage of this phenomenon it is possible to chemically alter a significant volume of clay.

This replacement of cations commonly results in a 200 to 300 percent improvement in both the strength and permeability of the clay. Because initial strength is quite low, this magnitude of increase is still relatively minor quantitatively although possibly sufficient to achieve stabilization. The replacement process can be reversible depending on the cations involved, the clay mineralogy, and the groundwater environment. The potential for reversed replacement can and should be studied.

In practice, it is necessary to obtain samples of the various clay minerals present and of the groundwater for laboratory testing. The proper chemical or combination of chemicals to yield the desired results is determined by the laboratory tests.

The treatment of the landslide itself is accomplished by introducing the chemical into cracks at the head and sides of the landslide and, if necessary, into borings at selected locations on the slide. A patent on this technique is held by Ion Tech, Inc. of Daly City, California. This firm also maintains the staff and equipment necessary to carry out the laboratory testing program.

This method appears to be theoretically sound and could be applicable to many landslide problems. It should also be emphasized that there are many landslides on which it would have little chance of success. The conditions necessary for successful ion exchange treatment are: (1) a clearly defined plane or zone of failure; (2) clay minerals along this zone; (3) saturation of the clay; (4) cracks and/or borings for the introduction of chemicals.

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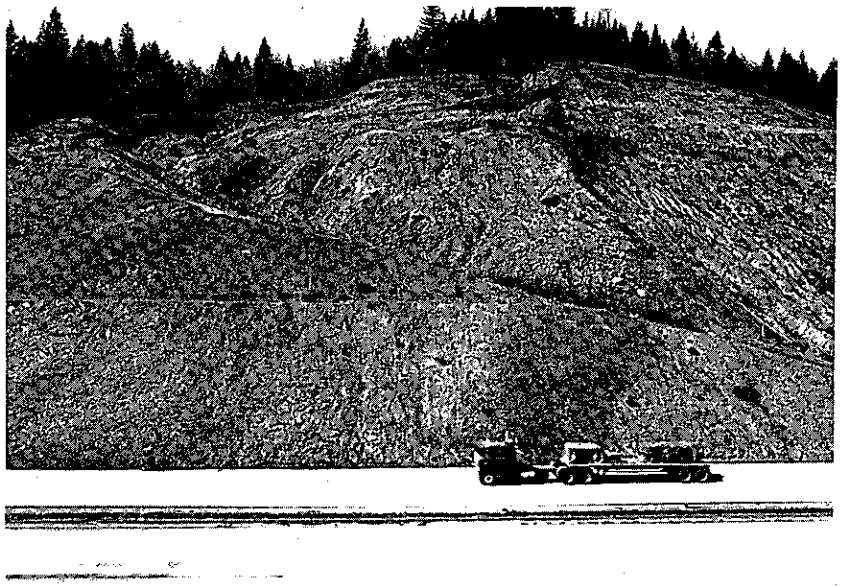

Plate 1 - Overall View

Plate 2 - Surface appearance near head of landslide

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Plate 3

Trees deflecting telephone line

Plate 4

Same line after trimming trees

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