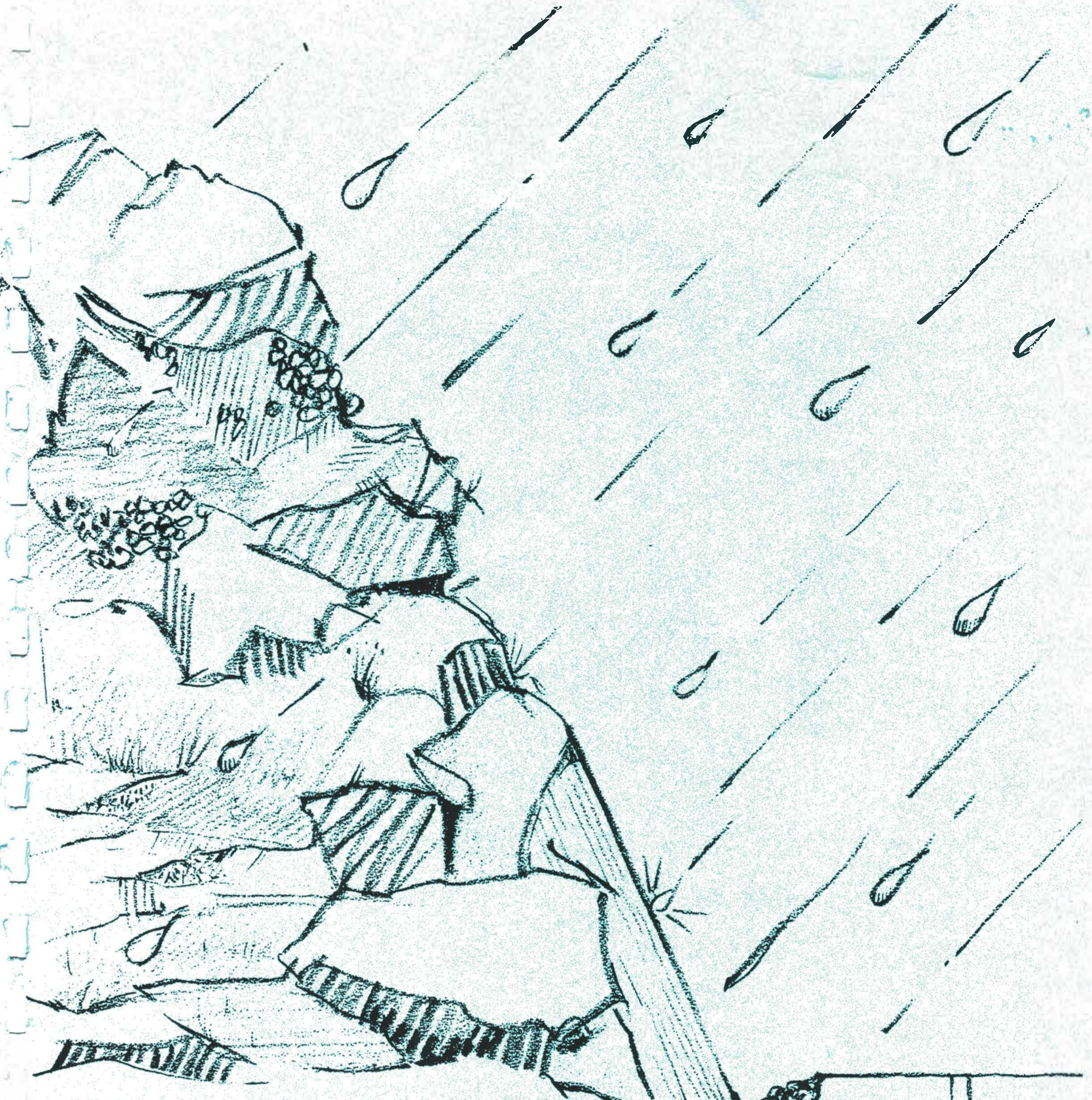

Slope Stability of Certain Selected Colluvial Soils

Research and Development Division
Oklahoma Department of Transportation

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessary those of the Federal Highway Administration.

SLOPE STABILITY OF CERTAIN SELECTED COLLUVIAL SOILS

by

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Research Project No. 71-05-1

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PREFACE

This report constitiutes an interim report of the findings of Research Report 71-05-1, "Slope Stability of Certain Selected Colluvial Soils." Included in this report are descriptions of soils known to be unstable. Also included are descriptions of ground water conditions and clay mineralogy. A stability analysis is presented to demonstrate how design criteria may be derived to use in constructing roads in landslide prone areas of Oklahoma and elsewhere.

Pedological and geological terms and description are used extensively throughout this report to demonstrate their usefullness for engineering purposes.

The author thanks the Oklahoma Department of Transportation Materials Laboratory, Dr. Lester Reed, Gary Hamacher, Charles Unsell, E.B. Kidd, and Virgil Wallace for their help in contributing to this report.

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16. Abstract

The objective of this study is to characterize natural clayey colluvial soils that occur in eastern Oklahoma. Three study sites were selected in areas of known landslides.

Piezometers and permeability bore holes were placed in the soils in undisturbed areas adjacent to landslides. Undisturbed samples were taken for laboratory analysis. Rainfall at the sites were monitored continuously.

Horizontal drains were installed to determine flow rates of subsurface water within the soils.

A stability assessment of the soils is presented to demonstrate the degree of landslide hazard in these areas.

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SUMMARY

Clayey colluvial soils with cyclic water tables cause stability problems in southeastern Oklahoma. When such soils occur on the steep slopes of mountainous terrain, conditions are created such that embankments or cuts in these areas promote the occurrence of slumps and landslides.

The colluvial soils of the Quachita Mountains are mostly deep and bouldery. They occur most frequently toward the base of the mountains. Rapid fluctuations in water table levels in these soils occur just after heavy rains. During the winter and spring months,the water tables are within the colluvium. During the summer months, the water levels fall below the base of the colluvium. Slumps and landslides occur during the late winter and spring when water table levels are highest.

Permeability tests indicate a very slowly permeable soil but horizontal drain flow rates indicate much higher permeabilities. It appears as if the high permeabilities are due to discontinuities in the soil.

A detailed investigation and stability analysis of the soils at three landslide sites was undertaken. Samples of soils were taken for physical, chemical and mineralogical analysis. Horizontal drains were installed to gauge flow rates of water from natural soils.

When high water levels are assumed, the safety factors approach 1.0. If discontinuities are accounted for, the factor of safety will be somewhat below 1.0. Additional investigation directed toward the kinds and orientations of discontinuities in colluvials soils is warranted.

IMPLEMENTATION STATEMENT

The results of this study point out the importance of conducting an adequate foundations reconnaissance prior to the final alignment decision. Slide problems can be of such a magnitude as to cause some projects to be risky if not unfeasible. The soils studied herein have been shown to have soil, water, and clay mineralogy that contribute to a lack of stability. The recognition of discontinuities within the soil mass modifies the results of standard tests and procedures by lowering safety factors.

A separate implementation manual has been developed to use as a guide for design and construction in landslide prone areas. This manual is available on request to the Oklahoma Department of Transportation Research Division.

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INTRODUCTION

Weak soils are becoming more and more a problem as modern roadways are designed and built. Luckily, most of Oklahoma is relatively flat and poses little risk of landslide failure. However, the eastern one-third of the state contains considerable areas of mountainous relief along with rainfalls exceeding 40 inches (102 cm) annually. The combination of geological and climatic conditions present cause the rock strata to weather into colluvial soils which are unstable. Colluvium is loose soil material that is usually at or near the foot of a slope and is brought there chiefly by gravity.

Engineers constructing highways in the southeastern part of Oklahoma are constantly plagued by water table and soil stability problems. Areas that appear to be dry. quickly develop water problems, especially during wet seasons. Construction workers and local residents note that some springs and seeps drain only during or just after heavy rains. Other springs in the area are known to be seasonal, and still others run constantly. The variability of water table conditions causes great problems with embankment and cut slope designs and their stability during and after construction.

The location and amount of underdrainage to be used, as well as underdrain types, has been difficult to determine. Most of the construction work is done during the dry summer season, or at least during dry spells between rainy periods. Therefore, a great many of the seeps and wet areas that may cause problems at a later date are not noticed. In almost every case, where colluvial soil material and high water table conditions are encountered, the embankments placed on these soils show signs of instability.

In this report the characteristics of certain landslide prone clayey colluvial soils were observed. The emphasis of this study is placed on a better understanding of the relationship of soil properties and ground water conditions on the stability of colluvial soils.

The properties of certain soils are drastically affected by their moisture content and ground water levels (40). Many clay soils are known to be exceedingly sensitive to changes in moisture (8). Camp and Gill (10) have found that soil strength increases on drying. The effect of wetting and drying is compounded if such soils occur on steep slopes and contain defects, e.g. slickenslides, bedding planes, or fissures (12,37). Abrams and Wright (1) note that a gradual reduction in shear strength due to swelling, pore pressures, water tables, aquifiers, and fissures, causes earth slope failures in highly plastic clay soils in Texas. Bjerrum (8) also notes the deleterious long term effects of excess pore pressure and fissures in fine grained soils. Parcher (28) says that cuts in stiff fissured clays should be made in terms of total stress for short term stability, while using residual strength (c=o) for long term analysis.

Since site conditions change depending on such things as water tables, topography, vegetation, geology, and climate, each landslide site is unique. This variability has helped to spawn the many kinds of stability analysis methods now in existence (6, 42, and 47). Much of the difficulty in accurately analysing colluvial soils for their slope stability, is in determining their degree of anisotrophy especially in terms of moisture content and inherent defects within the soil material. This, in turn, should govern the selection of the appropriate parameters to use in the selected method of analysis.

MATERIALS AND METHODS

All drilling for piezometers and permeability test holes was done by a Failing 1250 drilling rig using air as a drilling fluid. Sharp-edge Shelby tubes, 3 inches (7.62 cm) in diameter, were used to sample for the unconfined compression and direct shear tests. Piezometers were installed to determine water table levels. They were of the Casagande type and were installed according to Bureau of Reclamation procedure (44). A concrete and bentonite seal was placed at the surface to ensure that surface water did not affect the piezometer reading. Seven inch (18 cm) diameter holes were drilled to facilitate permeability tests. The bailing method of Maasland and Haskew (24) was used to determine permeability. Horizontal drains were installed in 4½ inch (11 cm) bore holes. The annular space was sealed with bentonite at the lower end.

In the laboratory, the sieve analysis, Atterberg limits, hydrometer, and shrinkage tests were performed on the soil samples. Direct shear tests were conducted on a Karol-Warner 570, using a strain rate of 0.05 inches/minute (0.13 cm/min.).

Soil densities were taken from Shelby tube samples. Analysis of the slope stability testing program was facilitated by using an IBM Model 58 computer.

SITE DESCRIPTION

PHYSIOGRAPHY

The three study sites are located in LeFlore County along Oklahoma SH 1 (Talimena Drive) in the Ouachita Mountains of southeastern Oklahoma (Fig. 1 & 2). According to Hart (15), the terrain of the study area is characterized as that of a ridge and valley topography produced by steeply dipping, thrust faulted sandstones and shales. The ridges commonly stand about 1,800 to 2,000 ft. (249 to 610 m) above the valleys. Mountain slopes are commonly very steep, mostly 21 to 28 degrees. The land surface is often hummocky and broken by many small V-shaped drainageways. Rock outcrops are common. Sandstone rock, cobbles, and boulders of various diameters of from 3 inches (76 mm) to 3 feet (1m) are common as surface debris and also within the colluvial soil mass. Quite often, boulders and soil

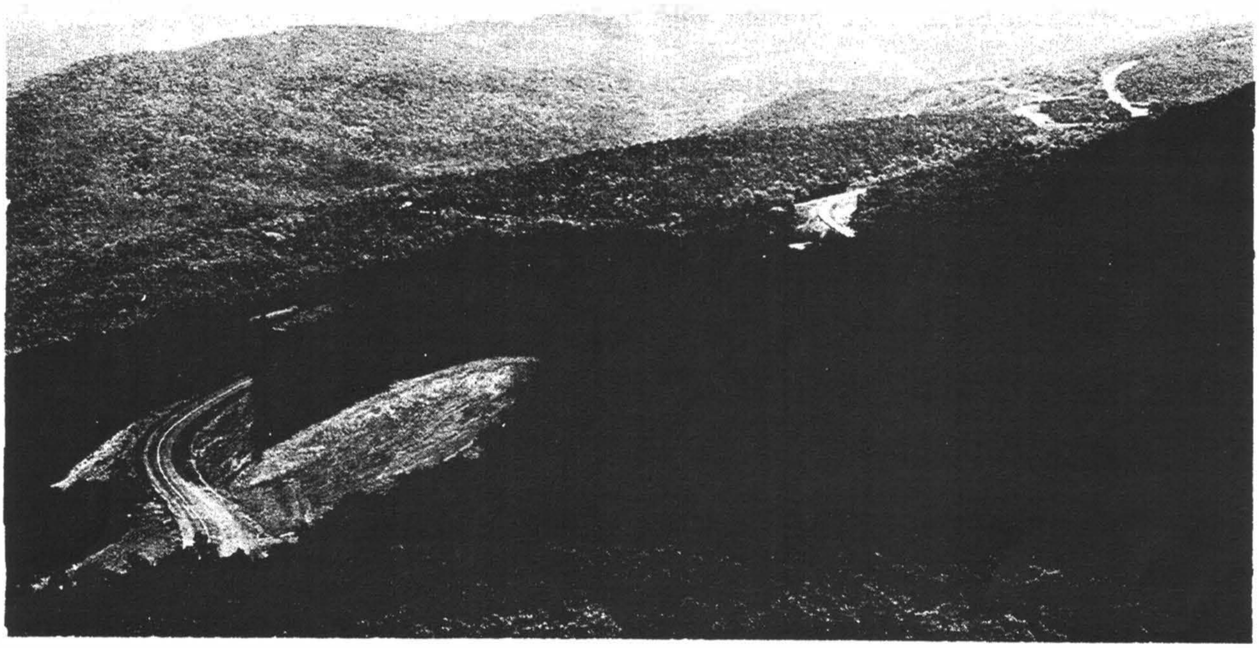

Figure 1. Landforms along Talimena Drive - Winding Stair Mountain, LeFlore County, Oklahoma.

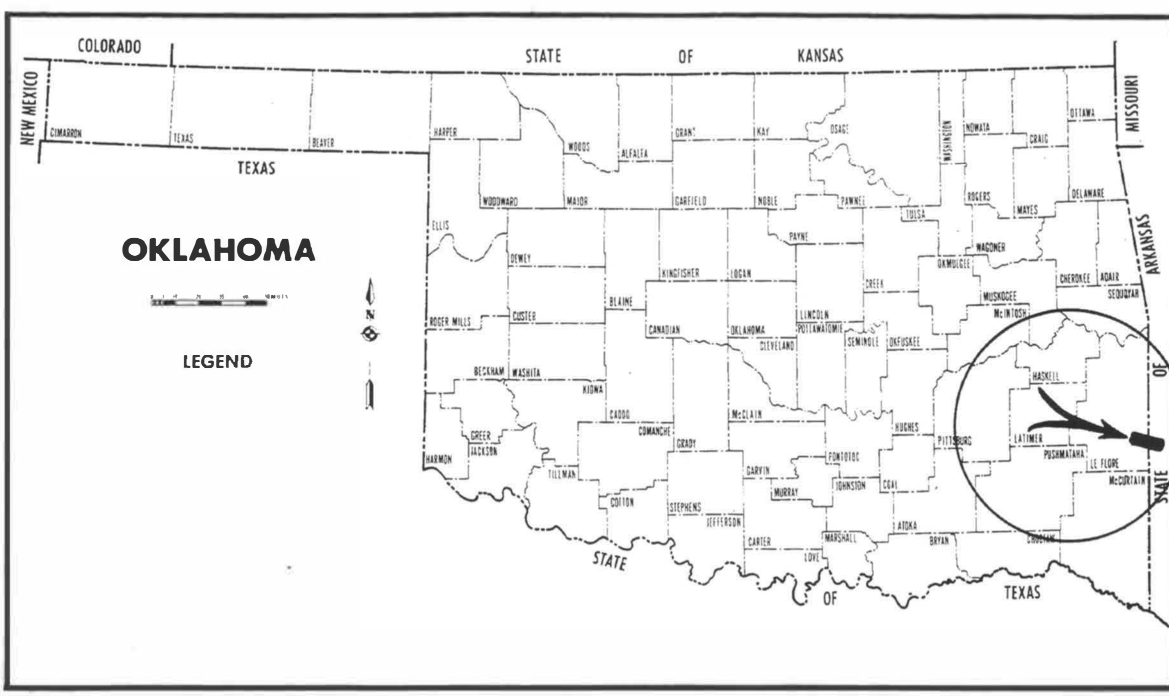

Figure 2. Location of Study sites.

debris tend to collect in the narrow and steep drainageways creating a boulder flow effect.

The study sites are all located within 1.5 miles (2.5 km) of each other. All the sites are located adjacent to recent landslides. Site One is on the north facing slope of a long ridge called Winding Stair Mountain. Sites Two and Three are on adjacent Spring Mountain. At all the sites the slope is near 25 degrees. Slope lengths are all nearly 2,000 feet (610 m).

The landslides associated with the research study sites occurred during 1969 and 1970, about 4 to 5 years after construction of Talimena Drive.

CLIMATE and VEGETATION

Located in a moist and humid area, the sites average 54 to 56 inches (137 to 142 cm) rainfall per year (27). The temperature averages 63^{o}F. (17^{o}C.) at Poteau which is located 23 miles (38.4 km) to the north. South-easterly winds prevail, bringing warm moist air from the Gulf of Mexico. Snowfall averages only 4 to 6 inches (10 to 15 cm) per year. The area is composed primarily of forestland. The dominant species are Oak (Quercus), Hickory (Carya), and Shortleaf Pine (Pinus Echinata) (26).

GEOLOGY

The study areas are located in the Ouachita Mountain geological province (Fig. 3 & 4). This is a structurally complex folded and faulted zone between two major faults, namely the Choctaw and Winding Stair. Sandstones and shales are by far the dominant rock types.

Site One is located along the north side of Winding Stair Mountain. In this area, 4,415 feet (1,263 m) of the Markham Mill, Prairie Mountain, and Upper Wildhorse Mountain formations are present. These rock strata are gray sandstones and siltstones interbedded with shales. Dips vary abruptly, but are near 45 degrees

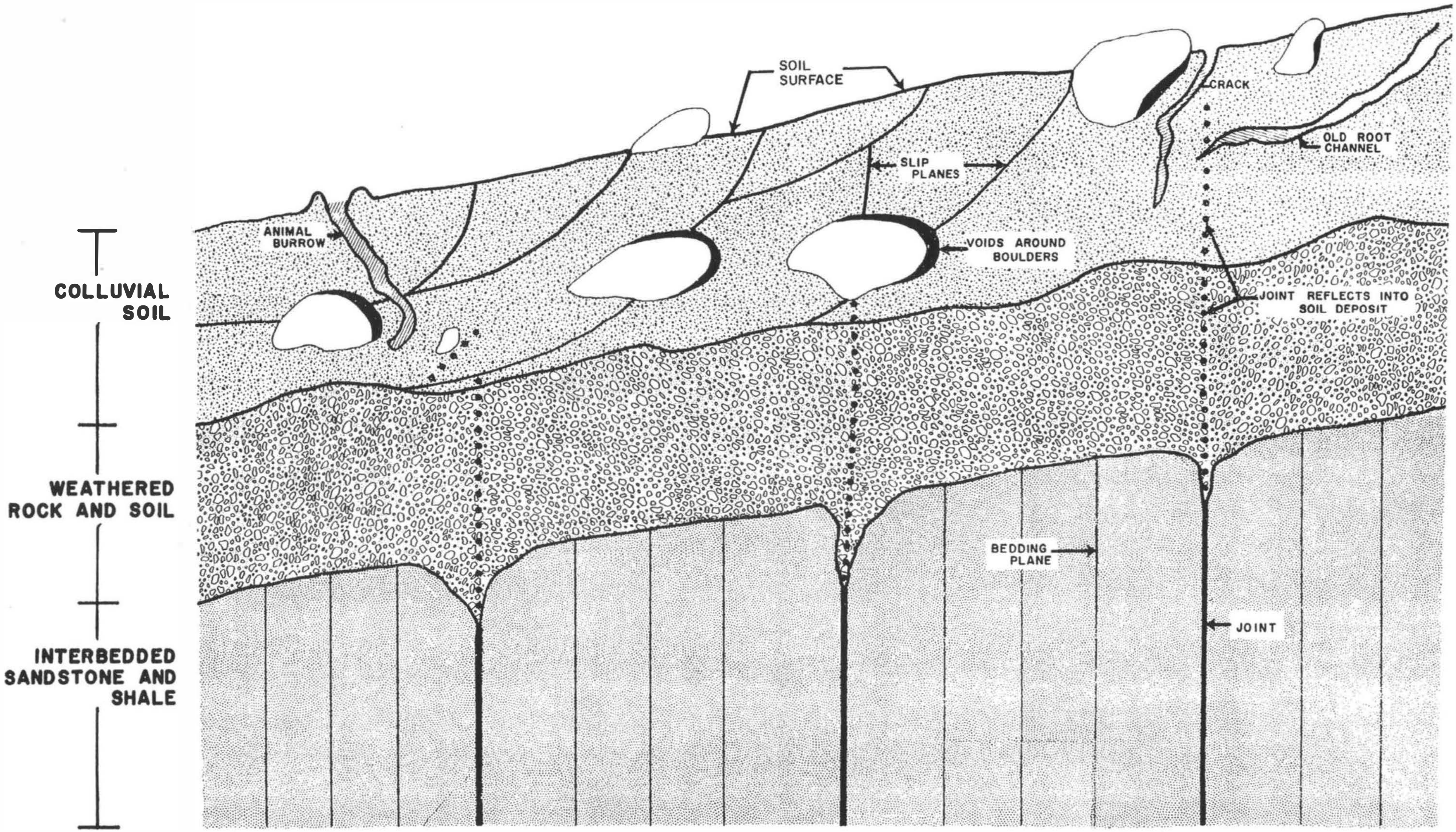

Figure 3. Cross Section of Geological Conditions at the Study Sites

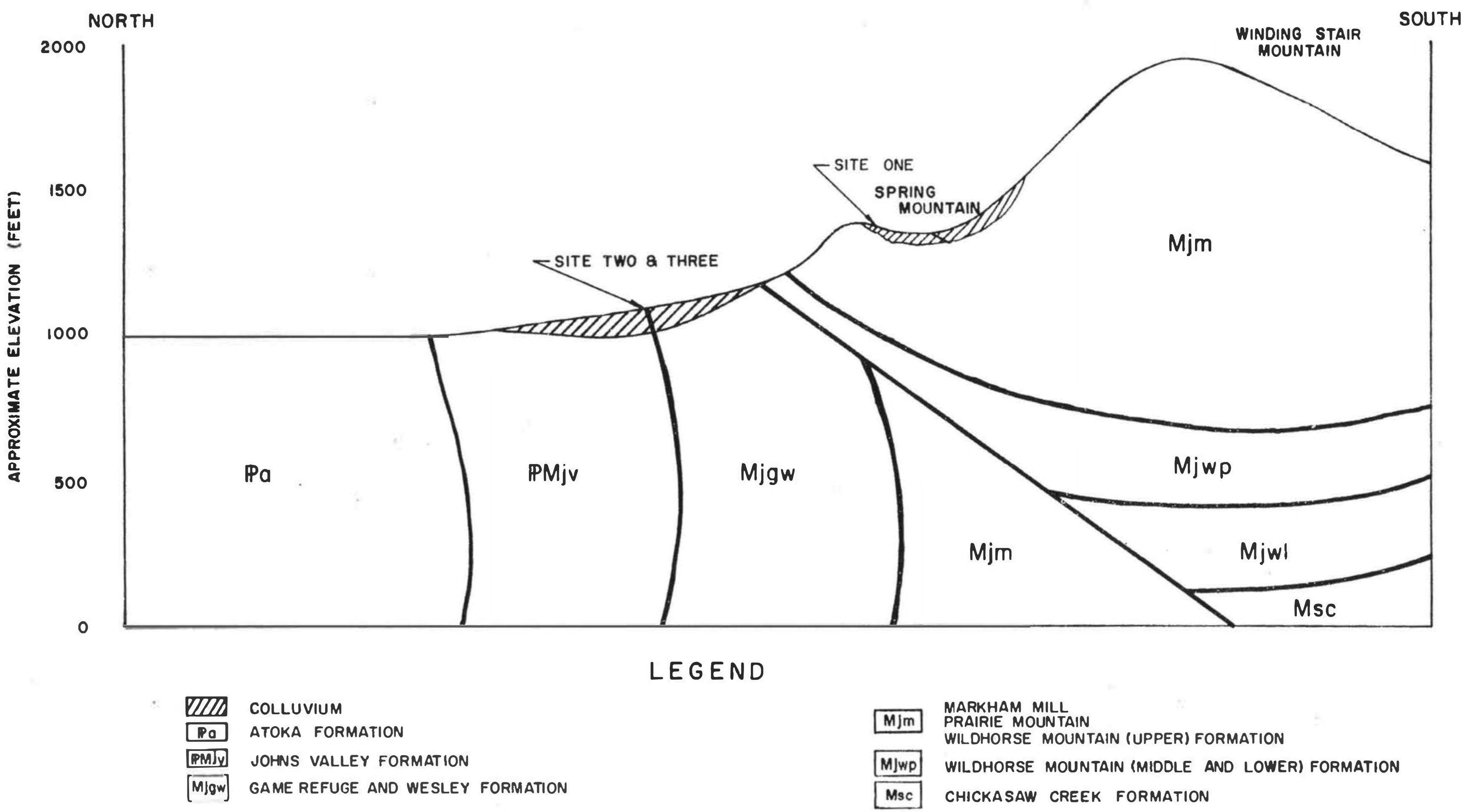

Figure 4. A Cross Section Map in the Vicinity of the Study Site.

south (overturned) at the study site. The presence of alternating soft and firm, as well as weathered and soil material encountered in drilling, suggests the possibility of a transverse fault running thhough Site One parallel to the drainageway.

The north side of Spring Mountain in the vicinity of Site Two and Three is comprised of 1,420 feet (433 cm) of the Game Refuge and Wesley rock units consisting of gray sandstones interbedded with thin gray shales in the upper zones and interbedded dark gray thin sandstones and shale in the lower part. The Johns Valley rock unit also occurs at Site Two and Three. The Johns Valley consists of 900 to 1,000 feet (247 to 305 m) of gray to black shale. This shale is locally conglomeratic.

At Sites Two and Three, all the rock units are overturned due to large tectonic (earth deforming) stresses imposed upon them (Fig. 4) They dip to the south-southwest at 70 to 85 degrees.

Thick deposits of colluvium up to 20 feet (6 m) thick are present in the drainageways on the mountainsides. The colluvium ranges from clayey to bouldery in size composition but is predominantly clayey.

SOILS

Two soil types account for nearly 90% of the unstable colluvial material present in the area of the study sites. These soils are deep, clayey, and yellowish red in color (Table 1). Although there is some evidence of creep, all the soils are at least stable enough for normal soil horizonation to form.

In the new system of pedological soil classifictation (39), these soils belong in the clayey family and are classified as Aquic and Typic Ultisols (paleudults). Ultisols are those soils that are restricted to humid climates and are considered to be old, highly weathered soils.

The transition to the underlying rock strata is usually gradual. Typically, the yellowish red color of the soil gradually changes to yellowish olive, then

Table 1 PARTICLE SIZE CLASSIFICATION

Horizon	Depth (cm)	AASHTO*	Unified	USDA**
		PROFILE I		
A1	0-13	A-4(0)	SM	silt loam
A2	13-25	A-4(0)	SM	fine sandy loam
B21t	25-48	A-2-4(0)	SM	loam
B22t	48-64	A-6(5)	ML	silty clay loam
B23t	64-112	A-7-6(22)	CH	clay
B24t	112-173	A-7-6(45)	CH	silty clay
B3	173-206	A-7-6(22)	CL	silty clay loam
R	206-229	A-6-(11)	CL	silty clay loam
		PROFILE II		
A1	0-10	A-4(0)	SM	fine sandy loam
A2	10-20	A-4(0)	SM	loam
B21t	20-80	A-7-5(22)	CH	clay
B22t	80-117	A-7-5(25)	CH	clay
B23t	117-175	A-7-6(20)	ML	silty clay
B24t	175-203	A-7-6(4)	SM	clay loam
B31	203-251	A-7-6(26)	CH	clay
B32	251-305	A-7-6-(27)	CH	clay
		PROFILE III		
A1	0-10	A-2-4(0)	SM	loam
A2	10-20	A-4(0)	SM	loam
B1	20-30	A-6(3)	CL	loam
B21t	30-56	A-7-6(8)	CL	clay
B22t	56-107	A-7-5(18)	MH	clay
B23	107-152	A-7-5(13)	MH	clay
B3	152-196	A-7-6(15)	MH	clay

*American Association of State Highway and Transportation Officials
**U.S. Department of Agriculture

Table 2A SOIL DESCRIPTION

Profile One, Site One

A1 -- 0-13 cm., dark grayish brown (10YR 4/2)* sandy loam; moderate fine granular, very friable; 17% by weight sandstone fragments; abundant roots, clear wavy boundary.

A2 --13-25 cm., yellowish brown (10YR 5/4) fine sandy loam; weak fine granular; very friable; 23% by weight sandstone fragments; plentiful roots; gradual wavy boundary.

B21 t--25-48 cm., strong brown (7.5YR 5/6) loam; weak fine subangular blocky; friable; 48% by weight sandstone fragments; few roots, clear wavy boundary.

B22 t--48-64 cm., yellowish red (5YR 4/8) clay loam; moderate fine subangular blocky; friable; few roots; gradual wavy boundary.

B23 t--64-112 cm., yellowish red (5YR 4/8) clay; common medium prominent mottles of red (2.5YR 4/6) and light gray (10YR 6/1); moderate fine subangular blocky; firm; few roots; gradual wavy boundary.

B24 t--112-173 cm., strong brown (7.5YR 5/6) and light gray (10YR 6/1) silty clay; weak angular blocky; very firm; few roots; gradual wavy boundary.

B3 --173-206 cm., strong brown (7/5YR 5/6) and light gray (10YR 6/1) silty clay loam, weak angular block; very firm; few roots, gradual wavy boundary.

R --206-229 cm., yellowish brown shale; silty clay loam.

Legal Description: Center E½, SE¼, Sec. 21, T2N, R25E, LeFlore County, Oklahoma.

*Munsell Soil Color Chart, Munsell Color Company, Inc., Baltimore, Maryland.

Table 2B

SOIL DESCRIPTION

Profile Two, Site Two

A1 -- 0- 10 cm., brown (10YR 4/3), fine sandy loam; weak fine granular; very friable; 32% by weight sandstone fragments; abundant roots; clear wavy boundary.

A2 -- 10- 20 cm., very pale brown (10YR 7/4) sandy loam; weak fine granular; very friable; 70% by weight sandstone fragments; plentiful roots; gradual wavy boundary.

B21 t -- 20- 81 cm., red (2.5YR 4/8) clay; moderate fine angular blocky; firm; 11% volume sandstone fragments; few roots; gradual wavy boundary.

B22 t -- 81-117 cm., red (10R 4/6) clay; common distinct medium mottles of light gray (10YR 6/1 and 7/1) and very pale brown (10YR 7/3); weak fine angular blocky; firm; few roots; gradual wavy boundary.

B23 t --117-175 cm., red (10R 4/6) and light gray (10YR 6/1) silty clay; weak fine angular blocky; firm; few roots; clear irregular boundary.

B24 t --175-203 cm., yellowish red (5YR 5/6) heavy clay loak; few distinct medium mottles of light gray (10YR 6/1) and red, (10YR 4/6); weak fine angular blocky; firm; 35% by weight sandstone fragments; few roots; clear irregular boundary.

B31 --203-251 cm., light gray (10YR 7/1) clay; many distinct medium mottles of red (10YR 4/6) and yellowish red (5YR 5/6); weak fine angular blocky; firm; 11% by weight sandstone fragments; few roots; clear irregular boundary.

B32 --251-305 cm., brownish yellow (10YR 6/6) and light gray (10YR 7/1) clay; few distinct medium mottles of red (10R 4/6); weak fine angular blocky; firm; 5% by weight sandstone fragments; few roots; clear irregular boundary.

Legal Description: About 1000 feet (305 m) south of the NW corner of the SW¼ of Sec. 23, T2N, R25E, LeFlore County, Oklahoma.

Table 2C SOIL DESCRIPTION

Profile Three, Site Three

A1 -- 0- 10 cm., dark grayish brown (10YR 4/2) moderate fine granular; very friable; 52% by weight sandstone fragments; abundant roots; clear wavy boundary.

A2 -- 10- 20 cm., very pale brown (10YR 7/4) loam; moderate fine granular; very friable; 23% by weight sandstone fragments; plentiful roots; gradual wavy boundar.

B1 -- 20- 30 cm., strong brown (7.5YR 5/6) loam; weak fine sub-angular blocky friable; 18% by weight sandstone fragments; few roots; gradual wavy boundary.

B21 t -- 30- 56 cm., yellowish red (5YR 4/8) clay; moderate fine sub-angular blocky; firm; 30% by weight sandstone fragment; few roots; gradual wavy boundary.

B22 t -- 56-107 cm., red (10R 4/6) clay; moderate fine subangular blocky; firm; 12% by weight sandstone fragments; few roots; clear irregular boundary.

B23 t --107-152 cm., red (10R 4/6) clay; weak fine subangular blocky; firm; 29% by weight sandstone fragments; few roots; clear irregular boundary.

B3 --152-196 cm., red (10R 4/8) clay; weak fine subangular blocky; firm; 12% by weight sandstone fragments; few roots; clear irregular boundary.

Legal Description: Center W½, SW¼, Sec. 23, T2N, R25E, LeFlore County, Oklahoma.

progressively to a darker gray. (See Tables 2A, 2B, and 2C). Only in a portion of Site One was the soil underlay anything other than dark gray shale. At the east end of Site One, a broken soft sandstone lay beneath a clayey sand colluvial soil.

A modal soil profile representing each of the three study areas was located. A sample of each was taken for testing. (See Tables 3A, 3B, and 3C). Disturbed samples were taken for chemical, mechanical, and mineralogical analysis (30).

PERMEABILITY

It is known by highway engineers that the colluvial soils in this area appear to become rapidly wetted. May seeps and springs occur soon after heavy rains, although quite often they begin to diminish within a few hours. It became important to determine the rate and manner of water movement in these soils.

Several types of permeability tests are available for use. These include the slug-injection (13) bailing (24) and pumping tests (46). The slug-injection test involves an instantaneous addition of a measured amount of water to a bore hole. This procedure was not used due to the very high water tables which developed during the spring. The water table at many of the bore holes was very close to the surface, and the addition of only small amounts of water would cause the holes to overflow.

A pumping test was considered because of data derived from landslide investigations in this area. It had been noted that many bore holes in disturbed landslide material have pumped from 1 to 4 GPM (4 to 15 liters/min.). Such volumes could have been pumped with permeability measurements taken from these flow rates. However, the bore holes made in undisturbed colluvials soils would not yield water anywhere near pumping test capabilities. The pumping tests were then discontinued.

Table 3A

ENGINEERING PROPERTIES OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA DRIVE, OUACHITA MOUNTAINS, SITE #1.

Depth cm	Horizon	Liquid Limit	Plasticity Index	Shrinkage Limit	Shrinkage Ratio	Volume[1] Change
0-13	A	22	2	18	1.77	7
13-26	A	18	3	13	1.92	8
26-49	B	24	10	13	1.95	16
49-64	B	33	16	14	1.92	23
64-87	B	50	28	15	1.89	46
87-148	B	68	41	14	1.92	64
148-181	B	45	21	15	1.90	45
181-204	R	33	12	13	1.92	32

1. From field moisture equivalent, AASHTO T-93

Table 3B

ENGINEERING PROPERTIES OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA DRIVE, OUACHITA MOUNTAINS, SITE #2.

Depth cm	Horizon	Liquid Limit	Plasticity Index	Shrinkage Limit	Shrinkage Ratio	Volume Change[1]
0-10	A_1	30	3	23	1.58	8
10-20	A_2	22	2	16	1.80	11
20-81	B_{21t}	58	26	16	1.85	66
81-117	B_{22t}	63	30	15	1.85	70
117-175	B_{23t}	44	20	15	1.88	53
175-203	B_{24t}	47	19	17	1.83	46
203-251	B_{31}	57	31	16	1.86	61
251-305	B_{32}	57	29	18	1.79	51

1. From field moisture equivalent, AASHTO T-93

Table 3C

ENGINEERING PROPERTIES OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA DRIVE, OUACHITA MOUNTAINS, SITE #3.

Depth cm	Horizon	Liquid Limit	Plasticity Index	Shrinkage Limit	Shrinkage Ratio	Volume Change[1]
0-10	A_1	25	1	19	1.63	9
10-20	A_2	21	3	15	1.86	12
20-30	B_1	27	11	13	1.93	24
30-56	B_{21t}	46	18	13	1.91	56
56-107	B_{22t}	58	24	17	1.79	64
107-152	B_{23t}	60	25	17	1.80	61
152-196	B_3	55	28	14	1.85	59
196-213	B_{32}	-	-	-		-

1. From field moisture equivalent, AASHTO T-93

The bailing test offers the best practical solution for determining permeability under the conditions present at these sites. In this test, a measured amount of water is withdrawn from the bore hole. By measuring depth to water and rate of rise subsequent to the bailing, permeability can be calculated. The permeability data related in Table 4 is from bailing tests.

Permeability (K) of the colluvial soils ranges from 1×10^{-6} to 1×10^{-7} cm/sec. These permeabilities seem to agree with the particle size and other standard soil parameters. However, the presence of springs and flowing underdrains seem to contradict the low permeability observations.

The grain size composition of soil largely determines the permeability of soil. Baver (3) says that the movement of water by gravitational forces in natural soils is related to (a) the amount and continuity of the non-capillary pores as determined by soils structures, texture (particle size), volume changes, and biological channels, (b) the hydration of the pores, and (c) the resistance of entrapped air. Terzaghi and Peck (43) related that while clean sand may posses permeability coefficients of 10^{-3} to 1, homogeneous clays may range down to only 10^{-7} or less.

Perhaps a major clue to the permeability problem is given by Baver when he mentions "biological channels." Since this area is forested, many old root channels should be available to convey ground water.

Lattman (21) has noted that concentrations of geological fracture zones have promoted the occurrence of landslides in the Appalachian ridges of the eastern U.S. He has also been able to observe fracture traces in unconsolidated geological materials, including colluvium. He believes that water movement in these fracture zones was a major contributor to landslides there.

At least a partial answer to why the permeability tests did not reflect the presence of high permeability soil layers may be due to the bore hole method as well as the bore hole drilling procedure. Finding large root channels with bore holes may be statistically difficult. Even if a fairly large hole was intercepted, it would

TABLE 4. PERMEABILITIES OF SOILS ON LANDSLIDE AREAS[1] ON OKLAHOMA STATE HIGHWAY #1, TALIMENA DRIVE.

SITE #1		SITE #2		SITE # 3	
Hole Number	Permeability K cm/sec.	Hole Number	Permeability K cm/sec.	Hole Number	Permeability K cm/sec.
18	2.6×10^{-7}	10	2.3×10^{-8}	1	3.4×10^{-6}
19	10^{-7}	16	5.7×10^{-7}	2	2.5×10^{-6}
20	1.8×10^{-7}			3	4.7×10^{-7}
21	6.1×10^{-7}			4	1.8×10^{-7}
22	2.4×10^{-6}			9	8.8×10^{-8}

1. These holes are at 25 ft. (7.6m) intervals perpendicular to the slope, across the colluvial soil deposit at each site.

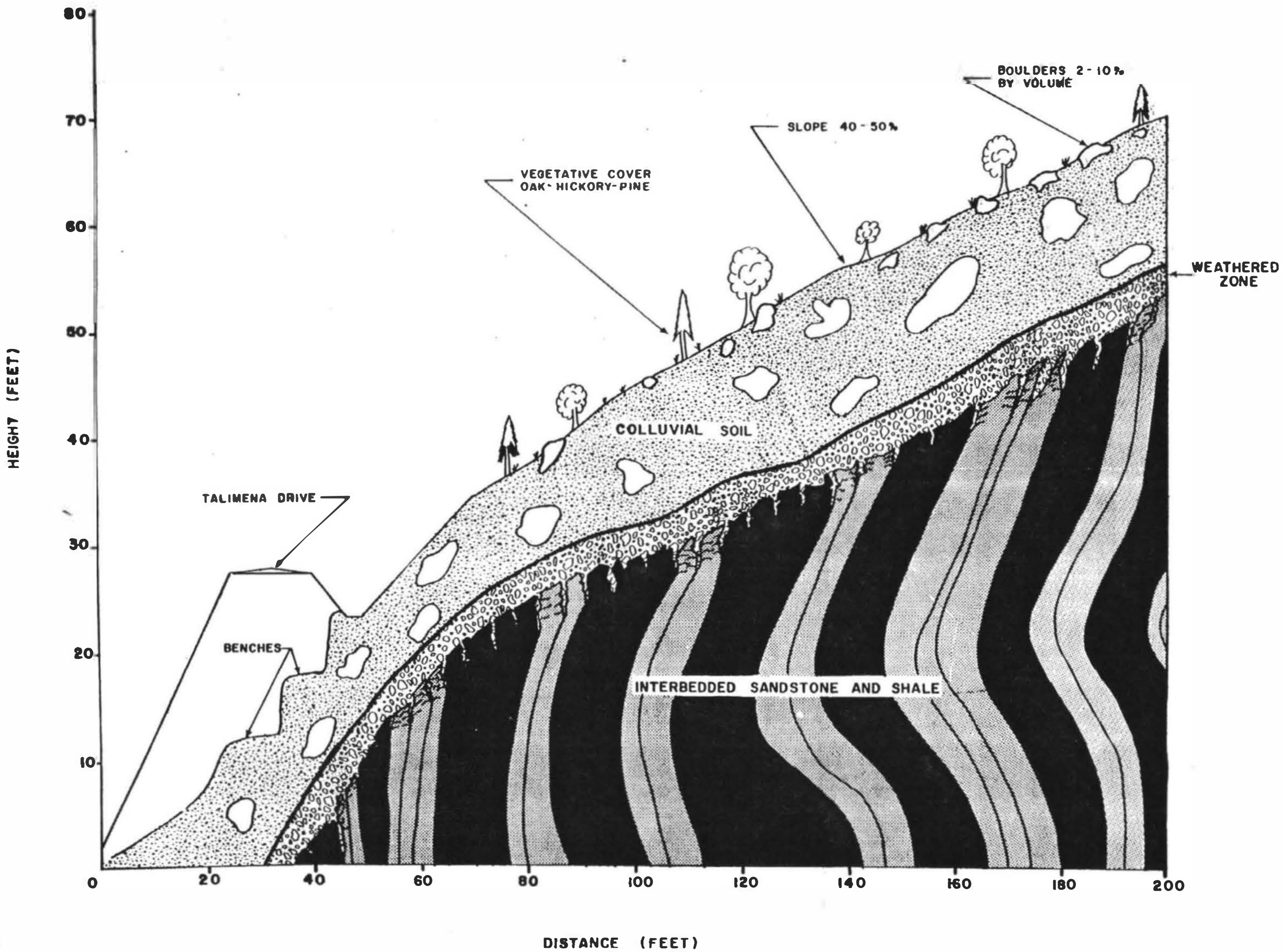

Figure 5. The View Shows the Relationship of the Colluvial Material to the Underlying Bedrock and a Highway Embankment

more than likely be filled with mud and/or smeared over by the action of drill bit and drill stem. No reliable method of cleaning out the hole and leaving it under natural conditions was conceived.

In an attempt to let the holes go back to nature, one series of tests were run in 1972 and another in 1975. It was hoped that by letting the holes stand for a long period that some or most of the permeability channels would reopen. The tests performed in 1975 indicated that no detectable changes had taken place.

PIEZOMETER RESPONSE

Piezometer responses confirm the suspected quick rise and fall of water tables in colluvial soil. Piezometers near the centers of the colluvial soil deposit can exhibit a rate of rise of about 0.8 feet (0.25 cm) per day to 2.0 feet (0.6m) per day. The rates of rise generally are slightly faster than the rates of decline.

Hole no. 13 at Site Three seems to be representative of the kinds of response to precipitation. This hole responds to heavy rains by rising at the rate of two feet (0.6m) per day. The rate of decline is 1.0 feet (0.3 m) per day (Fig. 6).

Such rates of change in water levels are representative of installations near the center of the colluvial soil deposits at the study sites. The piezometers away from the center of the deposit are progressively less responsive. In fact, the piezometers located away from the center usually go dry during the hot and dry summer months (Fig. 7).

In August 1972, about 11 out of 27 piezometers went dry. During April 1973, nearly all piezometers registered water levels. The maximum change observed was in hole no. 2 at Site One in which the water was observed to rise 29 feet (8.8 m) during the summer to winter seasonal cycle of 1972 and 1973. Hole no. 8 at Site One which was bored to the base of the colluvial soil, exhibited a change of 15 feet. In contrast, hole no. 19 at Site Three only fluctuated 0.9 feet (0.3 m) during the four

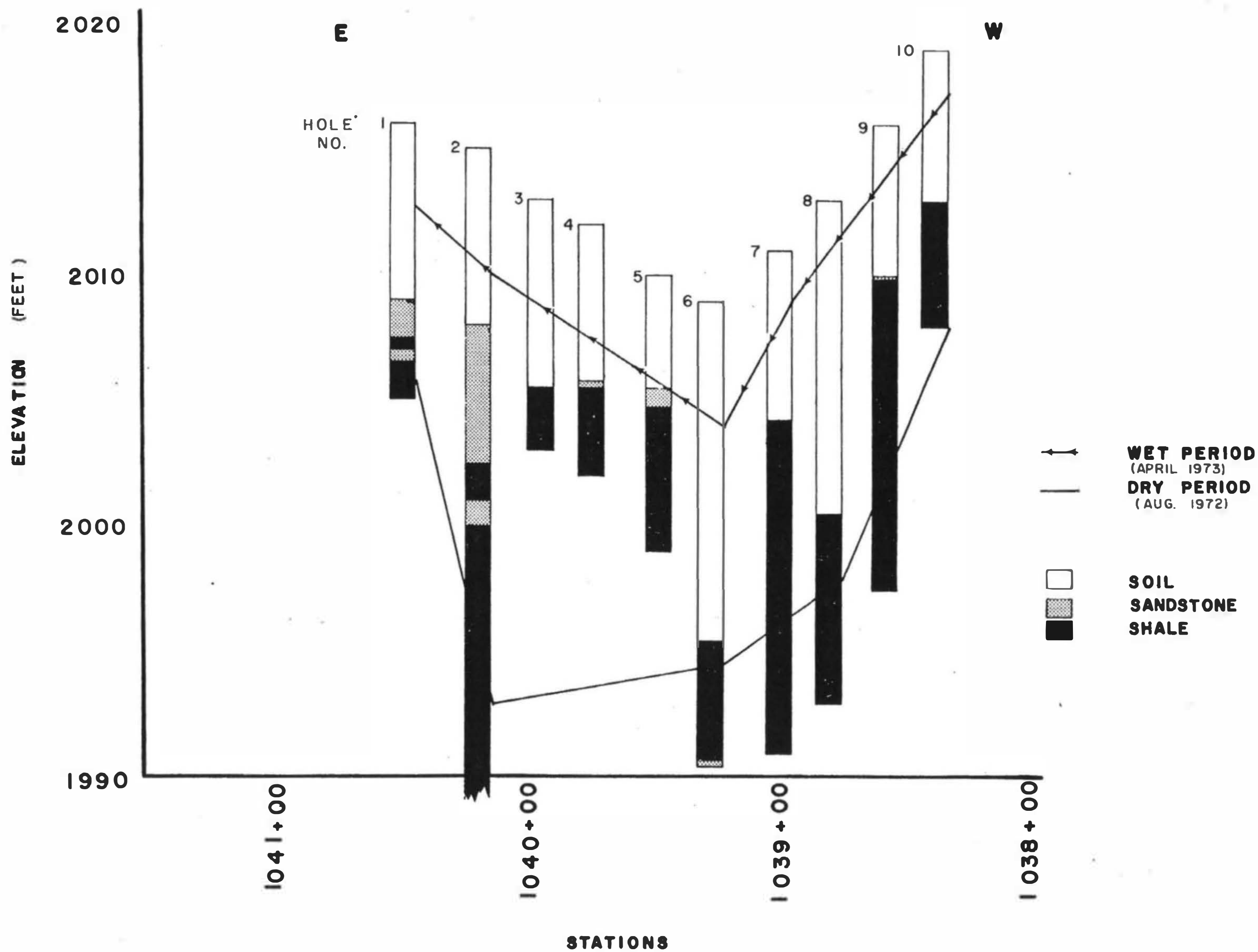

Figure 6. Piezometer responses to rainfall at Site One

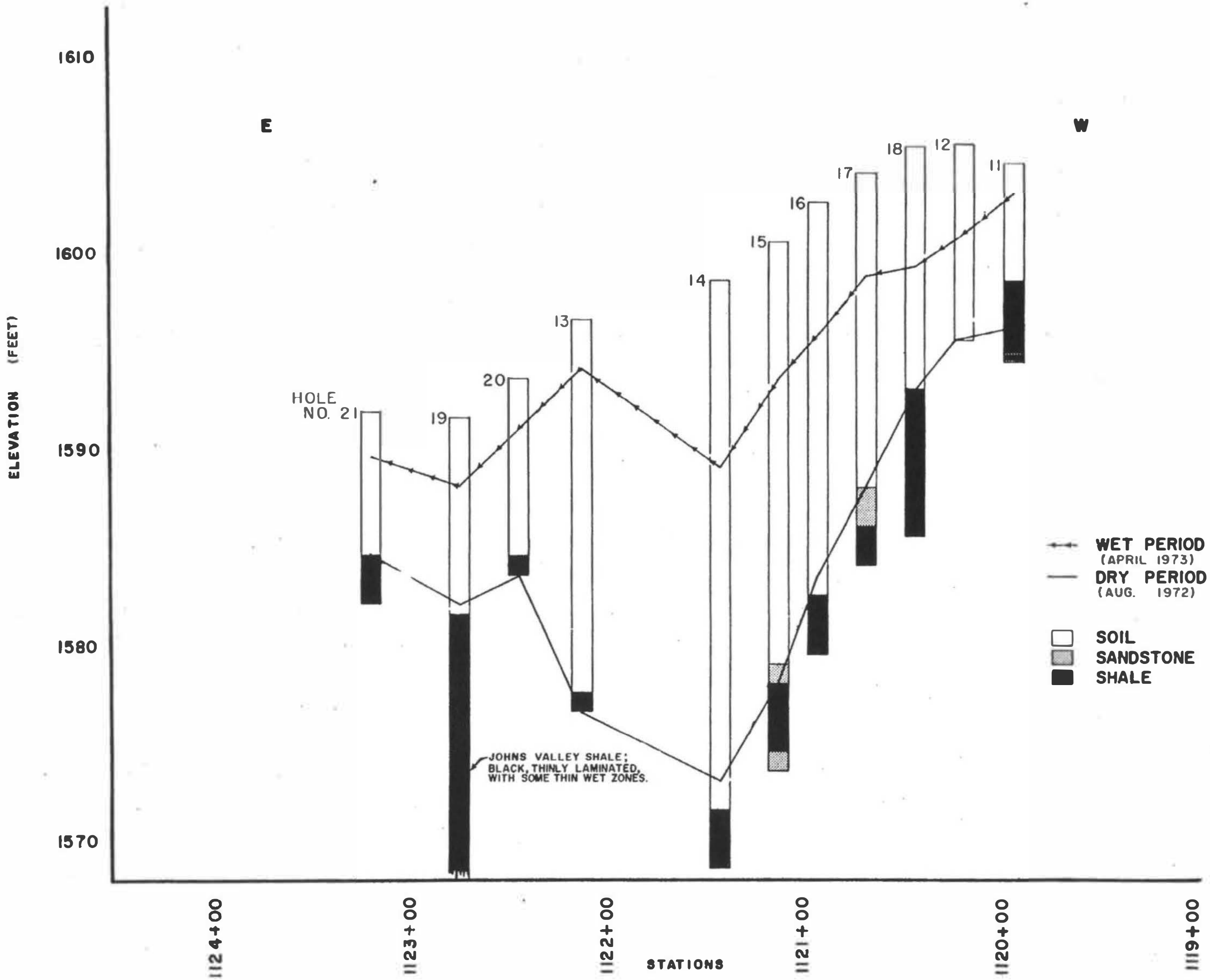

Figure 7. Piezometer responses to rainfall at Site Three

year study period (Fig. 8 & 9). It was drilled directly into a small spring.

Not all the piezometers react quickly. Some piezometers appear to be situated in areas of greater permeability or at least they have better access to the conditions causing rapid water level fluctuations. After heavy rains of about 2 to 3 inches or so in the preceeding 48 hours, piezometers located close to the center of the soil deposit begin to exhibit a rise in water levels. Other adjacent piezometers reflect smaller changes or slower reactions or register no change.

The piezometer readings show a strong seasonal response (Fig. 8 & 9). Peak water levels usually occur in April with the lowest levels in August. Theoretically, the peak water level should occur in June paralleling peak rainfall. It seems that evapo-transpiration from the heavy forest cover keeps this from happening.

An item worth noting is that during dry periods, the water tables usually drop out of the colluvial soil down into the geological bedrock. Those Site Three piezometers which do not penetrate into geological strata, go dry each summer.

Only the more significant rainfall amounts cause fluctuations in the piezometer readings. Rains of one inch (2.5 cm) or less do not seem to affect water levels. However, rains of 3 to 4 inches (7.10 cm) seem to cause a considerable rise in water levels. Response times vary but usually a 4 inch (10 cm) rain causes water levels to commence to rise from almost immediately to about 48 hours later.

HORIZONTAL DRAINS

Rainfall causes similar responses in horizontal drain flow rates and piezometer water levels (Fig. 10). Drain No. 2G, located near the center of the soil deposit at Site Two, flows almost the year round and shows typical responses. Rains of the first two weeks in March 1976 totaling 2.91 inches (74 mm) caused a rise in the flow rate from near 0.5 gpm (1.9 liters/min.) to a maximum of 1.3 gpm (4.9 liters/min.). Two rains in late March 1976 of nearly 3 inches (89mm) each caused a very abrupt rise from 0.4 gpm (1.5 liters/min.) to 21 gpm (80 liters/min.) in only 6

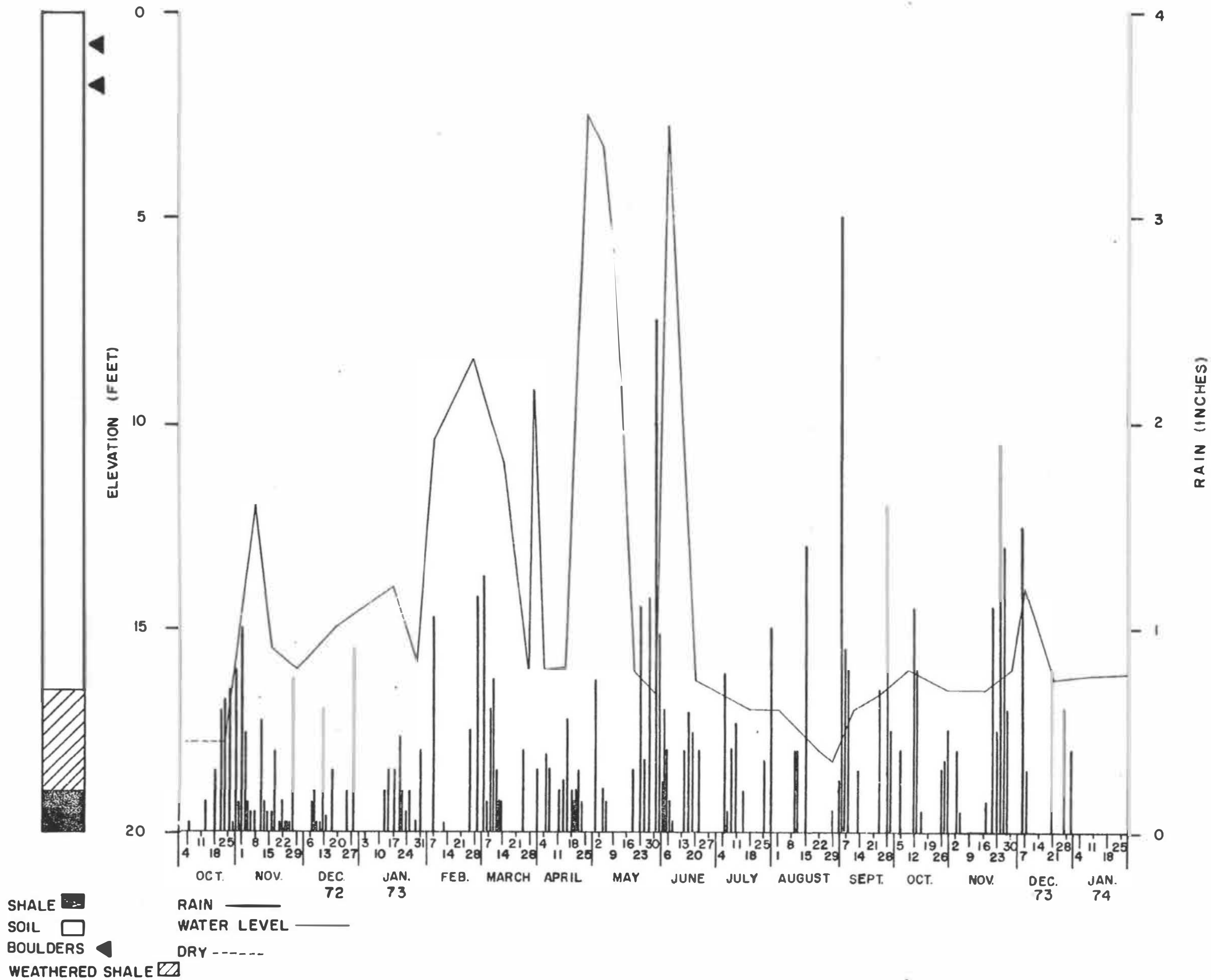

Figure 8. Seasonal Changes in Water Levels at Site One

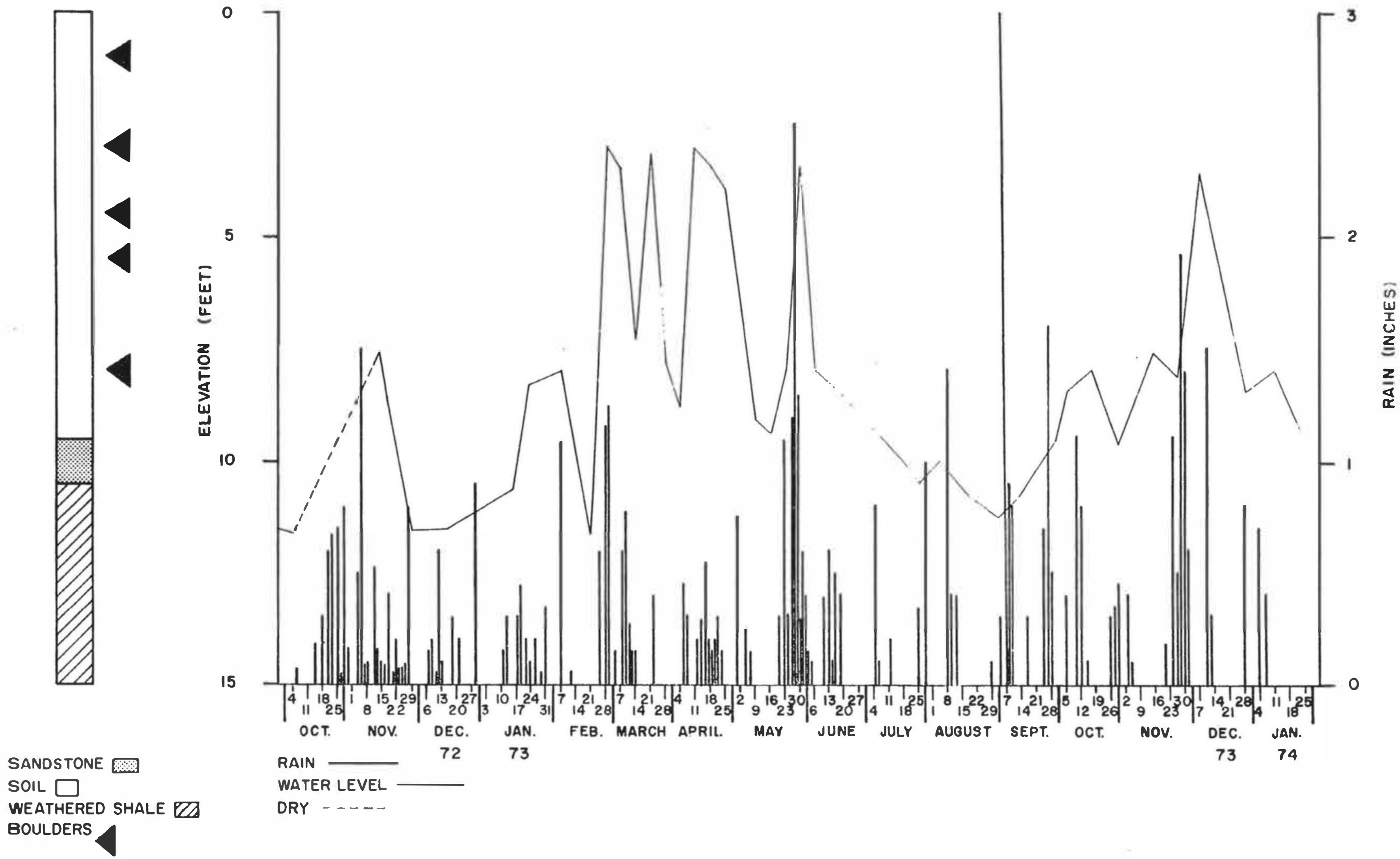

Figure 9. Seasonal Changes in Water Levels at Site Three

days. It's worth noting that the reduction in flow rate is nearly as abrupt as the rise. This also parallels the piezometer responses.

Twenty-six of the twenty-seven horizontal drains do not flow except after periods of high intensity rainfall totaling nearly 3 inches or more. On April 20, 1976, after 3.5 inches (89 mm) of rain in six days, twenty-four of the twenty-seven horizontal drains were flowing. The flow rates of most of the drains, which were usually dry did not exceed 1 gpm (3.8 liters/min.). These drains were not flowing at all three days later. The performance of the low flow rate drains parallels the performance of many of the piezometers, as many of the piezometers did not register water levels until after fairly heavy rains.

One horizontal drain was drilled into a permanent water table. This drain has produced discharge of from 0.06 gpm (0.23 liters/min) in dry periods up to 21 gpm (80 liters/min.) in the spring wet season after heavy rains.

Flow rates in the drains which function only after heavy rains ranges from no flow to about 0.2 (0.8 liters/min.).

Since installation, all the drains have been observed as discharging water, but only immediately after rains exceeding 3+ inches in the preceeding 48 hours. The majority of the drains will cease functioning 24 hours after a heavy rain. Therefore most of the drains are not draining water the majority of the time.

The holes were drilled at an angle of 6 degrees above horizontal. Drain lengths varied from 20 feet (6m) to 90 feet (27m) averaging 45 feet (14m).Considerable care was taken in drilling the horizontal holes so that only the colluvial soil was penetrated and not any geological strata. Boring was halted as soon as the soil color changed to an olive yellow indicating the proximity of the underlying shale bedrock.

The permeabilities of the soil from the permeability tests do not agree with the performance of the horizontal drains. It seems as if the movement conveyance of the water is through soil defects, e.g. around boulders, fissures, root channels, and

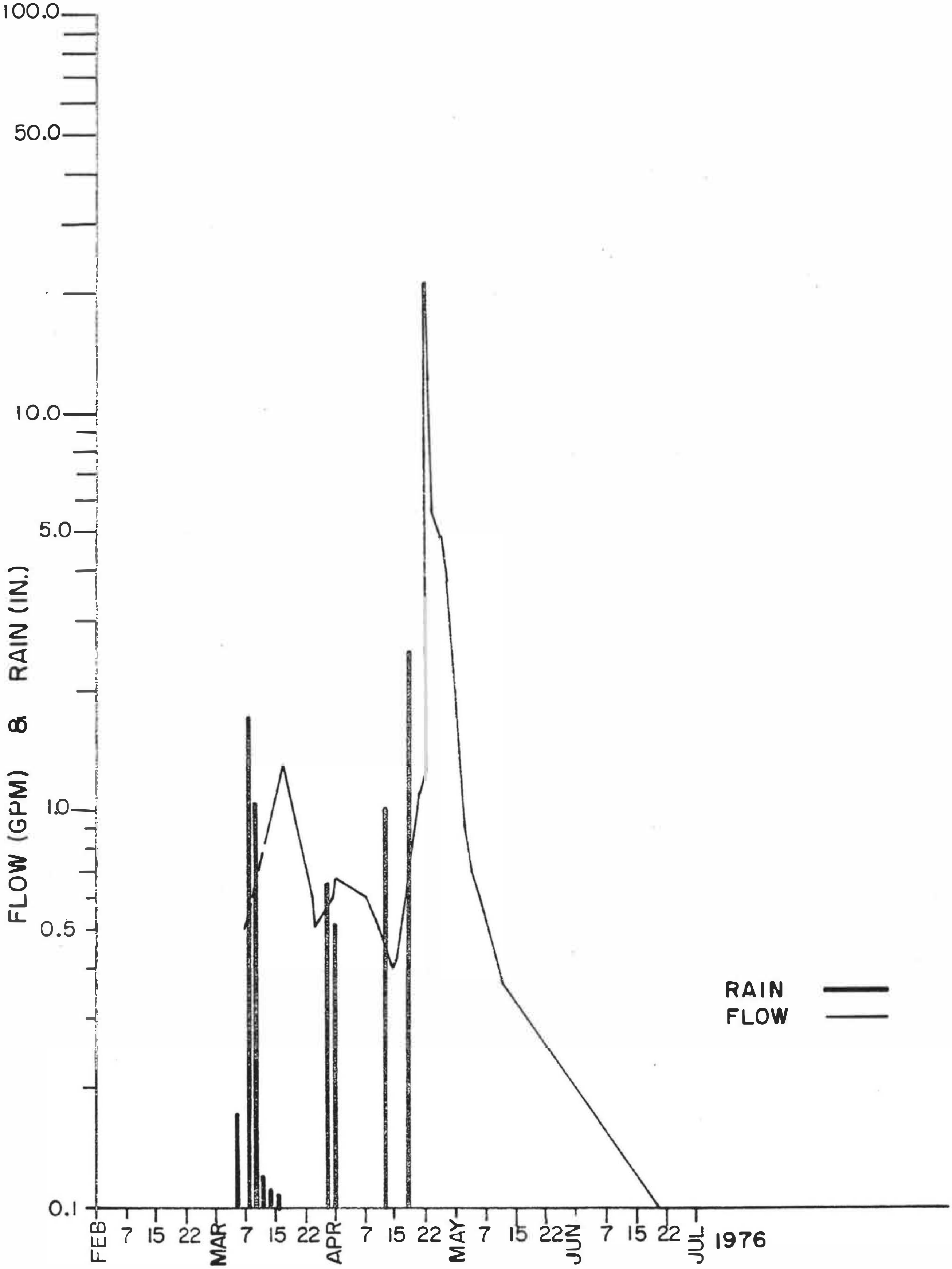

Figure 10. Horizontal Drain Flow

animals burrows (21). It also seems only these natural discontinuities can account for the high flow rates once the water tables are generated (Fig. 11).

MECHANISM FOR WATER MOVEMENT

Prior to the research reported here it was theorized that sand or gravelly layers would be found deep within the colluvial soil. It was assumed that perivous material would provide rapid water movement and allow dangerous high pore pressures to quickly develop (38). Distinct continuous gravel beds were not discovered in the several hundred feet of drilling in these soils. In fact, until the drilling of the horizontal holes, there were no good clues to the cause of the rapid fluctuation of the water levels. The cobbles and boulders encountered were bound and not grouped into layers.

It now appears that at least six types of soil discontinuities or combination of types can supply the answer to the rapid water movement through the soil. The discontinuities include fissures, voids, joint systems, bedding planes, animal burrows, and root channels (Fig. 11).

Soil fissures exist due to the unstable nature of the soil. Evidence of soil creep and old small slumps are seen locally in the colluvial soil areas along the mountainside. If slumps have taken place and creep occurs, then it follows that old slippage planes and other planes of weakness are incorporated into the soil mass. Such areas carry water at much higher rates than intact massive clay soil (23).

Voids occur around the many large, five feet (1.5 m) diameter and medium two feet (0.6 m) diameter entrained boulders. Apparently, these voids rapidly fill with water soon after heavy rains and are rapidly depleted soon after rainfall ceases. Moist zones and occasionally free water was encountered adjacent to boulders when drilling the vertical as well as the horizontal holes. Horizontal drill holes encountering the greatest amount of boulders seem to drain the most water, and respond the quickest to changes in water table levels (41).

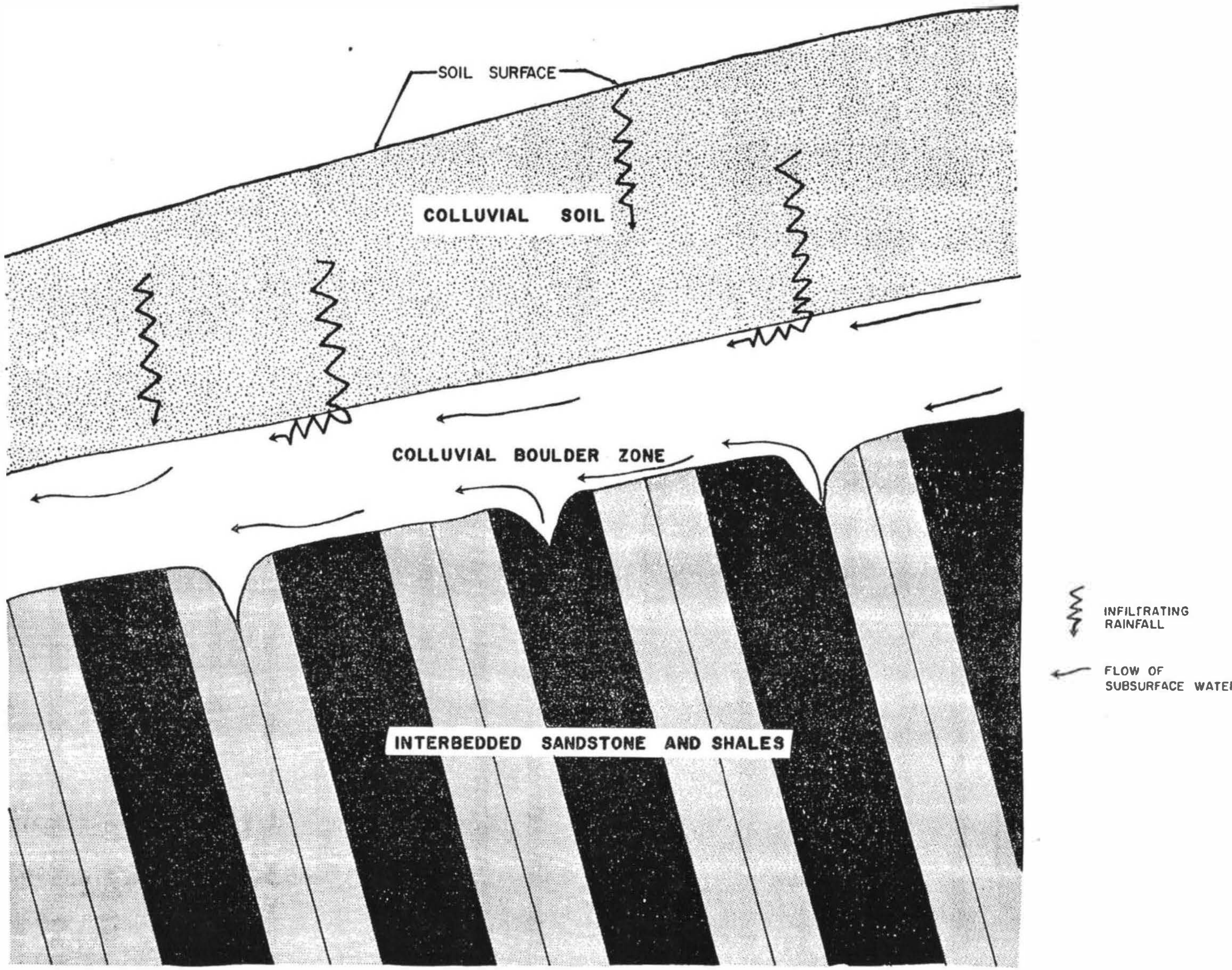

Figure 11. Subsurface Water Regime

Joint systems of the underlying rock may tend to produce pseudo joints or reflect planes of weakness in the soil masses that rest upon them. In this area where large earth movements have caused stress on the rock formations, many closely spaced joint systems are present. These may reflect upward into the soil mass and allow water movement along the joint surfaces (21).

Animal burrows and root channels are present but their effect is not known. Certainly they would contribute to water movement within the soil. Bedding planes as they are commonly known, were not recognized in this soil. Apparently the high degree of disturbance within this soil obliterates any evidence of bedding, if there ever was any. It may be possible that some reflection of the underlying rock formation's bedding planes may be present in the lower portion of the colluvial soil.

CLAY MINERAL ANALYSIS

In cohesive soils, such as those we are dealing with, the composition of the clay minerals can often be a significant factor contributing to stability. Knowledge of the clay mineral system allows a better understanding of soil strength.

It appears that the interaction of large amounts of water and the clay minerals in these colluvials soils can contribute to instability.

In natural soils systems, water is always present. Air drying soils can remove most of the free water, but can not remove the water closely adhering to the clay particle surface. This water is electrically attracted to the clay particle surface and is called adsorbed water. This kind of water has properties more like ice as opposed to free water. When clay particles are close together or touching, the adsorbed water lends some bonding strength to the system.

Rosenquist (33) says that the leaching of ions from soils can cause weaker bonding between clay particles. Ions can also cause pore water to be structured or become ice like. Ions are atoms which exhibit an electrical charge. A common soil ion is sodium which has a postive charge. The presence of certain ions can help strength and stability. Sodium ions can order a considerable amount of water. Layers of water molecules can be adsorbed or fixed around this ion for considerable distances. A change or reduction in the amount and type of ions can affect soil stability by changing the strength of the bonds. Leaching, due to weathering processes, removes adsorbed ions. Thus, the loss of the sodium ion can promote a condition whereby the clay particle bonds may more easily shear under high moisture conditions. The presence of ions in the adsorbed water layers alters the strength of the particle bonds. In these colluvials soils, the loss of the sodium ion through natural weathering processes may allow some water which was ordered to revert to pore water thus losing strength.

Dr. Lester W. Reed (30) has performed extensive tests on the soils from the study sites. Tables concerning particle size, clay distribution, acidity (ph), exchangeable cations, cation exchange capacity, base saturation, and X-ray diffraction (clay mineral analysis) are listed in the appendicies.

The tests indicate that the soils at Site Two and Three are highly weathered. The more soluble exchange cations such as sodium (Na) and potassium (K) are almost completely missing. Even the less soluble calcium (Ca) and magnesium (Mg) have been leached, but to a lesser extent. The soil at Site One is somewhat less weathered as indicated by the presence of more calcium and exchangeable cations throughout the soil profile.

The soils from all the sites exhibit strong (S) or very strong (VS) X-ray peaks at $14A^{o}$ (Tables 5 through 10). This indicates the presence of hydrous mica clay minerals. These clay minerals are generally "clean" due to the presence of aluminous interlayers. It may be possible that these clay minerals under conditions of rapid wetting could assist in producing conditions of low or zero cohesion and low internal friction angles. The rapid wetting takes place as the water tables rise quickly after heavy rains. Thus, colluvial soils containing hydrous mica clay minerals and low sodium ion contents may help indicate potential landslide soils.

TABLE 5. X-RAY DIFFRACTION OF COARSE CLAYS (2-.2μm) FROM SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #1.

Horizon	14A	10A	7A
A_1	M[1]	VW	W
A_2	VS	W	M
B_{21t}	W	W	W
B_{22t}	VS	M	S
B_{23t}	S	S	S
B_{24t}	S	S	S
B_3	S	W	S
R	W	W	W
Johns Valley Shale	W	W	W

[1]VS-very strong, S-strong, M-medium W-weak, VW-very weak

TABLE 6. X-RAY DIFFRACTION OF FINE CLAYS (<.2μm) FROM SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #1.

Horizon	14A	10A	7A
A_1	VW[1]	VW	VW
A_2	VS	VW	W
B_{21t}	VS	VW	VW
B_{22t}	W	VW	VW
B_{23t}	-	-	-
B_{24t}	VS	VW	S
B_3	VS	VW	VS
R	VS	S	VS
Johns Valley Shale	S	VW	W

[1]VS-very strong, S-strong, M-medium, W-weak, VW-very weak

TABLE 7. X-RAY DIFFRACTION OF COARSE CLAYS (2-.2um) FROM SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #2.

Depth cm	Horizon	14A	10A	7A
0-10	A_1	VW[1]	VW	W
10-20	A_2	S	W	S
20-81	$B_{21}t$	S	W	S
81-117	$B_{22}t$	VS	W	VS
117-175	$B_{23}t$	S	VS	VS
175-203	$B_{24}t$	W	VW	W
203-257	B_{31}	VS	VS	VS
257-305	B_{32}	S	S	S

[1]VS-very strong, S-strong, M-medium, W-weak, VW-very weak

TABLE 8. X-RAY DIFFRACTION OF FINE CLAYS (< 2um) FROM SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1 TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE # 2.

Depth cm	Horizon	14A	10A	7A
0-10	A_1	S	W	W
10-20	A_2	W	VW	VW
20-81	B_{21t}	S	VW	W
81-117	B_{22t}	S	VW	W
117-175	B_{23t}	VS	VW	S
175-203	B_{24t}	S	VW	W
203-251	B_{31}	VS	W	W
251-305	B_{32}	VS	S	S

[1]VS-very strong, S-strong, M-medium, W-weak, VW-very weak

TABLE 9. X-RAY DIFFRACTION OF COARSE CLAY (2-0.2 um) FROM SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #3.

Depth cm	Horizon	14A	10A	7A
0-10	A_1			
10-20	A_2	S	VW	W
20-30	B_1	VS	VW	S
30-56	B_{21t}	S	W	W
56-107	B_{22t}	VS	VW	S
107-152	B_{23t}	S	W	VS
152-196	B_3	S	VW	S
196-213	B_{311}	VS	W	S
Johns Valley		VS	S	S

[1]VS-very strong, S-strong, M-medium, W-weak, VW-very weak

TABLE 10. X-RAY DIFFRACTION OF FINE CLAY ($\leq .02$ um) FROM SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #3.

Depth cm	Horizon	14A	10A	7A
0-10	A_1			
10-20	A_2	VS	VW	S
20-30	B_1	VS	VW	VS
30-56	B_{21t}	S	VW	W
56-107	B_{22t}	S	VW	W
107-152	B_{23t}	VS	W	VS
152-196	B_3	VS	W	VS
196-213	B_{3II}	VS	W	VS
John Valley		VS	W	W

[1]VS-very strong, S-strong, M-medium, W-weak, VW-very weak

SLOPE STABILITY

Both ground water and discontinuities within the soil mass seem to play a major role in the stability of these soft clayey soils. Several kinds of discontinuities can be present in the soils. Skempton (38) classes them into bedding planes, joints sheeting, fissures, and faults. Voids around entrained boulders and voids from rotted roots and animal burrows may be other discontinuities contributing to instability. Old and active slip planes are also present in these soils.

Clay soils containing discontinuities often exhibit a marked reduction in strength. Cuts made in such material allow fissures to open due to lateral expansion of the soils. This allows ground water to travel through at considerably higher velocities. The phenomenon increases the effects of pore pressure on slope stability, particularly as time passes. (6, 45).

Skempton (36), as well as Carson (11), relate that little is known concerning the geotechnical properties of shallow weathered soils. Usually, long deep pits are required for adequate observation and sampling. Considerable expertise and diligence is necessary in order to observe and classify discontinuities. Only the most notorious soils, e.g. the London clay, have been properly investigated in terms of soil discontinuities. Skempton and Hutchinson (37) noted that fissures in London clay reduced strengths of soils by a considerable measure. They noted in their study that the strength of the clay mass was 65% of the conventional intact strength and 35% of the true intact strength. Thus, discontinuities reduce soil strength considerably.

In our case, it appears that fluctuating ground water levels and discontinuities in the soil mass are the main contributors to the soil's lack of adequate stability. While the moisture regimes in thses soils have been fairly well defined, there is a distinct lack of information regarding the types and amounts of discontinuities in these soils. The soil descriptions were taken from roadside cuts and landslides scarps. Many of the discontinuities were disturbed and obliterated. Further study concerning the discontinuities in colluvial soils is warranted.

There are several good methods available for determining soil stability (6, 9, 12, 14, 19, 36, 42). Many papers have been written concerning stability investigations on many different types of soils. Several textbooks are also available which relate to methods of determining soil slope stability. (43, and 47)

Calculations by the method related by Wu (47), based on direct shear tests, render factors of safety considerably above 1.0 in these colluvial soils. Only if parameters are introduced dealing with very high water tables and discontinuities, can the factors of safety approach lower and more realistic values.

Cohesion (c) and internal friction (ϕ) angles from direct shear tests indicated fairly high strengths for the colluvial soil. Compared to other reported cases, these values seem to be somewhat high (8). The direct shear test utilized here was the U.S. Corps Engineer EM 1110-2-1906. This is a quick (Q) test, which tends to give high values. A slow test may have given strength values more suitable to the actual conditions known to exist at the landslide site. (Table 11).

This brings us to another problem often encountered by soils engineers. The discontinuities present in a soil mass tend to cause poor sample retrieval when sampling with thin wall tubes. The sample simply pulls apart where the tube passed through a fissure or void. The same thing could happen in the laboratory as the sample is being prepared for testing. Often the "good" intact samples are the ones tested. These test conditions might then render safety factors of 1.0 or more. Since it is very difficult to test samples that are falling apart, some knowledge of the type and amount of discontinuities would be very helpful. Such knowledge might then allow some type of index numbers to be used in determining true slope stability from an adjustment in soil strength parameters.

TABLE 11 COHESION AND ANGLE OF INTERNAL FRICTION[1] FOR TWO SOILS ON LANDSLIDE AREAS ALONG TALIMENA DRIVE, STATE HIGHWAY #1, OUACHITA MOUNTAINS.

SITE #1			SITE #3		
Depth cm	c lbs/ft^2	Ø	Depth cm	c lbs/ft^2	Ø
76-112	1205 ($5882\ Kg/m^2$)	23°	168-206	1775 ($8666\ Kg/m^2$)	17°
112-142	705 ($3442\ Kg/m^2$)	10°	206-224	1105 ($5395\ Kg/m^2$)	24°
142-173			224-259	1730 ($8446\ Kg/m^2$)	19°
173-193	1280 ($6249\ Kg/m^2$)	28°	259-282	1900 ($9276\ Kg/m^2$)	12°
193-216	730 ($3564\ Kg/m^2$)	5°			
216-292	1470 ($7177\ Kg/m^2$)	20°			

1. U.S. Corps of Engineers EM 1110-2-1906; from T.W. Lambe, 1951, "Soil Testing for Engineers."

Perhaps in-situe test utilizing the penetration vane shear or dutch cone apparatus would render more accurate strength values. More research information is required in order to more adequately relate laboratory and field tests when dealing with long term strength in stiff fissured clays.

Appendix B contains a slope stability problem based on actual conditions present at Site Two. It is felt that almost any type of analysis would demonstrate the effect of high water tables on soil stability. The arc-plane-arc solution used herein seems to be a realistic approach to the stability problem in the local area since most of the failures occur in this configuration. This method will be proposed to the Oklahoma Department of Transportation Design Division for use in cut and embankment slope design.

CONCLUSION

The water regime is a strong factor in the degree of stability that these clayey colluvial soils posses. Fluctuation in water table levels are very rapid. It is possible that soils considered to be "wet" and unstable on one day would be "dry" and stable the next. The hydrous mica clay minerals present in the soils may also contribute to instability as they loose strength on rapid wetting.

Water movement in these soils takes place primarily in soil discontinuities. Soil discontinuities in colluvial soils include: fissures, cracks, joints, bedding planes, voids adjacent to boulders, animals burrows, and root channels. These discontinuities allow rapid build-ups of water zones and subsequent rapid drainage. Calculated safety factors may be exceeded about 48 hours or so after heavy rains when water tables are their highest. Rapid build ups of water tables in these soils cause a weakening of the soil and can cause landslides to occur. Slope stability calculations should take into account the effect of discontinuities and high water tables.

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APPENDIX A

Soil Properties

Dr. Lester Reed, professor of Agronomy at Oklahoma State University performed an extensive chemical and mineralogical analysis of soils from each of the three study sites. The tests performed included those tests required to characterize the soil as to its age and degree of weathering.

Generally speaking, the particle size test results indicate a high percent of clay and stones. Stones are described as those soil particles greater than 6mm in size. The distribution of stones is somewhat erratic, but stones tend to occur mostly in the upper portion of the soil profiles. Note that horizon B21t of the Site One soil contain 41% stones (Table A1).

The clay distribution shows a greater distinct clay accumulation zone. All three soils show a higher clay percentage in the upper and middle B horizons (Tables A1 through A3).

The mobility of the fine clay (0.2 mu) as opposed to coarse clay (2.0 to 0.2 mu) indicates some ability of the soil to drain internally (Tables A4 through A6). There is a slight tendency for the fine clay to accumulate in the upper B horizons.

The low pH (acidity-alkalinity of the soils also supports the concept of considerable weathering. Most of the soluble metallic cations that would cause high pH's have been leached away. It is also possible that the parent rocks may have been acidic as can be seen in tables A7 through A8.

The contents of exchangeable calcium, magnesium, potassium, and sodium are low. This condition substantiates the rigorous weathering regimes present in this area (Tables A9 through A12).

Intensive weathering leaches away soluble soil consituents. Table A13 shows the low contents of exchangeable bases. Soils of the less weathered prairie areas usually contains more exchangeable bases, about 20 to 40 meq./100gms. The cation exchange capacity (Table A14) is also fairly low for all the soils in the study area.

The percent base saturation (Table A15) indicates once again the high degree of weathering taking place here. The percent of exchange sites taken by bases is generally low except for the uppermost soil horizon which is influenced by the metallic (base) cations present in decaying forest floor litter.

Tables concerning free iron oxide content, total potassium oxide, and organic matter content are presented for further soil characterization information (Table A16 through A18).

Table A1 PARTICLE SIZE OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #1.

Depth cm	Horizon	%[1] Stones	% Separates[2] Sand	Silt	Clay
0-13	A_1	32	48	38	14
13-26	A_2	16	47	42	11
26-49	B_{21t}	41	43	38	19
49-64	B_{22t}	3	40	32	28
64-87	B_{23t}	-	30	34	36
87-148	B_{24t}	2	11	40	49
148-181	B_3	-	4	60	36
181-204	R	1	10	60	30

[1]+6mm Stones
[2]Non-stone%

TABLE A2 PARTICLE SIZE OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #2.

Depth cm	Horizon	%[1] Stones	% Separates[2]		
			Sand	Silt	Clay
0-10	A_1	33	37	40	23
10-20	A_2	17	46	46	8
20-81	B_{21t}	5	20	24	56
81-117	B_{22t}	17	14	34	52
117-175	B_{23t}	-	18	36	46
175-203	B_{24t}	30	34	26	40
203-251	B_{31}	5	14	36	50
251-305	B_{32}	6	20	39	41

[1] +6mm
[2] non-stone%

TABLE A3 PARTICLE SIZE OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #3.

Depth cm	Horizon	%[1] Stones	% Separates[2] Sand	Silt	Clay
0-10	A_1	40	38	58	4
10-20	A_2	18	40	44	16
20-30	B_1	17	34	40	26
30-56	B_{21t}	11	26	26	48
56-107	B_{22t}	18	20	17	63
107-152	B_{23t}	6	20	19	61
152-196	B_3	3	26	17	57
196-213	B_{3II}	3	28	20	52
Johns Valley Shale		0	2	26	72

[1]+6mm Stones
[2]non-stone%

TABLE A4 CLAY DISTRIBUTION OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA TRAIL OUACHITA MOUNTAINS, SITE #1.

Depth cm	Horizon	% Clay coarse 2-.2μm	Fine <.2μm
0-13	A_1	-	-
13-26	A_2	-	-
26-49	B_{21t}	10	90
49-64	B_{22t}	15	85
64-87	B_{23t}	29	71
87-148	B_{24t}	67	33
148-181	B_3	46	54
181-204	R	44	56

TABLE A5 CLAY DISTRIBUTION OF SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #2.

Depth cm	Horizon	% Clay coarse 2-.2μm	Fine <.2μm
0-10	A_1	75	25
10-20	A_2	11	89
20-81	B_{21t}	24	76
81-117	B_{22t}	37	63
117-175	B_{23t}	-	-
175-203	B_{24t}	28	72
203-251	B_{31}	-	-
251-305	B_{32}	-	-

TABLE A6 CLAY DISTRIBUTION OF SOILS ON LANDSIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA TRAIL, QUACHITA MOUNTAINS, SITE #3.

Depth cms	Horizon	% Clay Coarse 2-.2μm	% Clay Fine <.2μm
0-10	A_1	48	52
10-20	A_2	--	
20-30	B_1	--	
30-56	B_{21t}	--	
56-107	B_{22t}	31	69
107-152	B_{23t}	--	
152-196	B_3	31	69
196-213	B_{3II}	41	59
Johns Valley Shale		46	54

TABLE A-7 WATER (1:1) pH OF SOILS FROM LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY #1, TALIMENA QUACHITA MOUNTAINS.

Horizon	pH H_2O (1:1) Site 1	Site 2	Site 3
1	5.4	4.7	5.0
2	5.5	4.8	5.0
3	5.1	4.8	5.0
4	4.9	4.7	5.1
5	4.9	4.7	5.0
6	4.8	4.8	5.0
7	4.4	4.6	5.0
8	4.4	4.7	5.0
Johns Valley Shale			6.1

TABLE A-8 ONE NORMAL KCl (1:1) pH OF SOILS FROM LANDSLIDE AREA ON OKLAHOMA STATE HIGHWAY #1, TALIMENA TRAIL, QUACHITA MOUNTAINS.

Horizon	pH in KCl (1:1)		
	Site 1	Site 2	Site 3
1	4.9	3.8	3.8
2	4.4	4.1	4.1
3	4.0	3.7	3.8
4	3.8	3.7	3.5
5	3.7	3.4	3.8
6	4.8	3.3	3.4
7	3.6	2.9	2.8
8	3.7	3.2	3.4
Johns Valley Shale			5.1

TABLE A-9 EXCHANGE CALCIUM OF SOME SOILS ON LANDSLIDE AREAS ON OKLAHOMA STATE HIGHWAY 1, TALIMENA TRAIL, OUACHITA MOUNTAINS

Horizon	Ca m.eq./100gms		
	Site 1	Site 2	Site 3
1	2.50	3.00	—
2	1.10	0.25	0.30
3	0.80	0.10	0.22
4	0.60	0.02	0.17
5	0.30	0.02	0.12
6	0.15	0.05	0.02
7	0.55	0.02	0.02
8	1.65	0.07	0.10
Johns Valley Shale			8.80

TABLE A-10 EXCHANGE MAGNESIUM OF SOME SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY 1, TALIMENA TRAIL, OUACHITA MOUNTAINS.

Horizon	Mg. m.eq./100gms		
	Site 1	Site2	Site 3
1	1.12	1.00	0.83
2	0.87	0.33	0.29
3	1.25	2.17	0.92
4	2.46	1.33	1.58
5	3.54	0.79	1.25
6	7.58	0.54	0.46
7	11.33	0.67	0.33
8	12.83	0.67	0.37
Johns Valley Shale			12.00

TABLE A-11 EXCHANGE POTASSIUM OF SOME SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY 1, TALIMENA TRAIL, OUACHITA MOUNTAINS

Horizon	K m.eq./100gms		
	Site 1	Site 2	Site 3
1	0.13	0.21	0.14
2	0.12	0.10	0.12
3	0.17	0.38	0.18
4	0.18	0.31	0.28
5	0.23	0.26	0.21
6	0.40	0.15	0.15
7	0.36	0.29	0.15
8	0.31	0.21	0.14
Johns Valley Shale	—	—	0.38

TABLE A-12 EXCHANGE SODIUM OF SOME SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY 1, TALIMENA TRAILS, OUACHITA MOUNTAINS

Horizon	Na m.eq./100gms		
	Site 1	Site 2	Site 3
1	0.043	0.043	0.043
2	0.043	0.043	0.043
3	0.043	0.043	0.043
4	0.064	0.064	0.064
5	0.064	0.087	0.064
6	0.087	0.043	0.064
7	0.109	0.064	0.064
8	0.087	0.064	0.064
Johns Valley Shale			0.087

TABLE A-13 TOTAL EXCHANGEABLE BASES OF SOME SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY 1, TALIMENA TRAIL, OUACHITA MOUNTAINS

Horizon	Bases m.eq./100gms		
	Site 1	Site 2	Site 3
1	3.79	4.25	—
2	2.13	0.72	0.79
3	2.26	3.08	1.36
4	3.30	2.30	2.09
5	4.13	1.16	1.64
6	8.22	0.78	0.69
7	12.35	0.96	0.56
8	14.88	1.01	0.67
Johns Valley Shale			21.27

TABLE A-14 CATION EXCHANGE CAPACITY (CEC) OF SOME SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY 1, TALIMENA TRAIL, OUACHITA MOUNTAINS

Horizon	C.E.C. m.eq./100 gms.		
	Site 1	Site 2	Site 3
1	3.45	5.55	4.22
2	2.25	2.21	1.94
3	4.13	9.60	4.19
4	7.15	14.55	8.64
5	11.40	11.80	11.25
6	19.50	10.65	16.50
7	18.18	12.80	16.05
8	20.46	9.30	——
Johns Valley Shale			26.14

TABLE A-15 % BASE SATURATION OF SOME SOILS ON LANDSLIDE AREAS ON OKLAHOMA HIGHWAY 1, TALIMENA TRAIL, OUACHITA MOUNTAINS

Horizon	% Base Saturation		
	Site 1	Site 2	Site 3
1	100	77	—
2	95	33	39
3	55	32	32
4	46	16	24
5	36	10	15
6	42	7	4
7	68	7	3
8	73	11	—
Johns Valley Shale			81

TABLE A-17 TOTAL K_2O OF CLAYS EXTRACTED FROM SOME SOILS FROM LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS.

SITE #1

Depth cm	Horizon	$\%K_2O$ Coarse	Fine
0-13	A_1	2.16	1.35
13-26	A_2	2176	2.38
26-49	B_{21t}	1.70	2.78
49-64	B_{22t}	2.04	1.69
64-87	B_{23t}	1.47	1.47
87-148	B_{24t}	2.59	2.44
148-181	B_3		2.79
181-204	R	2.68	

SITE #2

Depth cm	Horizon	$\%K_2O$ Coarse	Fine
0-10	A1		
10-20	A_2	1.57	0.88
20-81	B_{21t}	0.58	1.39
81-117	B_{22t}	1.68	1.47
117-175	B_{23t}	3.19	2.82
175-203	B_{24t}	2.06	4.93
203-257	B_{31t}		3.36
257-305	B_{32}	2.61	4.59

SITE #3

Depth cm	Horizon	$\%K_2O$ Coarse	Fine
0-10	A_1		
10-20	A_2	1.71	1.32
20-30	B_1	1.39	1.17
30-56	B_{21t}		0.69
56-107	B_{22t}	1.78	0.97
107-152	B_{23t}		1.60
152-196	B_3	5.73	0.88
196-213	B_{3II}	4.24	1.09
Johns Valley Shale		3.38	3.14

$\%K_2O \times 10 = \%$ Mica Clays

TABLE A-16 FREE IRON OXIDE OF SOME SOILS FROM LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1 TALIMENA TRAIL, OUACHITA MOUNTAINS, SITE #1.

SITE #1			SITE #2			SITE #3		
Soil Depth cm	Horizon	% F_2O_3	Soil Depth cm	Horizon	% Fe_2O_3	Soil Depth cm	Horizon	% Fe_2O_3
0-13	A_1	0.30	0-10	A_1	0.43	0-10	A1	0.33
13-26	A_2	0.30	10-20	A_2	0.36	10-20	A_2	0.45
26-49	B_{21t}	0.41	20-81	B_{21t}	1.31	20-30	B_1	0.72
49-64	B_{22t}	0.77	81-117	B_{22t}	1.66	30-56	B_{21t}	0.94
64-87	B_{23t}	1.04	117-175	B_{23t}	1.18	56-107	B_{22t}	1.09
87-148	B_{24t}	2.22	175-203	B_{24t}	1.23	107-152	B_{23t}	1.33
148-181	B_3	1.02	203-251	B31	0.62	152-196	B_3	1.39
181-204	R	1.34	251-305	B32	1.49	196-213	B_{3II}	1.22

TABLE A-18 PERCENT ORGANIC MATTER OF SOME SOILS FROM LANDSLIDE AREAS ON OKLAHOMA HIGHWAY #1, TALIMENA TRAIL, OUACHITA MOUNTAINS.

SITE #1			SITE #2		
Depth cm	Horizon	%OM	Depth cm	Horizon	%OM
0-13	A_1	2.84	0-10	A_1	4.97
13-26	A_2	0.90	10-20	A_2	1.70
26-49	B_{21t}	0.60	20-81	B_{21t}	0.58
49-64	B_{22t}	0.40	81-117	B_{22t}	1.51
64-87	B_{23t}	0.43	117-175	B_{23t}	1.85
87-148	B_{24t}	0.33	175-203	B_{24t}	0.40
148-181	B_3	0.67	203-251	B_{31}	0.35
181-204	R	0.52	251-305	B_{32}	0.45

SITE #3

Depth cm	Horizon	%OM
0-10	A_1	4.35
10-20	A_2	1.47
20-30	B_1	1.02
30-56	B_{21t}	0.77
56-107	B_{22t}	0.38
107-152	B_{23t}	0.11
152-196	B_3	0.33
196-213	B_{31}	0.35
Johns Valley Shale		2.06

APPENDIX B

Stability Analysis

STABILITY ANALYSIS

Many types of stability analysis could be used to show the difference in safety factors caused by differences in water table levels. The arc-plane-arc or partial rotation solutions as described in Taylor's text[1] seems to best fit the conditions present along SH 1 in southeastern Oklahoma.

At Site Two, which is located at station 1190+50 or about 1/2 mile (0.8km) west of the U.S. 259 intersection, conditions typical of the local area occur. Actual data derived from on-site and laboratory tests were used in the analysis. The difference between the calculated safety factors (FS) is due to the maximum recorded change in water table conditions. The higher FS assumes a normal or usual condition throughout while the lower figures assumes saturated conditions.

It should be remembered that soil discontinuities could cause large changes in cohesion (c) values. A sharp drop in c or assuming c=o will produce safety factors less than 1.0. A detailed observation of soil discontinuities would probably shed more light on the stability properties of these soils, but they were not within the scope of this study.

A partial rotation and planer surface type analysis was used.[1] Angle of internal friction ϕ=8^{o} unit cohesion, c=620 lbs./ft. unit weight of soil, = 140.0 lbs./ft.^{3}

Angle between failure plane and major principal plane =25^{o}42' Concentrated load, Q=40 lbs./ft.^{2} on the surface. This is an assumed load for the rocks, and trees on the surface.

[1]The analysis was taken from Taylor, D. W., "Foundamental of Soil Mechanics", John Wiley, New York, 1948, pg. 418.

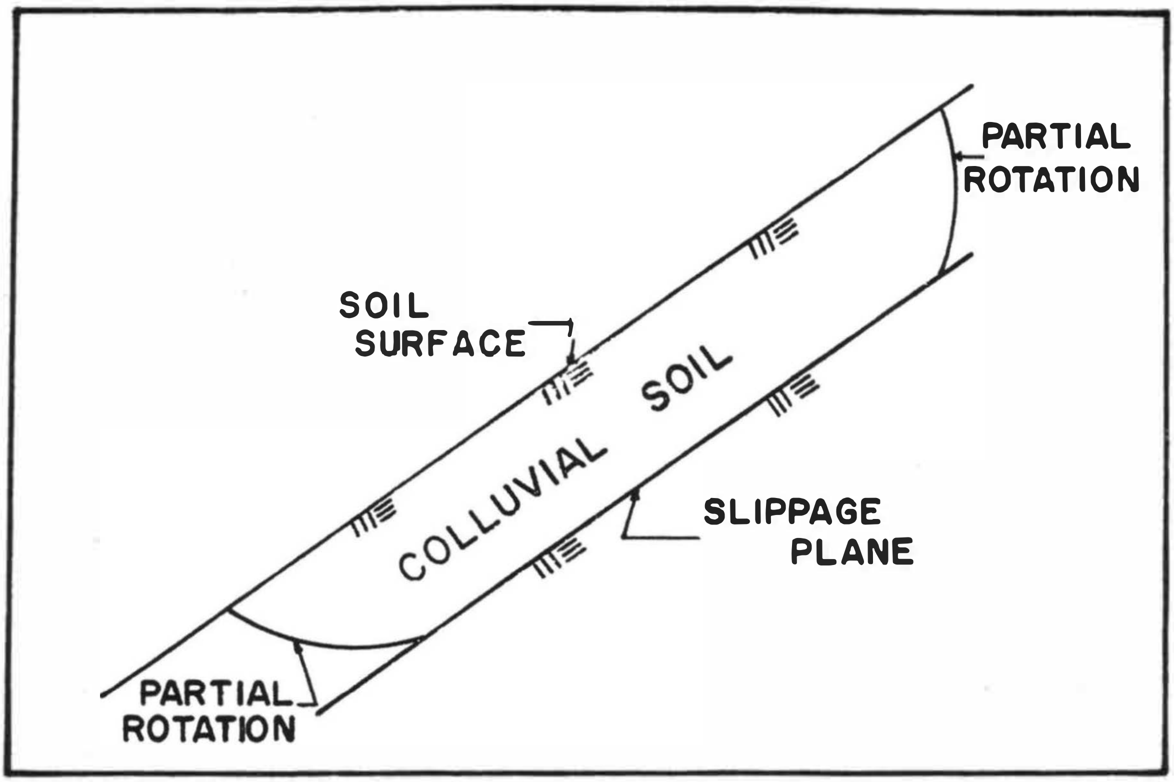

Fig. Bl. Illustration of analysis used.

Partial rotation on the right

Angle of parttial rotation arc, $\theta = 38.5^{\circ}$ θ in radians = 0.6715

Sin θ = 0.62251

Radius of the partial circle R = 39.56'

Area of rotational portion, A = $\frac{1}{2}(20(17) + \frac{1}{2} R^2(\theta - \text{Sin } \theta)$
= 170 + 782.5 (0.04944)
=208.69 ft.^{2}

Arc length, = Rθ = 26.58 ft.

Partial rotation on the left

$\theta = 36.5^{\circ}$ e in radians = 0.63704 Sin θ = 0.59482
R = 39.63
A= $\frac{1}{2}(25)(16) + \frac{1}{2} R^2(\theta - \text{Sin } \theta)$
= 200.0 + 785 (0.04222)
= 233.14 ft.^{2}
= Rθ 25.25 ft.

The factor of safety is given by the ratio of the shearing resistence to the shear force in which,

$$^{2}F.S. = \frac{\sum s\Delta l}{\sum t\Delta l} = \frac{\sum (c\Delta l\cos\alpha + \left[(\Delta W+Q-u\Delta l\cos\alpha) + (Tn-Tn+1)\right]\tan\phi) \frac{1}{\cos\alpha+(\tan\phi\sin\alpha/F.S.}}{\sum(\Delta W + Q)\sin\alpha}$$

Assume $\sum(Tn-Tn+1)\to 0$

ΔW - Weight of each slice
ΔU - pore water pressure of effective stress
ΔX - width of slice
Δf - $(\Delta W+Q) \sin\alpha$
Δfn- $(\Delta W+Q) \cos\alpha$

Δx	α	ΔW	Δl	$c\Delta l\cos\alpha$	Δf	$\frac{1}{\cos\alpha+(\tan\phi\sin\alpha/FS)}$ *	$s\Delta l$
20	39.5°	29,216.0	26.58'	12,716.0	19,092.9	1.18604	18,942.4
20	27.5°	46,200.0	22.20'	12,400.0	20,099.3	1.05282	19,321.4
20	27.5°	47,600.0	22.20'	12,400.0	20,989.1	1.05282	19,507.9
15	27.5°	35,280.0	16.65'	9,299.9	15,559.7	1.05282	14,574.8
25	8.0°	32,639.6	25.25'	15,473.8		1.00592	20,274.8
					$\sum$75,741.0		$\sum$97,303.0

*Assuming F.S. = 1.25

Therefore the factor of safety for conditions given is:

$$F.S. = \frac{97,303.0}{75,7411.0} = 1.29$$

For saturated conditions:

$\mu\Delta l\cos\alpha$	$\Delta Fn\tan\phi + c\Delta l\cos\alpha$	$\frac{1}{\cos\alpha + (\tan\phi\sin\alpha/F.S.^{*})}$	$s\Delta l$-
13,354.2	15,057.8	1.17736	17,728.5
20,596.0	17,262.7	1.04814	18,093.7
21,220.1	17,495.5	1.04814	18,300.0
15,727.9	12,132.1	1.04814	12,716.1
14,550.4	18,156.6	0.99278	18,025.4
			4,681.7
			$\sum$89,681.7

*Assuming F.S. = 1.15

Therefore at saturation conditions and all other parameters being the same:

$$F.S. = \frac{89,545.4}{75,741.0} = 1.18$$

[2]This equation was taken from WU, T.N. "Soil Mechanics"; Allyn and Bacon Boston, pp.248-250. Soil values are for undrained conditions.