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MAP SHOWING LANDSLIDE SUSCEPTIBILITY IN MARYLAND

By

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INTRODUCTION

This is the first example of a map of an eastern state that shows landslide susceptibility based on a numerical system indicating relative degree of slide proneness; a map of California that shows areas ranked according to their estimated relative number of landslides (Radbruch and Crowther, 1973) is also essentially a landslide susceptibility map. The prime purpose of this map is to serve as a forerunner for landslide susceptibility maps of other states at a scale of 1:500,000, a project supported by the Landslide Hazards Program of the U.S. Geological Survey (USGS). The map not only indicates areas where slope stability problems are serious, but also areas where the risk of instability is small. Such a map enables the user to make a rapid evaluation of the potential for mass movement. Planners, engineers, soil scientists, geologists, university faculty, and elected officials should find the map useful in the assessment of slope hazards for regional syntheses.

For the purposes of this map, all gravitational movements of earth material downslope are considered as landslides, with the exception of slow, ubiquitous creep. The term "landslide" as used here is synonomous with "mass movement" and "slope movement"; it is widely used as an all-inclusive term for almost all types of slope movements, including some that involve little or no true sliding (Varnes, 1978, p. 11). The term includes falls, topples, slides (rotational and translational), flows (fig. 1*A*), and complex forms (fig. 1*B*; Varnes, 1978, fig. 2.1). "Susceptibility" to landsliding is defined as the probable degree of response of the stratigraphic units and their derivative soils to natural events or to artificial slope modifications.

The map is highly generalized because of the small scale. Variations in slope sensitivity may occur at any specific point within a unit. Therefore, the map is unsuitable for local (county) planning or actual site selection where detailed geological or soil engineering investigations would be appropriate.

METHOD OF COMPILATION

The map uses a ranking system of 1 (very low to low susceptibility), 2 (low to moderate susceptibility), 3 (moderate to high susceptibility, and 4 (high to severe susceptibility). The susceptibility categories are largely subjective based on my field observations and use of pertinent published and unpublished data. Field investigations, which were conducted mainly during the spring months in 1985 and 1986, involved about 85 days of traverses and locality observations.

In order to gain a better understanding of the relationship of geology to slope failure processes, most attention was directed to areas in the Coastal Plain west of Chesapeake Bay, where the largest number of slide-prone units occur. This area includes the eastern and southwestern parts of suburban Prince Georges County, southwestern Baltimore County, Calvert Cliffs in Calvert County, and the Elk Neck peninsula at the head of Chesapeake Bay in Cecil County. A separate report dealing with Coastal Plain susceptibility and processes is in preparation.

Supplementing the field investigations were conferences with the U.S. Soil Conservation Service, selected County Planning and Licenses and Permits Departments, the Maryland Geological Survey, the Maryland State Highway Administration, and Woodward-Clyde Consultants, Rockville, Md. Ronald E. Smith (Woodward-Clyde Consultants) and A.D. Martin (State Highway Administration) were especially helpful.

Aerial photographs were examined at most Soil Conservation Service offices, selected county planning departments, and the Maryland Geological Survey. The availability of these photographs eliminated the potentially high cost of purchasing this information for the project. Nevertheless, it was still necessary to obtain high-altitude aerial photography for much of the state. Aerial photography that included several flight missions at different times was acquired for various slide-prone areas in the Coastal Plain.

Information related to landslide problems along highways was given by the State Highway Administration. Data from Soil Conservation Service county soil surveys were consulted. An engineering geologic report on correlative stratigraphic units in Pennsylvania proved helpful (Geyer and Wilshusen, 1982).

The three most significant (and interrelated) natural-cause factors that contribute to landsliding potential are precipitation, slope, and the nature of each geologic unit (mainly lithology but also structural features such as jointing). Of these factors, lithology is the most useful factor in the compilation of a map at this scale.

Annual precipitation in Maryland varies between 36 and 48 in. (91 and 122 cm)(fig. 2*A*). However, annual variation, seasonal distribution, storm intensities, and long-term trends (fig. 2*B*) are commonly more significant to the triggering of landslides than annual precipitation.

The interrelationship between slope gradient and stability is not simple. Personal observation has shown that landslides can occur along a wide range of slopes, ranging from 5° (9 percent) to 35° (70 percent) for earthflows, to as much as 45° (100 percent) for debris avalanches (fig. 3*A*). Furthermore, the steepest slopes may not always be the most likely to show failure. In fact, many steep slopes of competent rock are more stable than comparatively gentle slopes of incompetent or weak material (Varnes, 1984). Only in the Coastal Plain east of Chesapeake Bay, where the ground surface is essentially a low, flat plain, are slopes negligible. Mass movement can be found there only along shoreline bluffs or incised drainages.

To aid in the compilation of this map, the 1:250,000-scale geologic map of Maryland (Cleaves and others, 1968) was photographically reduced to 1:500,000. Several geologic units were combined based on lithologic similarities when plotted onto the smaller-scale base. A few modifications to the map were made in the Coastal Plain province either based on geologic mapping completed since the state geologic map was compiled or where I thought that it was more important to emphasize the outcropping Tertiary unit rather than the overlying Quaternary deposits.

DISCUSSION OF SUSCEPTIBILITY BY PHYSIOGRAPHIC PROVINCE

Each physiographic province in Maryland is distinctive not only in its geomorphic grain but in its underlying lithology and structure. As indicated on the map, Maryland is made up of five physiographic provinces which include, from west to east, the Appalachian Plateau, the Valley and Ridge, the Blue Ridge, the Piedmont, and the Coastal Plain. The Coastal Plain and the Piedmont provinces together make up more than 75 percent of the state; the Blue Ridge is the smallest province. Landslide susceptibility by physiographic province from highest to lowest is as follows: Coastal Plain, Appalachian Plateau, Valley and Ridge, Blue Ridge, and Piedmont.

Coastal Plain Province

About half of the state lies in the Coastal Plain, where the terrain ranges from flat to hilly with gentle to steep slopes. Maximum relief of 80 m occurs in the Elk Neck peninsula at the head of Chesapeake Bay.

Slope failures take place in virtually all of the exposed Cretaceous, Tertiary, and Quaternary units (table 1). Clay layers within the stratigraphic units have caused stability problems. The Potomac Group clays (fig. 4*A* and 4*B*) and the Marlboro Clay (rank 3 or 4) are the stratigraphic units most susceptible to slope movement (tables 2 and 3). Slumps, earthflows, or a combination of the two forms are characteristic of the mass movement in these two units. Because the Potomac Group is a non-marine complex, lithologies vary both horizontally and vertically within short distances. This variability precludes the designation of most areas underlain by the Potomac Group with a single ranking at this scale. A nearly 5-kilometer-long strip of shoreline at Indian Head shows continuous landsliding in the Potomac Group and younger units and is therefore assigned a rank of 4. Potomac Group clays are kaolinites and (or) illites with negligible to minor amounts of expandable clay minerals, except for the Fort Washington-Indian Head peninsula area (table 3). The less widespread and considerably thinner Marlboro Clay is of marginal marine origin and is more lithologically uniform. This unit lends itself to a less variable numerical designation. Landslides involving the Marlboro Clay are particularly numerous in southwestern and east-central Prince Georges County. The Marlboro Clay shows consistently more kaolinite than illite or illite-smectite (table 3).

The Upper Cretaceous post-Potomac Group units and the lowermost Tertiary units (Brightseat and Aquia Formations) are sandy with scant clayey interbeds (rank 1g). The sparse occurrence of slope movements within these units dictates the lowest ranking. Nevertheless, a low-ranked unit such as the Aquia Formation occasionally may become involved in a slope movement because of failure either below or above that unit.

Clay beds occur within the predominantly sandy Nanjemoy Formation and Chesapeake Group. The occurrence of slides (slumps, earthflows) within some Prince Georges County subdivisions in the Calvert Formation (Chesapeake Group) and the diverse slope-movement forms displayed along the Calvert Cliffs (Chesapeake Group; table 3) necessitate a variably low to high ranking. That part of the Calvert Cliffs south of Long Beach is commonly prone to extensive landsliding because of plastic clays in the St. Marys Formation (Chesapeake Group).

Inland, the Pliocene(?) to Holocene units comprising Upland and Lowland Deposits and Undifferentiated Deposits show few landslides and, therefore, have a low ranking. Along shoreline bluffs, however, the susceptibility can be very high because of a lack of lateral restraining force as demonstrated along the Calvert Cliffs (fig. 4*C*; Leatherman, 1986). Low-lying land along the eastern shore of Chesapeake Bay shows few slope failures, except in areas where bluffs are at least 3 m high. Small-scale slope movements involving spalling and slumping can be triggered by ground water, as demonstrated by Palmer (1973) in an erosion study of the lower Chester River east of Chesapeake Bay.

In the Coastal Plain the landsliding process takes place in the zone of weathering. All units susceptible to sliding have high-angle joints (Obermeier and others, 1984). Depending upon moisture conditions and the relative position of horizons in the section, perched water tables commonly lie above impermeable clay layers. This clay may serve as a slide surface if frictional resistance is lowered when water percolates through the overlying more permeable sand or silt and moves laterally to the slope face, where seeps are widespread. Not all failures, however, begin at this position. Fractures in the clay may allow downward migration of water. Thin horizontal and vertical silt zones within a clay unit (Woodward-Clyde Consultants, 1976) such as the Marlboro Clay become conduits for water and may also serve as loci for landsliding.

Nowhere is the slope movement process more clearly seen than in excavations and pits, especially in early spring. Shallow surface excavations made with a trenching tool along minor drainages at this time of year reveal the development of "minislides" where the contact of a permeable cover and underlying clay horizon is exposed. The Calvert Cliffs furnish a dynamic environment for observing various forms of slope failure, especially in the St. Marys Formation (rank 4s). Ground-water seepage is ubiquitous along the Calvert Cliffs, and this process induces sapping of loose noncoherent sand and silt lying above the line of seepage. The removal of support of the overlying sediments results in a collapse failure (fig. 4C). Translational (planar) movements at shallow depths controlled by subvertical stress-release joints may result from the failure of the overlying, mainly sandy material. Spalling takes place both above and below the seepage line along subvertical joints dipping steeply toward Chesapeake Bay. This process is continuous throughout the year but accelerates during the cooler months when freezing and thawing occur along the joints.

Wave action can induce slope failure by a removal of material from the toe of the slope. Observations along the Calvert Cliffs at various intervals from 1985 to 1987 have led to the conclusion that a series of closely spaced spalls at and slightly above beach level can lead to massive failure of the overlying slope material.

Construction-related problems in the Potomac Group take place periodically. Because of its widespread occurrence in the Washington-Baltimore-Philadelphia corridor and the inherent instability of several of its constituent lithologies, studies of individual problem localities revealed the Potomac Group at almost every site. Twenty of 21 cut slope and embankment problems in the Coastal Plain along state and federal highways involve the Potomac Group (Maryland Department of Transportation, unpub. data). Furthermore, a summary listing of projects in the Coastal Plain, for which flatter than 2:1 cut slopes were recommended because of soil-moisture conditions, reveals that the Potomac Group is involved in 13 of 19 sites (Maryland Department of Transportation, unpub. data). Toppling and other slope failures in steep-walled excavations commonly occur where the surface is underlain by massive clay or by interlayered sand and clay. A toppling failure in massive Potomac Group red clay at a Greenbelt excavation killed 5 men and injured 11 (Withington, 1964). Joints are normally tight or closed in undisturbed and unweathered clay, but cracks in the clay will open upon release of overburden pressure as in an excavation. Meltwater within joints in frozen clay caused a toppling of a 12-meter-long, 4.5-meter-high, and 0.3-meter-thick unsupported clay slab at this location. Sand horizons in the Potomac Group were the least stable wall material in the trench for the Susquehanna Aqueduct (Cleaves, 1968). Most bank failures in the trench took place in sand because of ground water or vibration.

Climatic records for the Maryland Coastal Plain (fig. 2*B*; National Oceanic and Atmospheric Administration, 1961-1986) indicate that the 1960's generally were drier than normal, whereas the period beginning with 1971 and extending to the end of that decade was wetter than normal. High summer rainfall in 1972, 1975, and 1979 was a result of a combination of drenching rains from tropical storms together with abnormally high rainfall at other times during the same season. As a result, several residential subdivisions that were started during the 1960's in southwestern Prince Georges County initially were free of landsliding, but later developed problems in the 1970's. Significant landsliding took place at one subdivision during and after a tropical storm in September 1975. Major landslide activity has not taken place there since that time despite a record maximum discharge at a nearby creek in September 1979 following a tropical storm (U.S. Geological Survey, 1980) and an unusually wet spring in 1983. A possible explanation for the cessation of major landslide activity might be that the slopes have adjusted to the surface modification resulting from construction in the 1960's and, therefore, have reached a state of equilibrium. Precipitation during the 1980-1986 period has been below normal, except for 1983.

Appalachian Plateau Province

Landslides are found in soils and weathered material overlying most of the bedrock units in this province (table 4). Five major gentle fold axes (two anticlinal and three synclinal) trending northeast-southwest make up the Appalachian Plateau in Maryland. The highest susceptibility for landslides (rank 2-3) is within much of the easternmost synclinal belt consisting of the Conemaugh Formation and younger rocks and a smaller area of Conemaugh Formation in the extreme northwestern part of the state. Landslide susceptibility is slightly diminished within the anticlinal belts, where Devonian rocks form the core.

Strip mine spoil bank slides are common throughout the region. Movement of most rock-waste slides is believed to take place within the waste-bank material itself or at the contact between the spoil and the colluvial surface of the slope (Kimball, 1974; Pomeroy, 1982). About 2 km north of Frostburg, a regraded strip mine surface above the Monongahela Formation has failed. An earthflow, roughly 200 m long by 30 m wide, has offset an abandoned railroad bench (fig. 6*A*). This earthflow is at least 30 years old, and its headward margin occurs along a 20° (37 percent) slope. The 2-meter-high toe below the railroad bench lies along a less steep 16° (28 percent) slope.

A large number of recent landslides are attributable to tropical storm Juan. Juan dumped 4 to 6 in. (10 to 15 cm) of rain during November 2-4, 1985 in most areas of the Appalachian Plateau in Maryland, but unconfirmed reports of up to 8 inches (20 cm) were reported in the Nov. 7th Oakland *Republican* for the Kitzmiller-Shallmar area. A 20-meter-wide planar earthflow northeast of Swanton along the steep slope between Crabtree Creek and the Conrail tracks (fig. 5) on the evening of the 4th caused a four-diesel unit with 135 coal cars to derail. One unit was carried downslope in the movement and was deposited in the floodwaters, killing the engineer. Colluvial cover downslope from the tracks is very thin to thin (<1 m). The Pocono Group crops out above the tracks along a 100 percent or greater slope, which furnishes abundant runoff from two narrow channels above the failure. However, slope undermining by flood waters is believed to have triggered the movement. Scouring of the slope by flood waters caused other shallow slides as wide as 30 m along both sides of the drainage.

Southwest of Bloomington, above the North Branch of the Potomac River, debris torrents from tropical storm Juan have rendered concrete sluiceways built to handle heavy storm runoff virtually useless by overfilling both below and above the railroad tracks.

Cut slopes above the tracks show recent slides whose planes of separation commonly lie at the contact of colluvium and bedrock.

Recent and former slide activity is evident along both sides of the North Branch of the Potomac River at Kitzmiller. One 12 m by 12 m earthflow west of the town, generated by tropical storm Juan, showed slippage at the contact of colluvium and bedrock. A debris torrent 1 km northwest of Kitzmiller emanated from several channels along a large laterally concave slope. Aerial photographs indicate that a 6-meter-deep gully that cuts through a coal spoil bank formed during a previous storm and not the November 1985 storm.

A nearly 1-kilometer-wide prehistoric landslide along the southeast-facing dip slope has been identified along Crabtree Creek upstream of the confluence of Spring Lick Run (fig. 5). Outcrops of Pocono Group red sandstone and shale under thin colluvium are widespread along the opposing northwest-facing slope. Thick colluvial deposits with a minimum thickness of 7 m lie in the toe area of the landslide. Both the cliff-forming lateral boundary on the southwest side and the head scarp can be sharply delineated based on topographic expression and are easily confirmed by field inspection. The toe area is a rolling hummocky surface. Floodwaters reactivated small slump-earthflow movements in a few places in the toe area. The ancient head scarp is nearly 0.8 km from the toe and about 180 m above the toe.

Rockfall hazards are serious, especially above the Westernport-Bloomington and the Bloomington-Savage Dam roads (fig. 6*B*) where thick beds of sandstone, overlying less resistant (and more highly weathered) shale of the Pottsville and Allegheny Formations, create overhangs. Other slope movements have taken place during and after reconstruction and relocation of Md. Route 36 between Westernport and Lonaconing. The new highway traverses the slope east of Georges Creek, which lies along the axis of a major syncline. Consequently, abundant surface and subsurface water from largely abandoned strip-mine operations in the Conemaugh and Monongahela Formations has affected movements of colluvium, especially above highway cuts.

In the Friendsville area, US Route 48 construction in 1973 was hampered by failure of an embankment overlying the Conemaugh Formation. The slope was rebuilt, but failed again in 1975 (Maryland Department of Transportation, unpub. data). The instability was caused by the failure of horizontal drains to dewater the embankment sufficiently in 1976, as revealed by subsurface investigation. About 5 km west of Friendsville a slope failed during construction in 1973 and again in 1974. The cause was attributed to a wet clay seam from the Allegheny Formation. A correction to flatten slopes to 3:1 and a wider bench alleviated the problem. A recent 15- to 18-meter-wide planar debris slide along a 100 percent slope 1.5 km southeast of Friendsville along the Bear Creek Road involves coarse fragmental colluvium underlain by a dominantly shale section containing blue-gray clay interbeds in the upper Pottsville or lower Allegheny Formation (table 3). A seep occurs at the contact of permeable colluvium and the clay bedrock; the clay serves as the slide surface. Because the exposure faces the south and the dip is to the northwest, bedding structure can be discounted as a factor in the slide. An older and wider slide area to the east was probably caused by the same lithologic relationships.

Several other examples illustrate the instability problem along roads.

(1) Red and green weathered shale from the Mauch Chunk Formation, which upon exposure forms clay, serves as a slippage plane for a 12 m by 12 m slide along a 28° (55 percent) slope above a secondary road 1 km west of Sang Run (table 3).

(2) A 70-meter-wide planar colluvial slope movement took place in red, silty, clayey soil above the Meadow Mountain Road 12 km south of Grantsville (table 3). The upper part of the Greenbrier Formation and the lower part of the Mauch Chunk Formation underlie the slope. A 390-meter-long segment of road has been rerouted away from this colluvial slope and is now built on fill. A 1.5-meter-high partial head scarp and vestiges of the northeast lateral margin of the movement can be seen in the woodland above the road.

(3) Cut failures developed during construction along US Route 219 1 and 3 km north of Accident. Critical factors were strata that dip towards the road and wet clay seams that caused spalling of the overlying Hampshire Formation (Maryland Department of Transportation, unpub. data) (table 3).

(4) Unstable slopes from the Pocono Group were encountered during US Route 48 construction, resulting in the flattening of a slope 8 km east of Grantsville (Maryland Department of Transportation, unpub. data).

Clays from Devonian to Pennsylvanian rocks are consistently dominated by illite with variable amounts of kaolinite and expandable clay (table 3).

Valley and Ridge Province

This nearly 110-kilometer-wide belt of folded and faulted Cambrian to Mississippian sedimentary rocks lies between the Blue Ridge and Appalachian Plateau Provinces. The eastern part of the province is part of the Great Valley and is underlain by Cambrian and Ordovician limestone, dolomite, and shale. To the west a complex sequence of ridges and narrow valleys has developed on largely clastic rocks of Ordovician to Mississippian age.

No landslides were seen during the reconnaissance of the Great Valley. However, red to yellow silty clays of the Hagerstown, Duffield, and Frankstown soil series show a moderate to high shrink-swell potential (Matthews, 1962). Slaking of weathered rock and soil is common in artificial cuts, and the potential for small slippages is always present. Also, solution activity resulting in fissures, caverns, and sinkholes is characteristic along the gentle slopes of the Great Valley. A rank of 1, indicating very low to low susceptibility has been given to this part of the province.

A low to moderate susceptibility (rank 2) is indicated for that part of the section involving the

Clinton Group (which includes the Rose Hill Formation), the McKenzie Formation, the Bloomsburg Formation, and the Wills Creek Shale, all of Middle to Late Silurian age. The units are largely shale and sandstone with siltstone, mudstone, and minor limestone. Significant research into 16 ancient Valley and Ridge rockslides of West Virginia and Virginia has revealed that 14 of the localities involve some part of the Silurian section (Southworth and Schultz, 1986a, 1986b).

A large ancient rockslide, which averages 750 m in width and 600 m in length, occurs as a scar along the west limb of the Wills Mountain anticline 3 km northwest of Cumberland (fig. 7; C.S. Southworth and A.P. Schultz, USGS, unpub. data). Although the core of the anticline is in the Upper Ordovician Juniata Formation, most of the dip slope is in Tuscarora Sandstone. Shale beds are reported by deWitt and Colton (1964) and Berryhill and others (1956) in the upper part of the Tuscarora sandstone. One of these beds could have served as a slippage plane. However, the Juniata Formation is exposed in the floor of the scar (C.S. Southworth and A.P. Schultz, USGS, unpub. data), so the possibility exists that shearing took place on the topmost red shale bed in the Juniata. The focus of triggering might have been at the base of the slope, which is in the Rose Hill Formation and forms the bank along an entrenched meander of Wills Creek. The Rose Hill Formation is largely incompetent because of its lithologic make-up; its gray to red mudstone and shale are full of small-scale folds and faults, some of which are probable shear planes caused by slope movements. Outcrops of the weak rock commonly weather to clay. Interbeds of sandstone occur throughout the unit.

Less-well-defined old slides with inferred head scarps in the Rose Hill Formation occur lower on the slope northward to the Pennsylvania border. The toes of these slides are not influenced by any drainage. The cause can only be speculated, but the head areas are underlain by weak strata of the Rose Hill Formation.

Failures in the Rose Hill Formation have been created by road construction on both sides of the Wills Mountain anticline west of Cumberland (Maryland Department of Transportation, unpub. data). A 200-meter-wide slide above the north side of Md. Route 48 on the east limb of the anticline was caused by failure in weathered shale (Upper Tuscarora Sandstone or lower Rose Hill Formation). The combination of a dip slope towards the road, a rapid decomposition of the shale to clay when exposed to the atmosphere, and precipitation were critical contributory factors.

Another more serious slide developed downhill from the preceding locality during Md. Route 48 construction along the east limb of the Wills Mountain anticline. An embankment failure resulted along a sidehill fill (fig. 8*A*), which had been constructed upon an unstable section of older landslide material; the failure plane was within the colluvium. In addition to destroying the completed roadbed construction, sections of two streets lying below the failure, a utility pole line, and at least two houses were ruined.

The failure, probably best described as a slump-earthflow, took place along the north flank of an 800-meter-wide east-facing prehistoric(?) landslide. The McKenzie and Bloomsburg Formations (Silurian) underlie the colluvium according to the geologic map of Allegany County (Berryhill and others, 1956).

The failure occurred on May 28, 1968. Although precipitation in May was above the normal 7.3 inches (19 cm) at Cumberland, (National Oceanic and Atmospheric Administration, 1969), precipitation during the 1968 spring and winter months and fall of 1967 was generally below normal. A total of 1.1 inches (2.9 cm) fell at Cumberland on the day of the failure. About 2.4 inches (6.1 cm) of rain fell during the four-day period prior to the 28th (National Oceanic and Atmospheric Administration, 1968). Although no specific mention is made of the precipitation factor in Balter (1970), rainfall undoubtedly acted as the triggering element.

Bore-hole data (Balter, 1970) in the head area of the slide indicated that shale bedrock was encountered at 5.7 to 7.0 m below the existing slope after failure. In the lower part of the slide moist to wet fill and colluvium were observed to a depth of 8.5 m below the post-failure slope. Organic matter, roots, and topsoil extended to a depth of 3.5 m in the lower slope.

In addition to the instability created by the placement of the sidehill embankment over an older failed slope, Balter (1970) cited an excavation for a water line in the lower part of the slope which, after emplacement of the embankment, removed a significant restraining force. The Balter report mentioned the presence of a storm-water line which permitted water to infiltrate the subgrade above the north side of the road. The excavation below the road exposed a steeply dipping drag fold of unreported dimensions which contained clay seams and allowed for water passage. A further contributing force to the instability were the uphill-sloping benches that intercepted surface run off. These benches forced water to infiltrate the bedrock and surcharge the fill and colluvial material below the road.

The remedial action (fig. 8*B*) included: (1) Removing old and new slide material and remaining weakened rock material, (2) Creating a set of benches which served as a base for thoroughly compacted layers of the excavated material, and (3) Minimizing water infiltration by piping drainage from the roadway down the hill.

Less-costly highway slides east of Cumberland developed within deep cuts during modification or construction of US Route 40, Interstate I-70, and Md. Route 51 (fig. 9). Either the overburden soils (commonly on dip slopes) failed because of lack of support after excavation, or shale layers that contained thin clay seams with bedding planes dipping towards the highway cut failed. Some of the failures of the latter type took place in highly fractured and complexly folded bedrock (Maryland Department of Transportation, unpub. data). Bedrock units involved were the Oriskany Group, Mahantango Formation (Hamilton Group), and Chemung Formation, all of Devonian age. In summary, the presence of shale and an unfavorable dip direction were most commonly involved.

Landforms, one of which is suggestive of a probable relict debris flow, emanate from the Allegheny Front immediately west of Cresaptown. The probable relict debris flow (fig. 10) closely resembles more definitive relict debris flows in northwestern Pennsylvania (Pomeroy, 1983, 1986). Less-distinctive and smaller old debris flows(?) are found both north and south of the Cresaptown locality along the Allegheny Front.

Blue Ridge Province

An overturned anticlinal fold consisting of sedimentary, metasedimentary, gneissic, and metavolcanic rock of Precambrian to Cambrian age make up this 16-kilometer-wide province. South and Catoctin Mountains are distinctive topographic features. The Catoctin Metabasalt (Godfrey, 1975) and its interbeds of green tuffaceous phyllite form a commonly red, silty to clayey soil which shows instability. Soils belonging to the Fauquier-Highfield-Myersville series have a moderate to high plasticity index (Matthews, 1985).

At Sabillasville along a northeast-facing slope, field reconnaissance revealed an 800-meter-long, 150-meter-wide, fairly to poorly preserved, prehistoric colluvial debris flow. Recognition of additional ancient debris flows is difficult. Godfrey (1975) recognized that frost action and mass movement (mainly solifluction) were important processes in the Pleistocene periglacial climate of the Blue Ridge, but indicated that the location of the transition from mass movement to fluvial transport had been obliterated.

Along the west side of Interstate I-70 2 km west of Myersville and 2 km southeast of the I-70 rest area, a 2:1 cut slope failed during construction (Maryland Department of Transportation, unpub. data). The Catoctin Metabasalt underlies the area. Aerial photographic interpretation revealed the affected area to be roughly 200 m long by 200 m wide.

A relatively small embankment failure involving a cut where colluvium overlies the Harpers Formation (phyllite) at the junction of US Route 15 and a secondary road at Catoctin Furnace necessitated a retaining wall.

Although the incidence of present-day landsliding is low in areas underlain by the Catoctin Metabasalt (Godfrey, 1975), the susceptibility is considered to be low to moderate.

Piedmont Province

Although the Piedmont constitutes nearly 25 percent of Maryland, landslides are not common; the susceptibility is generally very low to low despite generally deep residual soils and thick saprolite over most of the area. Examination of Maryland Department of Transportation data revealed a lack of problems along federal and state roads in the Piedmont. Costa (1974) refers to a lack of slope failures in a watershed area north-northwest of Baltimore despite 10 in. (25.4 cm) of rainfall in one day from tropical storm Agnes in June 1972.

Despite the generally low susceptibility, the varied lithologies have distinctive physical and engineering properties, some of which have a bearing on slope stability. The Piedmont has been subdivided on the map into various subgroups. They are, in decreasing order of areal extent: metasedimentary and metaigneous rock; gabbroic, metagabbroic, diabasic, metabasaltic, and ultramafic rock; clastic Triassic sedimentary rock; and limestone and marble with minor schist.

The major subunit of metasedimentary and metaigneous (mostly acidic) rock occupies a belt ranging from 50 km in width in the south to 115 km in the north. One recent 20-meter-wide earthflow was examined along a 15° (25 percent) woodland colluvial slope adjacent to a gneiss dome northwest of Baltimore. Saprolite was not believed to be involved, although the slippage plane could possibly have been located at the colluvium-saprolite contact. Bedrock dips moderately to steeply towards the road. Triggering of the slope movement is assumed to have taken place because of road construction or widening of the road at the toe.

Other selected woodland areas with 15 to 40 percent slopes were traversed without detecting significant recent or older slope movement, though creep was evident. Creeping saprolite has already been documented (Costa and Cleaves, 1984, p. 10). Although all parts of this belt were reconnoitered, particular emphasis was placed in those areas having a greater-than-average thickness of overburden. Overburden thickness is a reflection of lithology, landforms, and metamorphism (Costa and Cleaves, 1984). Slopes, particularly underlain by the Loch Raven Schist in the area north and west of Baltimore where gneiss domes are prevalent, suggest a greater thickness of overburden than slopes underlain by the Pretty Boy Schist (Crowley, 1976), which crops out north of the gneiss dome area. No recently active movements were seen along slopes underlain by the Pretty Boy Schist.

Small fill failures were noted along secondary roads and in multiple-housing parking areas in the suburbs of Montgomery and Baltimore Counties. Cursory examination showed that the failure surfaces originated within the fill or at the fill-colluvium interface.

Soils derived from mafic and ultramafic igneous rocks show a moderate to high shrink-swell potential. These slowly permeable, silty clay to clay soils include the Aldino, Chrome, Kelly, Legore, Montalto, Relay, and Watchung soil series, which show poor to fair stability in roadfills and embankments (Reybold and Matthews, 1976). Most of the areas are underlain by the Baltimore Complex. Major road cut problems in these rocks are uncommon (Maryland Department of Transportation, unpub. data). However, failures along joint planes in gabbro saprolite were noted by Cleaves (1968) in the Susquehanna Aqueduct trench.

Small slope movements were detected in the Patapsco River gorge and a north-south trending tributary 1.1 km northwest of the Interstate I 95-Patapsco River intersection. Colluvial debris avalanches with an average width of 4 m above the east side of the tributary were probably triggered by high water and facilitated by the dip of the foliation towards the creek. Elsewhere, few slope movements were seen despite the commonly clayey nature of the weathered rock.

The commonly red to reddish-brown soils derived from sandstones and shales of Triassic age are generally thin. These soils belong to the Penn, Readington, and Craton series (Matthews, 1985) and mask the gently rolling to level topography. Natural slopes with as much as 30 m of relief along the Monocacy River in Frederick County did not show any slides, even with a favorable dip direction. No stability problems in roadcuts have been documented. The susceptibility to landsliding is very low.

Soils underlain by the Cockeysville Marble and its associated schist and gneiss are similar to those of the Great Valley (previously discussed in the Valley and Ridge section) in their physical properties. A sticky, plastic, red clay is common, but no slope movements were seen.

More data related to the engineering properties of similar weathered metamorphic rocks in northern Virginia is given by Obermeier (1979) and Obermeier and Langer (1986).

SUMMARY

A variety of landslides is present in all five physiographic provinces. A vast majority of the bedrock and unconsolidated rock units show landslides, most commonly within their weathered products and derivative soils. Large prehistoric landslides can be identified in the western part of the state, but are rarely preserved in the Coastal Plain province. In terms of total damage costs and areal extent of active landsliding, the Coastal Plain shows the highest susceptibility. Most of the landslide problems in the Appalachian Plateau and the Valley and Ridge provinces have been generated by highway construction.

Lithology and precipitation are the major factors in landslide genesis. Clay layers within the Coastal Plain sediments and clay (or weathered shale) layers within the Paleozoic sequence have caused stability problems. Climatic records for the state indicate that the 1960's generally were drier than normal, whereas the 1970's were wetter than normal. Precipitation during the 1980's has been generally below normal, except in the extreme western part of the state. Specific landslide events can be correlated with periods of above-normal precipitation.

REFERENCES CITED

Amsden, Thomas, 1953, Geologic map of Garrett County [Maryland]: Maryland Department of Geology, Mines, and Water Resources, scale 1:62,500.

Andersen, R.H., and Matthews, E.D., 1973, Soil survey of Cecil County, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 119 p.

Balter, R.B., Soil and Foundation Consultants, 1970, Landslide problems and recommended design procedures for western Maryland highways: Owings Mills, Maryland, 62 p.

Berryhill, H.L., Jr., Colton, G.W., de Witt, Jr., Wallace, and Johnston, J.E., 1956, Geologic map of Allegany County [Maryland]: Maryland Department of Geology, Mines, and Water Resources, scale 1:62,500.

Cleaves, E.T., 1968, Piedmont and Coastal Plain geology along the Susquehanna Aqueduct, Baltimore to Aberdeen, Maryland: Maryland Geological Survey Report of Investigations No. 8, 45 p.

Cleaves, E.T., Edwards, Jonathan, Jr., and Glaser, J.D. (compilers), 1968, Geologic map of Maryland: Maryland Geological Survey, scale 1:250,000.

Cloos, Ernst, and Broedel, C.H., 1940, Geologic map of Howard County [Maryland]: Maryland Geological Survey, scale 1:62,500.

Costa, J.E., 1974, Response and recovery of a Piedmont watershed from tropical storm Agnes, June 1972: Water Resources Research, v. 10, no. 1, p. 106-112.

Costa, J.E., and Cleaves, E.T., 1984, The Piedmont landscape of Maryland--a new look at an old problem: Earth Surface Processes and Landforms, v. 9, p. 59-74.

Crowley, W.P., 1976, The geology of the crystalline rocks near Baltimore and its bearing on the evolution of the eastern Maryland Piedmont: Maryland Geological Survey Report of Investigation No. 27, p. 1-40.

Crowley, W.P., Reinhardt, Juergen, and Cleaves, E.T., 1976, Geologic map of Baltimore County and City [Maryland]: Maryland Geological Survey, scale 1:62,500.

de Witt, Wallace, Jr., and Colton, G.W., 1964, Bedrock geology of the Evitts Creek and Patterson Creek quadrangles, Maryland, Pennsylvania, and West Virginia: U.S. Geological Survey Bulletin 1173, 90 p.

Edwards, Jonathan, Jr., 1978, Geologic map of Washington County [Maryland]: Maryland Geological Survey, scale 1:62,500.

Geyer, A.R., and Wilshusen, J.P., 1982, Engineering characteristics of the rocks of Pennsylvania: Pennsylvania Geological Survey Environmental Geology Report 1, 300 p.

Glaser, J.D., 1971, Geology and mineral resources of southern Maryland: Maryland Geological Survey Report of Investigations No. 15, 84 p.

_____1976, Geologic map of Anne Arundel County, also showing geologic factors affecting land modification: Maryland Geological Survey, scale 1:62,500.

_____1978, Geologic map of the Mount Vernon and Piscataway quadrangles, Maryland: Maryland Geological Survey Quadrangle Geologic Map QA 8, Atlas Map no. 1, scale 1:24,000.

Godfrey, A.E., 1975, Chemical and physical erosion in the South Mountain anticlinorium, Maryland: Maryland Geological Survey Information Circular 19, 35 p.

Hack, J.T., 1977, Geologic map for land-use planning, Prince Georges County, Maryland: U.S. Geological Survey Miscellaneous Investigation Map I-1004, scale 1:62,500.

Hall, R.L., and Matthews, E.D., 1974, Soil survey of Charles County, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 94 p.

Keefer, D.K., and Johnson, A.M., 1983, Earth flows--morphology, mobilization, and movement: U.S. Geological Survey Professional Paper 1264, 56 p.

Kimball, L.R., Consulting Engineers, 1974, Slope stability, v. 1, Report and field book [Research and demonstration of improved surface mining techniques in eastern Kentucky]: Washington, D.C., Appalachian Regional Commission Report ARC-71-66-T3, U.S. Department of Commerce National Technical Information Service PB-262-492, 80 p.

Kirby, R.M., Matthews, E.D., and Bailey, M.A., 1967, Soil survey of Prince Georges County, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 170 p.

Kirby, R.M., and Matthews, E.D., 1973, Soil survey of Anne Arundel County, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 127 p.

Leatherman, S.P., 1986, Cliff stability along western Chesapeake Bay, Maryland: Marine Technology Society Journal,, v. 20, no. 3, p. 28-36.

Matthews, E.D., 1962, Soil survey of Washington County, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 136 p.

_____1985, Frederick County, Maryland soil survey supplement-text and tables: Catoctin and Frederick Soil Conservation Districts, in cooperation with U.S. Soil Conservation Service, 217 p.

Matthews, E.D., and Hershberger, M.F., 1968, Soil survey of Howard County, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 104 p.

National Oceanic and Atmospheric Administration, 1961-1986, Climatological data, annual summary, Maryland: v. 64-89, no. 13.

Obermeier, S.F., 1979, Slope stability map of Fairfax County, Virginia: U.S. Geological Survey Miscellaneous Field Studies Map MF-1072, scale 1:48,000.

Obermeier, S.F., Swanson, P.G., Jones, J.S., Jr., and Schnabel, J.J., 1984, Engineering geology and design of slopes for Cretaceous Potomac deposits in Fairfax County, Virginia and vicinity: U.S. Geological Survey Bulletin 1556, 88 p.

Obermeier, S.F., and Langer, W.H., 1986, Relationships between geology and engineering characteristics of soils and weathered rocks of Fairfax County and vicinity, Virginia: U.S. Geological Survey Professional Paper 1344, 30 p.

Palmer, H.D., 1973, Shoreline erosion in Upper Chesapeake Bay—the role of groundwater: Shore and Beach, v. 41, no. 2, p. 18-22.

Pomeroy, J.S., 1982, Mass movement in two selected areas of western Washington County, Pennsylvania: U.S. Geological Survey Professional Paper 1170-B, 17 p.

_____1983, Relict debris flows in northwestern Pennsylvania: Northeastern Geology, v. 5, no. 1, p. 1-8, 6 figs.

_____1986, Slope movements in the Warren-Allegheny Reservoir area, northwestern Pennsylvania: U.S. Geological Survey Bulletin 1650, 15 p.

Radbruch, D.H., and Crowther, K.C., 1973, Map showing areas of estimated relative amounts of landslides in California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-747, scale 1:1,000,000.

Reybold, W.U., III, and Matthews, E.D., 1976, Soil survey of Baltimore County, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 149 p.

Shattuck, C.B., 1902, Cecil County [geologic map]: Maryland Geological Survey, Johns Hopkins Press, Baltimore, 322 p., scale 1:62,500.

Smith, Horace, and Matthews, E.D., 1975, Soil survey of Harford County area, Maryland: U.S. Soil Conservation Service, in cooperation with Maryland Agricultural Experiment Station, 118 p.

Southwick, D.L., and Owens, J.P., 1968, Geologic map of Harford County [Maryland]: Maryland Geological Survey, scale 1:62,500.

Southworth, C.S., and Schultz, A.P., 1986a, Photogeologic interpretation reveals ancient, giant rockslides in the Appalachian Valley and Ridge province, Virginia and West Virginia: Association of Engineering Geologists Newsletter, v. 29, no. 2, p. 31-33.

_____1986b, Characteristics of giant rockslides in the Appalachian Valley and Ridge, Virginia, West Virginia, Maryland, and Pennsylvania: U.S. Geological Survey Open-File Report 86-94, 5 p.

U.S. Geological Survey, 1972, Water resources data for Maryland and Delaware: U.S. Geological Survey Water-Data Reports MD-71.

_____1973, Water resources data for Maryland and Delaware: U.S. Geological Survey Water-Data Reports MD-72.

_____1976, Water resources data for Maryland and Delaware: U.S. Geological Survey Water-Data Reports MD-75.

_____1980, Water resources data for Maryland and Delaware: U.S. Geological Survey Water-Data Reports MD-79.

_____1984, Water resources data for Maryland and Delaware: U.S. Geological Survey Water-Data Reports MD-83.

University of Maryland, 1963, State of Maryland-precipitation map: College Park, Maryland, Prepared by the Civil Engineering Department, in cooperation with the Maryland State Roads Commission and the U.S. Department of Commerce, Bureau of Public Roads, scale 1 inch to 7 miles.

Varnes, D.J., 1978, Slope movement types and processes, Chapter 2 *in* Schuster, R.L., and Krizek, R.J., eds., Landslides—analysis and control: National Research Council, Transportation Research Board Special Report 176, p. 11-33.

_____1984, Landslide hazard zonation—a review of principles and practice: Paris, International Association of Engineering Geology commission on landslides and other mass movements on slopes, United Nations Educational, Scientific, and Cultural Organization (UNESCO), 63 p.

Withington, C.F., 1964, Joints in clay and their relation to the slope failure at Greenbelt, Maryland, December 28, 1962: U.S. Geological Survey Open-File Report 706, 7 p.

Woodward-Clyde Consultants, 1976, Geotechnical investigation, Chalfont Avenue landslide, Forest Knolls subdivision, Prince Georges County, Maryland: Rockville, Maryland, 20 p.