soil materials will produce problems. The defining of excavation loosening by seismic velocities has been reasonably effective in this zone. An occasional pinnacle of resonably sound rock can be expected even in the saprolite and soil zones; an occasional weathered zone can also be expected deep in the sound rock.

SUMMARY

The residual materials of the Piedmont and Blue Ridge exhibit engineering behaviors typical of both soils and rocks. In-place they retain the relict structure of the rock as well as the nonhomogeneity, anisotropy, and surfaces of weakness. When excavated and recompacted as fill they have the texture of sandy silts and silty sands. The mica in most of the residual soils contributes to high void ratios, high compressibilities, and low compacted densities. The strengths are higher than might be expected for soils of such void ratios. The usual index tests do not reflect the engineering potential of Piedmont and Blue Ridge materials (except the soil horizon). Instead, the degree of weathering as exhibited in the total profile, the void ratio, and mica content are more useful indexes.

ACKNOWLEDGMENT

The data on the properties of the soils were obtained from the files of Law Engineering Testing Company. These data reflect thousands of projects and tens of thousands of samples throughout the Piedmont and Blue Ridge. The greatest concentration of data was from MARTA, for which Law Engineering was the Geotechnical Consultant (acting through the general engineering consultant, Parsons Brinckerhoff/Tudor).

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Thickness of Weathered Mantle in Piedmont: Variability and Survey Techniques

ANTONIO V. SEGOVIA

The thickness of overburden measured at construction sites is, in many instances, different from that predicted by regional geomorphologic models. Variations in the thickness of residual soils and weathered rock, on the order of 10 m, have been found to occur over distances as short as a few meters. Problems, ranging from tilting and fracturing of structures to spots that require chronic maintenance on roads, can result from differential settling induced by such variability of the weathered mantle. Geologic and soil maps help to predict problem areas where the variations result from changes in underlying rock facies, such as soluble to insoluble rock. However, sudden variations are common in areas where little or no change in either lithologies or soil types is apparent in such maps. In these areas thickening of the weathered layer is commonly associated with the presence of fracture zones (or zones of closely spaced jointing), which provide preferential loci for water percolation and weathering of the underlying rocks. Such fracture zones can vary in width from one meter to tens of meters. Methods effective in locating fracture zones in the Piedmont include: (a) analysis of aerial photographs, topographic maps, and satellite images to map possible fracture traces and (b) field check carried out by one or more of the following techniques: shallow seismic, magnetic or electric surveys, and trenching or augering. Expeditious field evaluations, based on the examination of samples obtained with a hand auger to determine variations in pedologic characteristics associated with varying rates of water infiltration, can provide a useful guide to the more expensive and time-consuming geophysical surveys.

Estimations of the thickness of the weathered mantle are necessary to determine depth of excavation to bedrock, expected settling of structures, attenuation capacity of the mantle for potential groundwater contaminants from waste disposal, cost of landscaping, and the impact of soil erosion on future land productivity. Incomplete evaluation of the variations in the nature and thickness of the weathered mantle can result in problems. These may include the tilting and fracturing of structures, cost overruns in excavation contracts, high maintenance cost of highways, and unexpected contamination of water supplies.

The standard county soil surveys and county maps, which depict the thickness of overburden, are not adequate for site-specific design purposes. Soil maps rarely provide information beyond 1-1.5 m below the surface, whereas maps of thickness of overburden are usually generalized and, in most cases, they neglect the effect of fracture zones. The maps for Montgomery County, Maryland, among the most recent

Figure 1. Variations in thickness of the weathered mantle associated with changes in lithology of unfractured substrata.
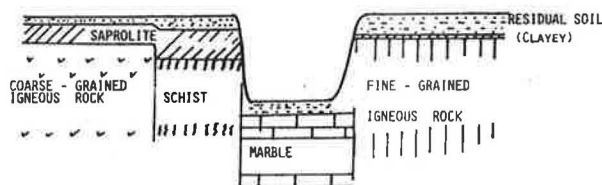

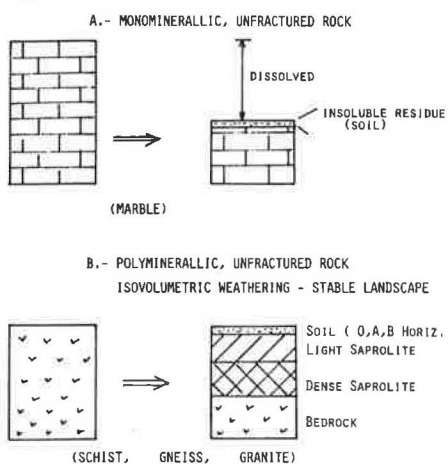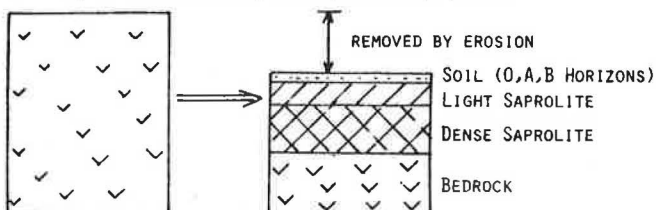Figure 2. Conversion of rocks to soil in the Piedmont.

Figure 3. Conversion of polyminerallic rocks to soil in the Piedmont under conditions of isovolumetric weathering and unstable landscape; i.e., erosion caused by climatic fluctuations, land use, or landscape position.

in the Piedmont, are an example of competent geologic and pedologic work that, for reasons of scale and purpose, do not satisfy the requirements of site-specific interpretation (1-3).

Conceptual models for the variations in thickness of residual soils and saprolite have been advanced (4-6), but they should be used with caution because the depth to bedrock has been found to depart from the models in many localities. The depth can vary suddenly from less than 1 m to about 10 m over a distance of a few meters (7-9). The terms overburden and weathered mantle in this paper include all materials above bedrock. Saprolite is included by pedologists as the C-horizon of residual soils (10). However, the engineering properties of saprolite are often distinctive enough that, for convenience, it is separated from the overlying (O, A, B) horizons. This differentiation is maintained in this paper, where it is helpful in clarifying some concepts.

GENERAL MODEL OF CONVERSION OF ROCKS TO SOILS IN THE PIEDMONT

The conceptual models of thickness of the weathered mantle commonly used are based on (a) an interpreta-

tion of the evolution of the landscape; (b) effective time of action of the processes of weathering, or intensity and rates of weathering; (c) assumptions about the volumetric relations between residual soils (including saprolite) and parent rock (4); and (d) relative resistance of the various rock types to chemical decomposition (11).

Figure 1 represents schematically a model based on differential resistance to weathering for the most common rock types found in the Piedmont. The basic assumptions in this model are as follows:

1. Each rock type is homogeneous and isotropic to the action of weathering agents,
2. Each agent of weathering acts uniformly over the area considered,
3. Transformation operated by weathering is essentially an isovolumetric phenomenon, and
4. Degradation of the landscape is either negligible or fairly uniform, except for areas of soluble rocks such as marble, where the ratio of volume of residual soil to volume of parent material is very small compared with the ratio for other rocks (Figure 2).

A model that combines isovolumetric weathering and landscape degradation for areas underlain by polyminerallic rocks is shown schematically in Figure 3. Overall erosion of the land could have been episodically accelerated by climatic fluctuations and land use (12,13). Locally, strong erosion could be caused by a combination of moderate-to-steep slopes with runoff and mass wasting.

LOCAL DEPARTURES FROM THE GENERAL MODEL

Models of weathering based on the factors and assumptions outlined in the previous paragraphs have often turned out to be inadequate to explain local variations in depth to bedrock. Additional factors appear to be responsible for variations in the thickness of the weathered column. Some of these additional factors are discussed in the following paragraphs.

Inhomogeneities are found within mappable geologic units because small bodies of diverse lithologic composition, resistance to weathering, and engineering properties may be grouped within a given geologic unit for mapping purposes.

Variations in thickness of the weathered mantle can also be caused by folding and faulting, which followed or accompanied the regional metamorphism that affected the Piedmont rocks. The folding and faulting that accompany metamorphism would have resulted from the action of regional compactional stresses acting on a complex, anisotropic mass. Even though each lithologic component of the mass may have behaved uniformly under stress, the geometry of some of the rock bodies probably varied independently from that of the others. In such a case, even though the region was subjected to a fairly uniform stress, differential compaction of irregularly shaped bodies of varying mechanical properties would have required the development of tight folds and faults with horizontal, oblique, and even vertical components of movement. Such faults resulted in the juxtaposition of materials of different resistance to weathering. Given geologic time, this resulted in the current variations in the thickness of residual soils. The bewildering discontinuities of topographic ridges in metamorphic terrains reflect the great numbers of disruptions and dislocations caused by such adjustments. The left side of Figure 4 illustrates variations of this type.

The presence of thin, long intrusive bodies, usu-

Figure 4. Soil-landscape associations in the Piedmont and their relations to bedrock type and structure.
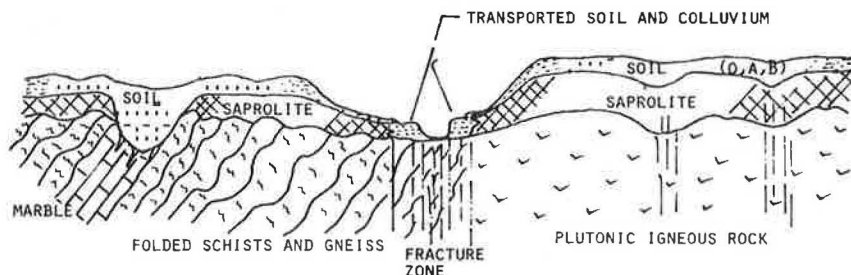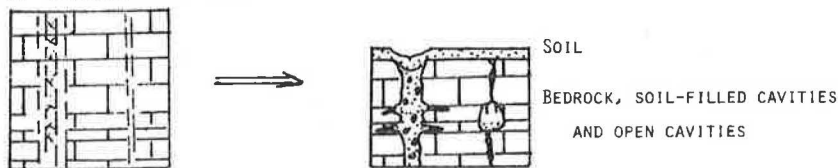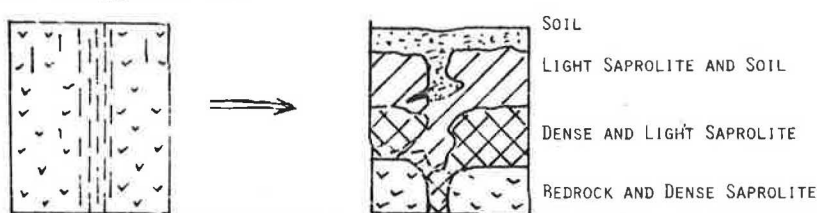

Figure 5. Irregular weathering caused by presence of fracture zones in rocks of Piedmont.

ally vertical or nearly vertical in attitude also creates variations in thickness of the weathered column. Some of these dikes are granitic, but the most common ones in the Piedmont are basaltic in composition.

Fracture zones usually have very sharp boundaries and may vary in width from less than a meter to a hundred or more meters. They are perhaps the most troublesome features encountered in attempting to predict depth to bedrock. The fracture zones control water infiltration into the ground (14). In turn, water circulation controls weathering and the rate of formation of residual soils. Thickness of soils may vary from a few tens of centimeters outside the fracture zone to ten meters within the fracture zone, over a horizontal distance of a few meters, as shown in Figures 4 and 5.

The following characteristics of fracture zones have been observed in the Piedmont:

1. Orientation: Even though there appear to be two conjugate, dominant sets, with orientations that probably rotate gradually with the regional tectonic grain or latitude, local sets are also superposed on the regional ones (15). From the engineer's point of view the local sets, in some instances, may be more important than the regional ones. The local sets are apparently related to deformation caused by the intrusion of igneous masses, such as the Boyds laccolith, whereas others may be associated with changes in compositional and mechanical properties of the rocks below (15).

2. Age: Observations of soils developed on fracture zones in the Piedmont suggest that some fracture zones are probably very old, affecting

weathering for more than a hundred thousand years, whereas others appear to be young, perhaps no more than a few thousand years old.

Grouped collectively under geomorphologic factors, and more restricted in occurrence than fracture zones are (a) filled, paleostream channels, (b) fluvial terraces and floodplain alluvium in stream valleys, (c) veins filled with crushed quartz that promote fast water percolation, (d) erosion associated with local land use, (e) eolian erosion and preferential deposition in certain loci (wind-transported material is slowly incorporated into the soil profile and becomes difficult to differentiate from some residual soils), and (f) stream and gully erosion.

DETERMINATION OF LOCAL VARIATIONS IN DEPTH TO BEDROCK

Emphasis is placed on techniques for mapping variations in thickness of the weathered mantle caused by the presence of fracture zones. However, the same field procedures listed below can be used to locate similar features of different origin.

Lattman (16) described the techniques still in common use to map photogeologic fracture traces and lineaments. Unfortunately, the features thus mapped have come to mean fracture traces, fracture zones, or simply faults and fractures to many later workers. Many of the linear features so mapped are not associated with fracture zones. For this reason, such features must be evaluated in the field in every case. For the same reason, the term regmite from the Greek regma (fracture) and mimos (imitator, mimic), was introduced to differentiate mere linear
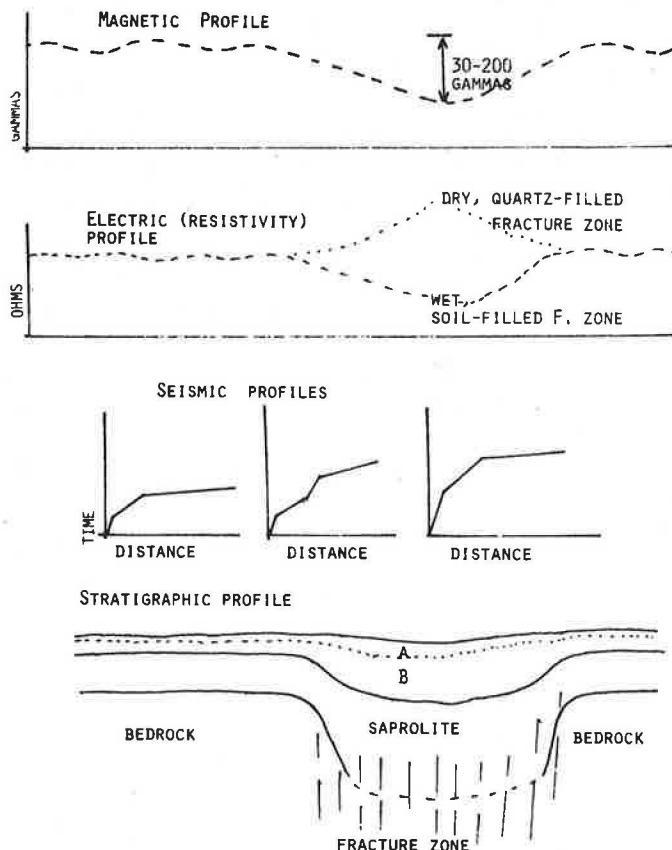
features traced on aerial photographs from those verified in the field (17). The terms linear, lineament, and fracture traces commonly mean regmites in the literature and are rarely used to mean verified fracture zones.

Survey techniques to map fracture zones that may affect the thickness of the weathered mantle include the following steps:

1. Aerial photographs should be analyzed, preferably in stereoscopic models, to identify changes in soil tone and linear features manifested as vegetation alignments, stream deflections, or rectilinear reaches, topographic breaks in slope, and scarps (16), complemented by analysis of topographic maps and satellite images. The preferred scale of the aerial photographs should be 1:12,000 or larger.

2. The importance of field evaluation cannot be overemphasized. This includes field observation of vegetation, soil variations, and geomorphologic features. These observations are accompanied by examination of soil samples obtained with a hand auger. A bucket auger can easily reach down to about 1.5-2 m in weathered material. This depth is usually sufficient to provide reliable clues as to differential rates of water percolation and soil development. The colors are characteristically redder and more vivid in the fracture zone than in the surrounding areas. The field check is completed by using one or more portable geophysical tools, such as a seismic device, magnetometer, and resistivity meter. The magnetometer is an excellent tool for a fast check of suspected fracture zones in most areas of the Piedmont, whereas the seismic devices, though slightly more cumbersome to use, can provide reliable data on depth to bedrock.

Figures 6 and 7 illustrate the variations in geophysical parameters and soils parameters usually found along traverses as one crosses a fracture zone. Figure 8 shows the expression of two fracture zones in the magnetometric survey of a site in Olney, Maryland. Figure 9 shows a seismic traverse across a fracture zone in the vicinity of Clarksburg, Montgomery County, Maryland. Bedrock is a biotitic schist within the Ijamsville Formation (1).

Figure 7. Hand-auger traverse across a fracture zone in the Piedmont.
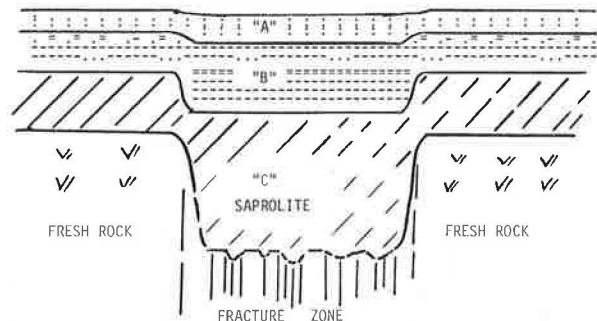
Note: All soil horizons are typically thicker in the fracture zone. Colors are also redder and more vivid than outside the zone.

Figure 6. Expression in geophysical surveys of variations in thickness of weathered mantle.

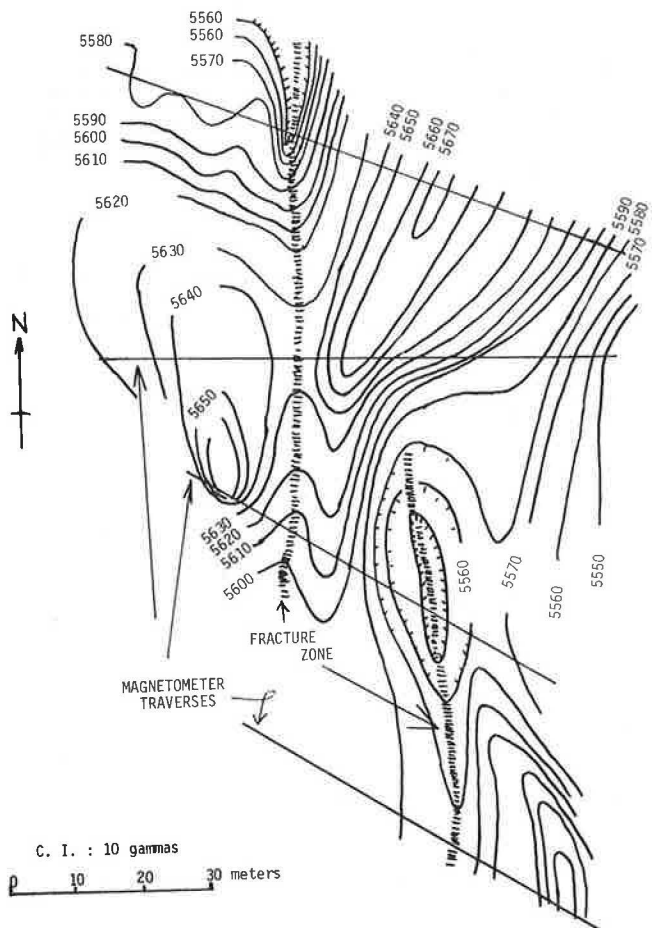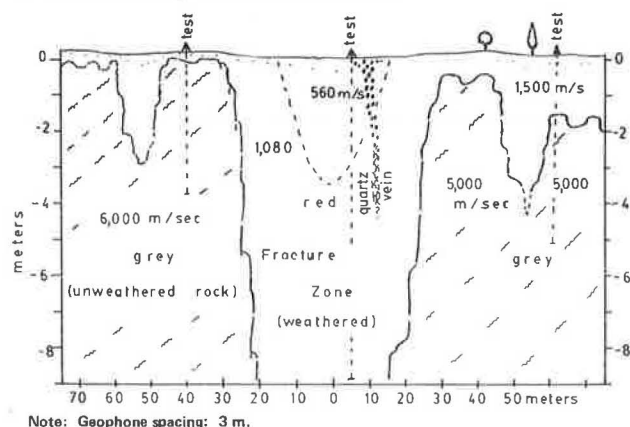Figure 8. Expression of fracture zones in magnetometric survey site in Olney, Md.

Figure 9. Interpretation of a seismic traverse across a fracture zone in the vicinity of Clarksburg, Montgomery County, Md.

Note: Geophone spacing: 3 m.

SUMMARY

Variations in thickness of the weathered mantle at specific sites are difficult to predict on the basis of regional models of weathering for the Piedmont. Therefore, design and site selection of engineering works that can be affected adversely by differential settling and tilting, or for which there is a required amount of soil thickness between base and bedrock, should be preceded by detailed terrain evaluation. The emphasis should be on the detection of fracture zones. Such zones can cause sharp variations in thickness of overburden over short distances because they tend to localize water percolation and increase depth of weathering. Detailed geomorphologic analysis by means of interpretation of aerial photographs, followed by field evaluation using hand augers and portable geophysical equipment such as magnetometers, resistivity meters, and seismic devices have proved to be an effective method for locating fracture zones and variations in depth to bedrock in the Piedmont.

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