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GEOLOGIC ASPECTS OF A RECENT LANDSLIDE IN VINTON COUNTY, OHIO¹

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ABSTRACT

A study was made of a recent landslide along a newly opened, relocated section of U. S. Route 50 in Vinton County, Ohio. This segment of highway is located in the abandoned valley of a minor tributary of the Teays River system. The investigation revealed that a highly laminated lake deposit was the major component of the slide. Mineralogical and particle-size determinations show that this material is an extremely fine-grained, illitic clay having characteristics similar to those of the Minford Silt. Several of the physical properties determined in this study suggest that this type of deposit is likely to become unstable wherever disturbed by heavy construction and, since material of this type appears to be widespread in the valleys of the Teays drainage system, such deposits should be given special attention by design engineers.

INTRODUCTION

Shortly before 9:30 am on January 7, 1966, a landslide occurred along a newly opened section of relocated U. S. Route 50 in Vinton County, Ohio. This segment of the highway is located in the abandoned valley of a minor tributary of the ancient preglacial river called the Teays (fig. 1). The slide site is approximately $3\frac{1}{2}$ miles east of the village of Londonderry, in the NW $\frac{1}{4}$ of the SW $\frac{1}{4}$ section 20, Harrison Township (Byer 7 $\frac{1}{2}$ ' quadrangle), Vinton County, Ohio. The slide apparently took place within 30 minutes or less, since residents of the area report that it had not taken place at 9:00 am. A "crack" at the top, however, was observed by local residents as early as the preceding September.

Both lanes of the highway were closed by large blocks of clay, 30-40 tons in weight, which had been pushed down onto the pavement. It is estimated that a minimum of 33,000 tons of material was involved in the slide. The slide area extended approximately 350 feet along and 150 feet back from the edge of the pavement. The elevations of the toe and crown were 683 and 725 feet respectively.

Figure 2 illustrates the situations at highway station 71+00 before and after the failure. As indicated in figure 2A, a cut averaging 30 feet in depth was made to accommodate the new road and a 2:1 grade was placed on the cut slopes. The natural slope in this vicinity is about 10:1.

The situation after the slide had taken place is shown by figure 2B. The landslide appears to have resulted from a combination of "slump" and "earthflow," as classified by Sharpe (1938). There is slumping at the top and the formation of a bulging, highly crevassed dome at the toe. The three main divisions of Rogers (1929) are also in evidence: "(1) at the head, a down-slipped block or series of blocks, with surface tilted into the slope; (2) in the central part, a buckled and

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disrupted area, with wide fissures transverse to the direction of movement; (3) in the lower part of the slide, an anticlinal ridge or series of ridges, the foremost of which may be overthrust." Although it is not evident in the figure, there is a steep inward-facing scarp at the lateral margin.

Some mud flowage accompanied the failure, but the volume of material involved was insignificant compared to that moved by slumping and earthflow. It has been suggested that this liquid mud came from a zone in the area of the shear plane where it provided lubrication for the movement of the solid material. The mud probably did come from the shear zone, but the authors believe that, in the initial stages of the slide, it may well have been a result of the slippage rather than a cause of it.

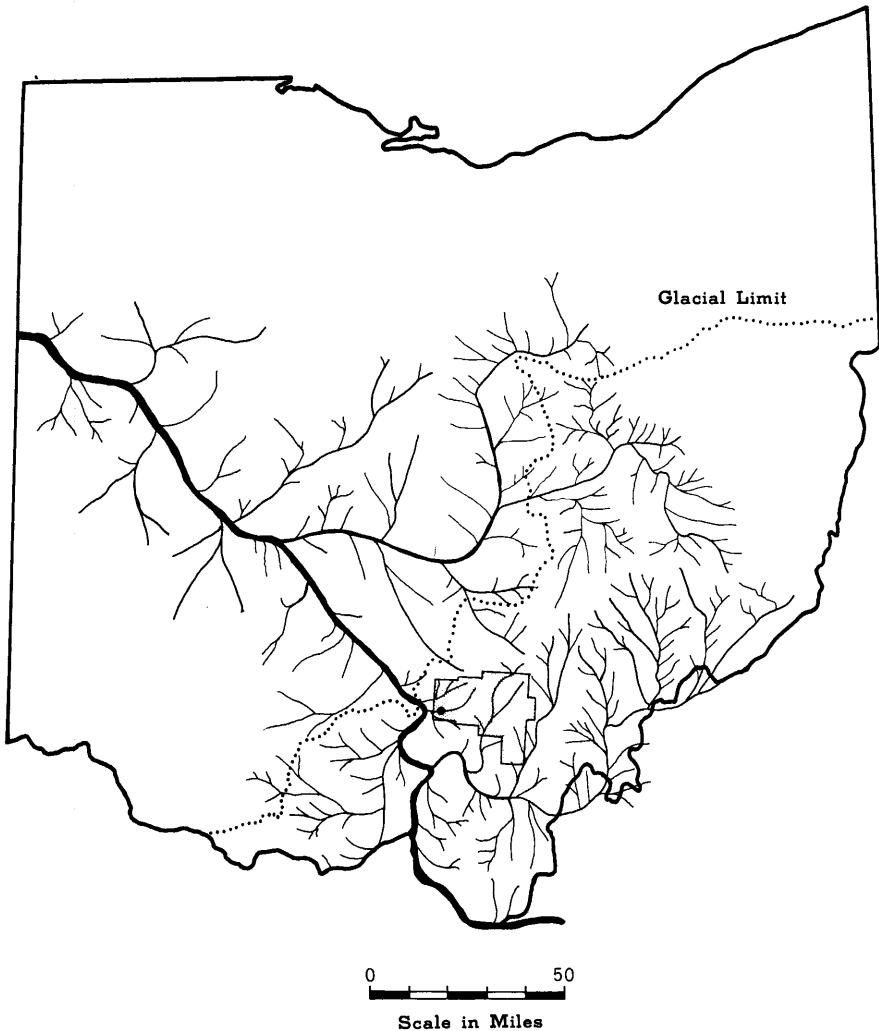


FIGURE 1. Teays drainage system in Ohio (modified from Stout, et al., 1943); Vinton County is shown by small box in south-central part of map; slide location is indicated by large dot.

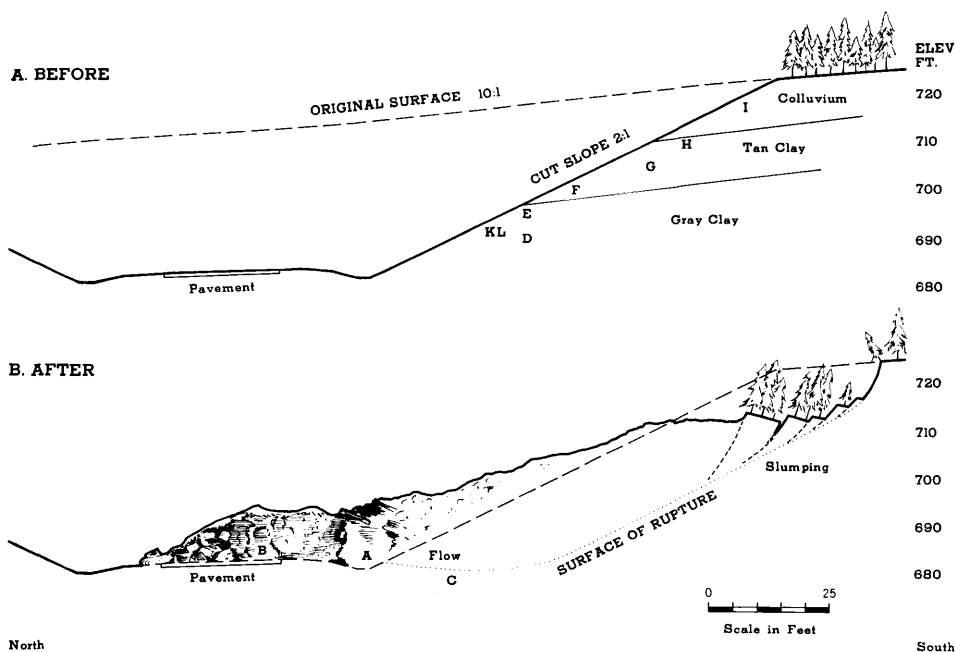


FIGURE 2. Cross-section of slide area before (2A) and after (2B) failure.

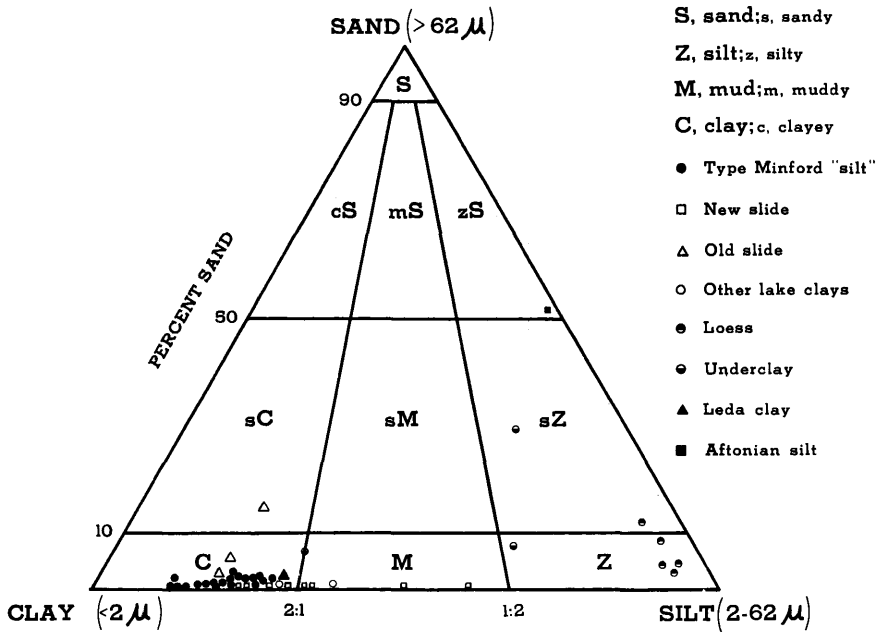
SAMPLE DESCRIPTIONS AND SIZE ANALYSIS COMPARISONS

The material involved in this slide is a highly laminated tan-and-gray clay capped by a colluvial-like material of variable thickness. Thirteen feet of light-gray (Munsell 10YR 6/2 to 10YR 7/2) calcareous clay overlain by thirteen feet of tan (Munsell 10YR 7/3 to 10YR 7/5) noncalcareous clay is exposed. The overlying colluvium (Munsell 10YR 8/4) exhibits a prismatic soil structure and contains abundant fragments of sandstone and siltstone from the local Logan and Cuyahoga Formations (Mississippian). Within 24 hours after the slide, moisture samples 82-0643 A and B were obtained by trenching and immediately sealed in air-tight containers. Moisture sample 82-0643C and all outcrop samples (82-0643 D-K) were collected 11 days later when the shear zone and west lateral scarp were exposed by bulldozers cleaning up the debris.

Particle-size analyses were made of all but two of the slide samples. For purposes of comparison, analyses were also made of loess, silt, underclay, lake clay, "Leda Clay," Minford Silt from the type area, and material from another landslide in the vicinity. Wet sieve and hydrometer techniques were employed in making these analyses. For comparison, three samples were also analyzed by the pipette method. The size data are summarized in figure 3; this triangular diagram and the ten textural groups are those proposed by Folk (1964). The comparison samples have been included to emphasize the fine-grained texture of the slide material and to clarify the character of the Minford Silt.

The Minford Silt analyses represent a set of channel samples taken at two-foot intervals in sequence down through the section designated by Stout and Schaaf (1931). Most of these samples would have to be classified as clays. One sample each of loess from along the Illinois and Missouri Rivers and three samples of Vicksburg loess were also analyzed. The particle-size distributions of all the loesses are very similar; only the Illinois loess falls outside the silt classification.

The Aftonian silt is actually a silty sand, although it falls near the sand-silt line. Three samples of underclay are plotted, showing a wide range of textures. The Carmichaels and Fargo clays are lake-clay samples. The Carmichaels clay represents terrace deposits in West Virginia thought to have formed when the northward-flowing Monongahela River was blocked during Kansan glaciation. The Fargo clay is a gray plastic varved clay deposited in Lake Agassiz in North Dakota. The "Leda Clay," generally considered to be a marine sediment deposited in the Pleistocene Champlain Sea in Ottawa, Canada, is extremely sensitive (Eden and Crawford, 1957) and has been responsible for many landslides along the St. Lawrence River and its tributaries. Data indicated as "old slide" refer to a 1965 landslide which occurred in material similar to that of the present slide at a site about one and a quarter miles to the east along relocated U. S. Route 50.



Modified from Folk, 1964

FIGURE 3. Particle-size distribution of slide material and samples selected for comparison. Triangular diagram and textural groups are taken from Folk, 1964.

The clay from the recent slide is characterized by less than one per cent sand and a somewhat variable clay-silt ratio. The authors feel that the most outstanding feature of this clay is its extremely fine-grained texture. It is composed primarily of particles with diameters of one micron or less (fig. 4). The slide samples are comparable in grain size to samples of the Minford Silt and the other lake clays. The average median grain size is slightly less than one micron for the Minford, about one micron for the "Leda" and lake clays, 15 microns for the underclays, 22 microns for the loess, and 63 microns for the Aftonian silt.

Size-distribution curves determined by the pipette method were very similar to those obtained by hydrometer, although the percentage of less-than-two-micron particles obtained by the pipette method was consistently two or three

per cent lower than the corresponding hydrometer value. Because the percentage of silt was determined by the difference between the sand and clay values, it also varied by two or three per cent.

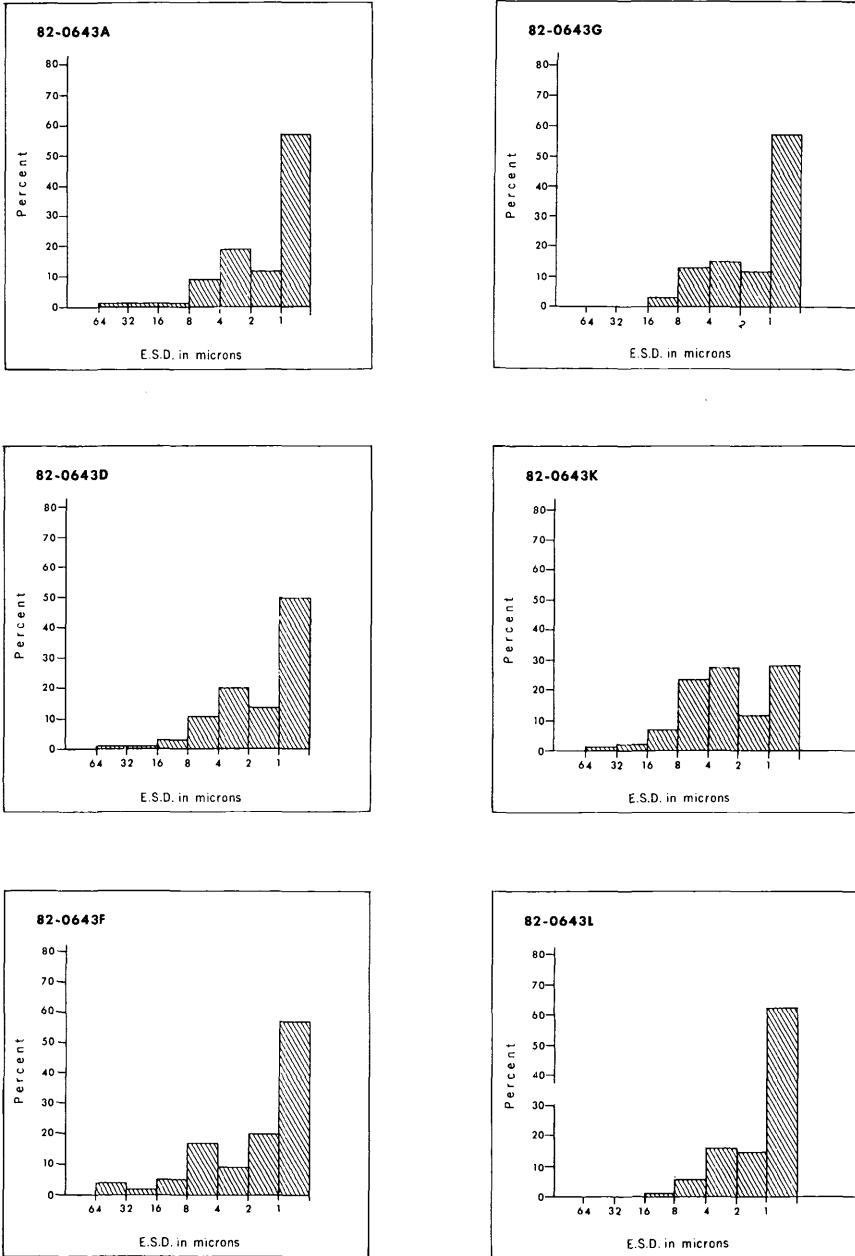


FIGURE 4. Particle-size histograms of slide material.

VARVES

In order to study the bedding features, thin sections perpendicular to the laminations were attempted. The resulting sections leave much to be desired, though they do provide some useful information. The material comprising the light-colored layers includes relatively coarse-grained (silt size) quartz particles. Fine-grained clay constitutes the matrix in the light layers and is present in amounts approximately equal to that of quartz. The dark-colored layers are composed essentially of clay. The particle-size distribution of a light layer is shown in fig. 4K and that of a dark layer in fig. 4L. It is noteworthy that the dark layers contain the highest percentage of clay-size particles and the light the highest percentage of silt. The contact between a light layer and the dark layer immediately above is gradational. The contact between a dark layer and the next higher light layer is moderately sharp. In these several respects, the laminae have definite varve-like characteristics. The light-colored material is thought to represent summer deposits, and the darker material winter deposits. The varves average two millimeters in thickness. The light laminae are generally slightly thicker than the corresponding dark laminae. Root (1958, p. 141) suggests that summer laminae, being rich in silt, provide much water for absorption by the winter layers. However, this would not appear to be a valid assumption with respect to the varves in question. These summer laminae contain adequate clay material to fill the silt interstices; consequently, their permeability appears to be very low. Upon drying, however, there is a tendency for the material to crack parallel to the lamination, thus providing innumerable avenues for the entrance of water.

CLAY MINERALOGY

Slides for X-ray diffraction were prepared from the hydrometer sample after the size analysis was completed. A portion of the less-than-two-micron fraction was obtained by settling and used to make oriented slides in a manner similar to that described by Grim (1934). The material for unoriented clay slides was prepared by grinding it in a porcelain mortar until it passed a 230-mesh screen. The clay mineral composition of the less-than-two-micron fraction was determined by X-ray diffraction, using a Norelco unit with Cu K α radiation at a scanning speed of one degree per minute. The oriented aggregates were run untreated at room temperature, after ethylene glycol treatment and after heating for one hour at 500°C.

Diffraction patterns of samples D, L, and K from the slide are reproduced in figure 5. Diffraction patterns of Minford Silt from the type area are also presented for comparison. In order of decreasing abundance, the clay minerals present in the slide material are illite, chlorite, kaolinite, mixed-layer, and montmorillonite, of which the latter two are present only in trace amounts.

The asymmetry of the (001) illite peak indicates that some of the illite is degraded. The strong (001) and (003) reflections of the chlorite suggest that it is magnesian. The mixed-layer material appears to be a regularly interstratified mineral with some expansion capabilities. Upon glycolation, the "peak" moves from $4.5^\circ 2\theta$ to $4.15^\circ 2\theta$ indicating expansion of 1.65 Å in the "c" direction. Heating changes the spacing of the reflection to $4.7^\circ 2\theta$.

The appearance of a reflection at $4.85^\circ 2\theta$ upon glycolation is interpreted as indicating the presence of a small quantity of montmorillonite. When immersed in water, the clay swells sufficiently for the increase in size to be readily discernible with the naked eye.

In general, the diffraction patterns of the Minford Silt are similar to those of the slide material. Illite is the dominant clay mineral and a portion of it is degraded. Magnesian chlorite is the next most abundant. Kaolinite is present, but is relatively less abundant than in the slide sample. There is again evidence

for a trace of montmorillonite and mixed-layer material, but in the type Minford Silt the interstratification appears to be random.

The clay mineralogy of the less-than-two-micron fractions of the varves is very similar. Illite is the dominant mineral in both, but there is relatively more chlorite than kaolinite in the dark varve and relatively more kaolinite than chlorite in the light lamina. Mixed-layer material in the dark layer is similar to that in sample D, but in the light lamina this material appears to be of a more random nature.

X-ray diffraction patterns of samples A and E were almost identical to those of D, indicating that there is very little vertical variation in the clay mineralogy

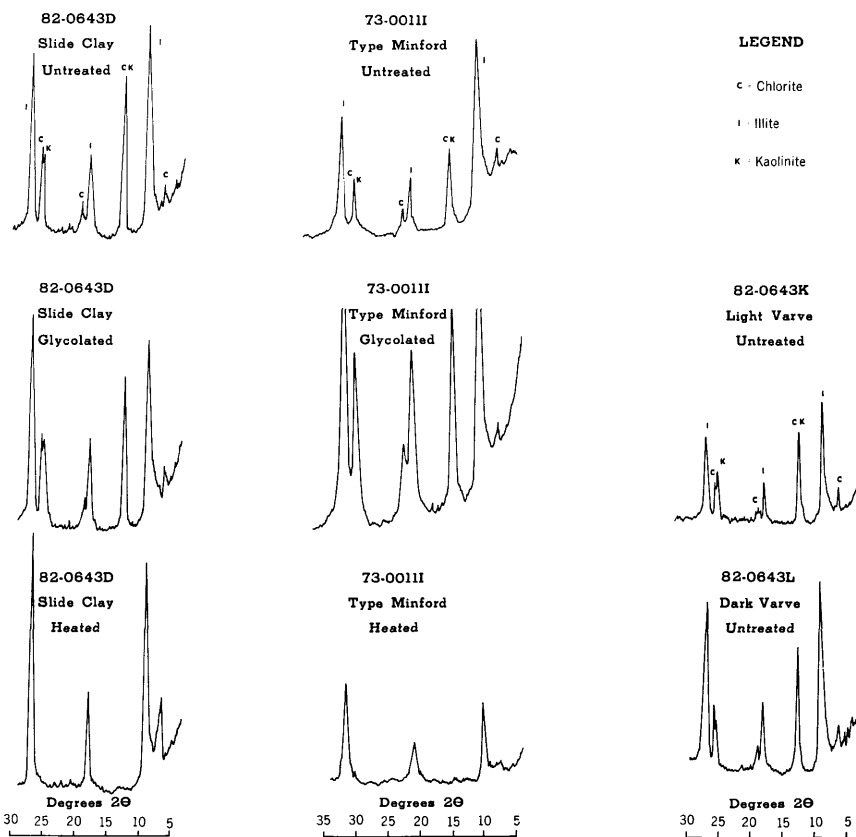


FIGURE 5. X-ray diffraction patterns of oriented less-than-two-micron fraction material.

of the gray laminated clay. Analysis of sample F indicates that the tan clay is slightly richer in kaolinite and poorer in chlorite than the gray. The tan clay also contains a higher percent of degraded illite. The colluvium-tan-clay transitional zone (sample H) contains relatively more illite than any other sample and kaolinite exceeds chlorite, but neither kaolinite nor chlorite is present in more than minor quantities.

Illite is the principle component of the less-than-two-micron fraction of the colluvium. Kaolinite is more abundant than chlorite, and mixed-layer material composes a significant part of the assemblage.

SIGNIFICANCE OF THE CLAY MINERALOGY

The clay mineralogy of the slide material is very similar to that of the type Minford Silt. There is expandable material present and, although montmorillonite and mixed-layer material both exist as minor components, they may exert more influence upon the plastic limit, liquid limit, plasticity index, swelling, water adsorption, and shrinkage than some of the more abundant clay minerals. In general, the Atterberg limits of montmorillonite are greater than those of illite which in turn are greater than those of kaolinite. The plastic properties of chlorite are not known, but they are thought to be similar to those of illite.

ATTERBERG LIMITS AND RELATED DATA

The Atterberg limits of a soil include the liquid limit and plastic limit. In conjunction with the plasticity index, they are widely used by members of the engineering profession as the basis for predicting the load-bearing and stability characteristics of materials used for foundation footings, highway subgrades, and earth-filled embankments.

The liquid limit is the moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil will just begin to flow when lightly jarred. It refers to the moisture content at which a soil changes from the plastic to the liquid state. The plastic limit is the lowest moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil can be rolled into threads $\frac{1}{8}$ inch in diameter without breaking, but when rolled to a diameter smaller than $\frac{1}{8}$ inch breaks into pieces. It is the moisture content at which a soil changes from a semisolid to a plastic state. The plasticity index is the difference between the liquid limit and the plastic limit. It is the range of moisture content through which a soil is plastic. The greater the difference between the liquid limit and the plastic limit, the more likely the soil is to become unstable and plastic under field conditions. A high liquid limit usually indicates that the soil will absorb a large percentage of moisture by capillary action.

The liquid limit was determined in accordance with the Standard Method of Determining the Liquid Limit of Soils (AASHTO Designation: T89-60), and the plastic limit in accordance with the Standard Method of Determining the Plastic Limit of Soils (AASHTO Designation: T90-56). The plasticity index was calculated according to the Standard Method of Calculating the Plasticity Index of Soils (AASHTO Designation: T91-54). The Atterberg limits for the several samples of slide material and for type Minford Silt are presented in table 1.

Field moisture content is here defined as the moisture content, expressed as a

TABLE 1
Atterberg limits and related data

| Sample no. | Liquid limit | Plastic limit | Plasticity Index | Field moisture content | Remarks |
|------------|--------------|---------------|------------------|------------------------|---------------------|
| 82-0643 A | | | | 35 | Recent Slide (1966) |
| 82-0643 B | 51 | 28 | 23 | 32 | " " " |
| 82-0643 C | 47 | 23 | 24 | 38 | " " " |
| 82-0643 D | 49 | 27 | 22 | | " " " |
| 82-0643 E | 53 | 30 | 23 | | " " " |
| 82-0643 F | 62 | 33 | 29 | | " " " |
| 82-0643 H | 51 | 24 | 27 | | " " " |
| 82-0573 A | 49 | 27 | 22 | 39 | Old Slide (1965) |
| 82-0573 B | 59 | 30 | 29 | 39 | " " " |
| 82-0573 C | | | | 40 | " " " |
| 73-0011 I | 52 | 27 | 25 | | Type Minford Silt |
| 46729 | 56 | 27 | 29 | | " " " |
| 46730 | 62 | 31 | 31 | | " " " |

percentage by weight of the oven-dry soil, of a soil in the field at any given time. The field moisture content of material at a given locality varies with such factors as relative humidity, temperature, wind conditions, and rainfall, and is valid for only a given instant in time.

The liquid limit of the slide material averages 52 per cent; for the Minford Silt, it averages 57 per cent. The plastic limit of both is 28 per cent. The resulting average plasticity indices are 24 and 29 respectively. White (1949, p. 510) and Woods, Johnstone, and Yoder (1953, p. 35-53) report comparable values for similar material from Jackson County, Ohio.

Field moisture values of samples of slide material obtained on different visits to the area all exceeded 32 per cent and suggest that the material is theoretically in a plastic state much of the time.

MAJOR FACTORS CONTRIBUTING TO THE FAILURE

Ladd (1935, p. 1104-1108) and Sharpe (1938, p. 84-87) list a large number of possible contributing factors for slope failure and, as with most landslides, several of them appear to have been operative here. The authors are of the opinion, however, that the causative factors can be grouped into three broad categories: (1) materials, (2) water, and (3) engineering design.

The material involved is a clay, from the standpoint of both size and mineralogy, and as such was in itself a contributing factor to the failure. The fine-grained nature of clay permits the material to become wet by capillarity. X-ray diffraction indicates that minor amounts of expandable clay minerals are present. These minerals have the ability to exert expansive pressures. Small percentages of swelling clays can cause a relatively great increase in the plastic properties of the material. The structure of montmorillonite is such that, when it is interlayered with other clay minerals, it forms planes of weakness that permit a breakdown of the clay particles with an attendant great increase in plasticity. Montmorillonites absorb water between the individual silicate layers with resulting high swelling.

Illite and chlorite compose the bulk of the clay minerals present. Moisture heave apparently can take place in such material even in the absence of expandable clay minerals (Grim, 1962, p. 251). Such materials apparently have a texture which does not come to equilibrium under consolidation pressure so that the material swells when pressure is removed and additional water becomes available. Although moisture does not expand the lattice of these clay minerals, it does serve as a lubricant between the particles so that strains may be relieved.

The material, upon drying, displays a tendency to part along its laminae. The fact that it is highly laminated suggests that an essentially unlimited number of horizontal planes are available as avenues for the entrance of water.

Climatological data of the slide area indicate that there was an abundance of water available just prior to the failure. The rainfall during the first three days of January totaled about three inches. The increased water content would provide weight and reduce the shear strength. The recent seeding of the cut slopes may have contributed indirectly to the failure by retarding runoff and evaporation.

The design feature of importance as a possible causative factor is the oversteepening of the material by excavation. The clay was essentially at equilibrium with a natural slope of 10:1. The 2:1 slopes resulting from the excavation reduced the stability. The authors believe that, once the cut was made, the stage was set for eventual failure. Material had been slowly sliding into the drainage ditch prior to the main failure and, although the removal of this toe material probably triggered the slide, the removal was not in itself a basic cause.

CONCLUSIONS

The material involved in this slide was a highly laminated, extremely fine-grained, varved, illitic clay very similar to the Minford Silt of Stout and Schaaf

(1931). Montmorillonite and mixed-layer material were both present only as minor components, but, even in these small percentages, they are believed to have exerted great influence on the plasticity of the slide material. The clay mineralogy, size data, and Atterberg limits all indicate that caution should be used wherever this type of material is encountered during heavy construction.

The ancient Teays River system drained a substantial portion of the state and, because the distribution of this type of material is apparently related to this system, it would seem prudent to be on the lookout for it wherever highways in valleys are relocated. Wherever possible, deep cuts into material of this type should be avoided. Where excavation is necessary, more gentle cut slopes will greatly reduce the risk of a slide.

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