GROUND WATER in the PIEDMONT

Proceedings of a Conference on
GROUND WATER in the Piedmont
of the Eastern United States

October 16-18, 1989
Charlotte, North Carolina

Edited by:

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Richard K. White
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HDR Engineering, Inc.
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Published by

CLEMSON UNIVERSITY
113 McAdams Hall
Clemson, South Carolina 29634-0357
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THE TRANSITION ZONE BETWEEN BEDROCK AND REGOLITH: CONDUIT FOR CONTAMINATION?

Douglas A. Harned and Charles C. Daniel III

ABSTRACT

Preliminary results of an investigation of the ground-water system in the regolith and fractured bedrock in the North Carolina Piedmont indicate that the transition zone at the base of the regolith is a primary lateral transmitter of ground water and, potentially, of ground-water contaminants. A zone of weathered rock fragments, residual boulders, and lesser amounts of saprolite is generally present between the base of the saprolite and the top of the bedrock. Saprolite is clay-rich, decomposed bedrock. Careful augering of three wells in Guilford County, North Carolina, indicated that the transition zone was approximately 15 feet thick. This transition zone has been observed in Georgia, Maryland, and North Carolina by several investigators and is described as being the most permeable part of the system, even slightly more permeable than the soil zone. This observation is substantiated by reports from well drillers of so-called "first water," "sand," and "boulders" at the base of the regolith.

The high permeability of the transition zone is probably due to less advanced weathering relative to the upper regolith. Chemical alteration of the bedrock has progressed to the point that expansion of certain minerals causes extensive fracturing of the crystalline rock, yet has not progressed so far that formation of clay has clogged these fractures.

The transition zone may serve as a preferential channel for rapid movement of contaminants to nearby wells, or to streams that have cut their channels into or through the zone to bedrock. The presence of a high-permeability zone between the bedrock and saprolite may create a favorable zone of rapid flow within the ground-water system. Because the distance from the point at which a molecule of water or waste enters the flow system in the Piedmont to where that molecule may discharge to a stream is commonly less than half a mile, ground-water contamination can rapidly become surface-water contamination. How rapidly any contamination moves through the system may be largely a function of the characteristics of the transition zone.

The customary practice in construction of water-supply wells in the Piedmont is to set casing through the regolith into the weathered bedrock. This practice has the benefit of supplying water clear of the fine-grained sediment (clay, silt, and sand) found in the overlying zones. At the same time, this practice makes identification of potential contamination within the transition zone difficult and complicates scientific study of the characteristics of the transition zone.

KEY WORDS:, Piedmont, Ground-water movement, Water pollution, Saprolite, Bedrock, Transition zone.

INTRODUCTION

The Piedmont province of the Eastern United States is one of the more developed and populated areas in the country and has an ever-growing need for high-quality water supplies. Yet, little is known about the ground-water system and the quality of the ground water because most large water supplies in the Piedmont have been developed from surface-water sources.

Because most favorable surface-water sites have been developed and because concerns about the environmental effects of reservoir construction, inter-basin transfer of water, and declining surface-water quality have multiplied, interest in the use of ground water for larger supplies has been rekindled. Recent studies by Richardson (1982), Cressler and others (1983), Daniel and Sharpless (1983), and Daniel (1985) have focused on the potential of ground-water supply in the Piedmont. Other studies have stressed issues of ground-water quality management (LeGrand, 1984; Mew, 1985). In 1987, the Appalachian-Piedmont Regional Aquifer Study by the U.S. Geological Survey (USGS) began with the objective of synthesizing information about the ground-water flow systems of the region.

The Toxic Waste, Ground-Water Contamination Program of the USGS involves a series of ground-water appraisals throughout the United States (Helsel and Ragone, 1984). As part of this program, the ground-water quality of areas of widely differing geohydrology, climate, and land uses is being examined with the objective of developing a national assessment. An initial reconnaissance study was done for the Piedmont province to design a program of future study and develop hypotheses about the contaminant flow system (Harned, 1989).

The purpose of this paper is to summarize current thinking behind one of the more tantalizing hypotheses about the flow system proposed by the USGS reconnaissance study--that the zone between bedrock and saprolite may serve as a channel for rapid transport of contaminants.

HYDROGEOLOGIC FRAMEWORK

Heath's (1980) description of the ground-water system for the Piedmont and Blue Ridge provinces provides a basis for the description of the hydrogeologic framework of the Piedmont flow system. An idealized sketch of the fundamental structure of the ground-water system (Fig. 1) shows the following components of the system:

1. The unsaturated zone in the regolith, which generally contains the organic layers of the surface soil,
2. The saturated zone in the regolith,
3. The transition zone between the regolith and bedrock, and
4. The fractured crystalline bedrock system.

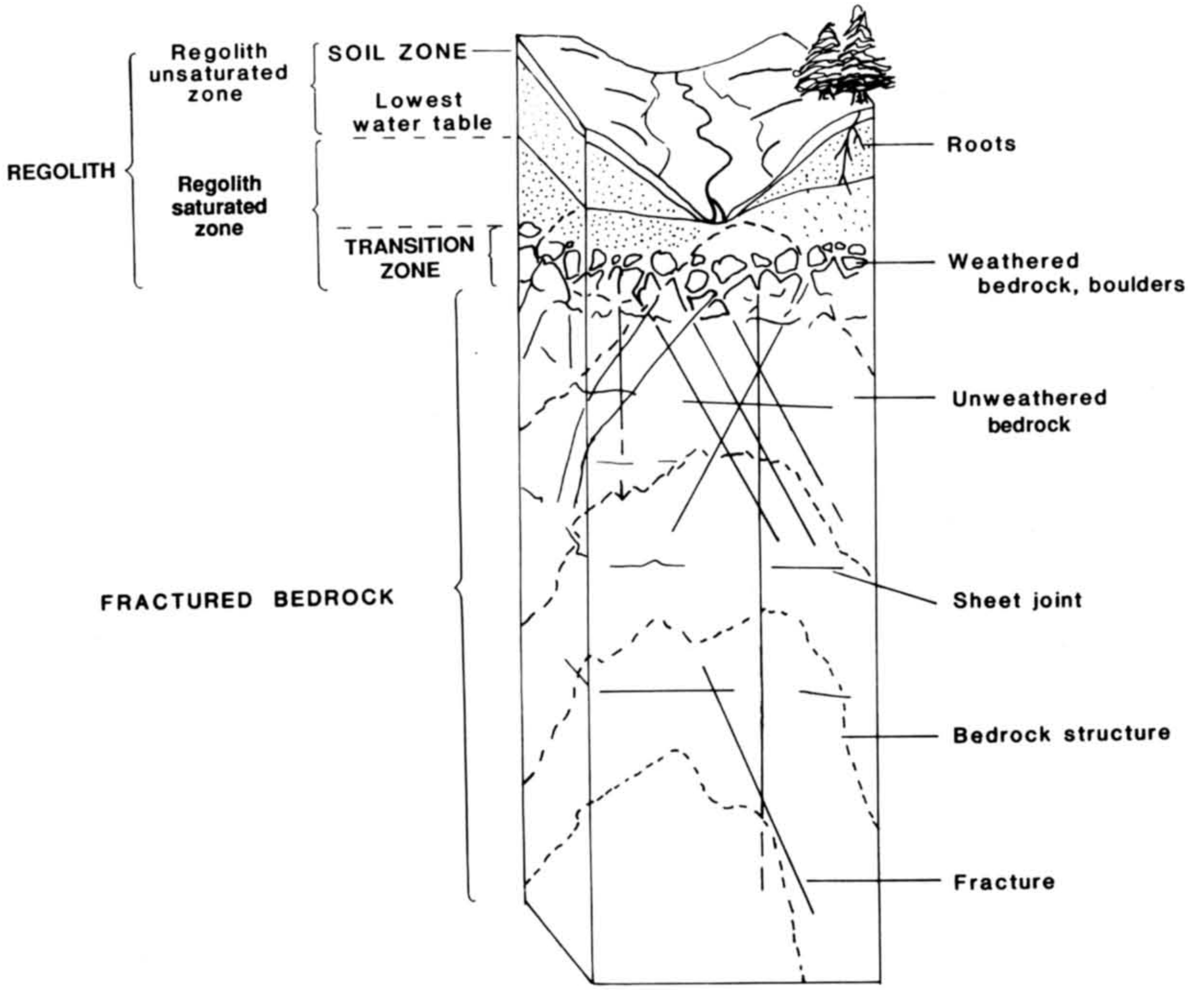

Figure 1. -- Conceptual structure of the Piedmont ground-water system.

Collectively, the uppermost layer is the regolith, which is composed of saprolite, alluvium, and soil (Daniel and Sharpless, 1983). The regolith consists of an unconsolidated or semiconsolidated mixture of clay and fragmental material ranging in grain size from silt to boulders. Because of its porosity, the regolith provides the bulk of the water storage within the Piedmont ground-water system (Heath, 1980).

Saprolite is the clay-rich, residual material derived from in-place weathering of bedrock. Saprolite is often highly leached and, being granular material with principal openings between mineral grains and rock fragments, differs substantially in texture and chemical composition from the unweathered crystalline parent rock in which principal openings are along fractures. Because saprolite is the product of in-place weathering of the parent bedrock, some of the textural features of that bedrock are retained within the saprolite. Evidence of relic quartz veins, dikes, and shear zones are commonly seen in outcrops. Saprolite is usually the dominant component of the regolith, in that soil is generally restricted to the uppermost layer and alluvium deposits are restricted to locations of active and former stream channels and river beds.

The uppermost part of the Piedmont crystalline bedrock contains numerous closely spaced fractures which can be related to the local and regional tectonic history of the area. The greatest number of open fractures in the Piedmont bedrock generally occur at depths less than 400 feet.

THE TRANSITION ZONE AND GROUND-WATER FLOW

In the transition zone, unconsolidated material grades into bedrock. The transition zone consists of partially weathered bedrock and lesser amounts of saprolite. Here, particles range in size from silts and clays to large boulders of unweathered bedrock. The thickness and texture of this zone depend a great deal on the texture and composition of the parent rock. The best defined transitional zones are usually those associated with highly foliated metamorphic parent rock, while those of massive igneous rocks are commonly poorly defined, with saprolite present between masses of unweathered rock.

A diagram showing how the transition zone may vary due to different rock type is presented in Figure 2. It is thought that the incipient planes of weakness produced by mineral alignment in the foliated rocks facilitates fracturing at the onset of weathering, resulting in numerous rock fragments. The more massive rocks do not possess these planes of weakness, and weathering tends to progress along fractures. The result is a less distinct transition zone in the massive rocks.

In the Piedmont, 90 percent of the records for cased bedrock wells show combined thicknesses of 97 feet or less for the regolith and transition zones (Daniel, 1987). Careful augering of three wells indicated that this transition zone was approximately 15 feet thick (Table 1) at the Guilford County, North Carolina, test site. This zone has been found in Georgia as reported by Stewart (1962) and in Maryland as reported by Nutter and Otton (1969). They describe this zone as being more permeable than the upper regolith and slightly more permeable than the soil zone. This observation is substantiated by reports from well drillers of so-called "first water" in drillers' logs (Nutter and Otton, 1969).

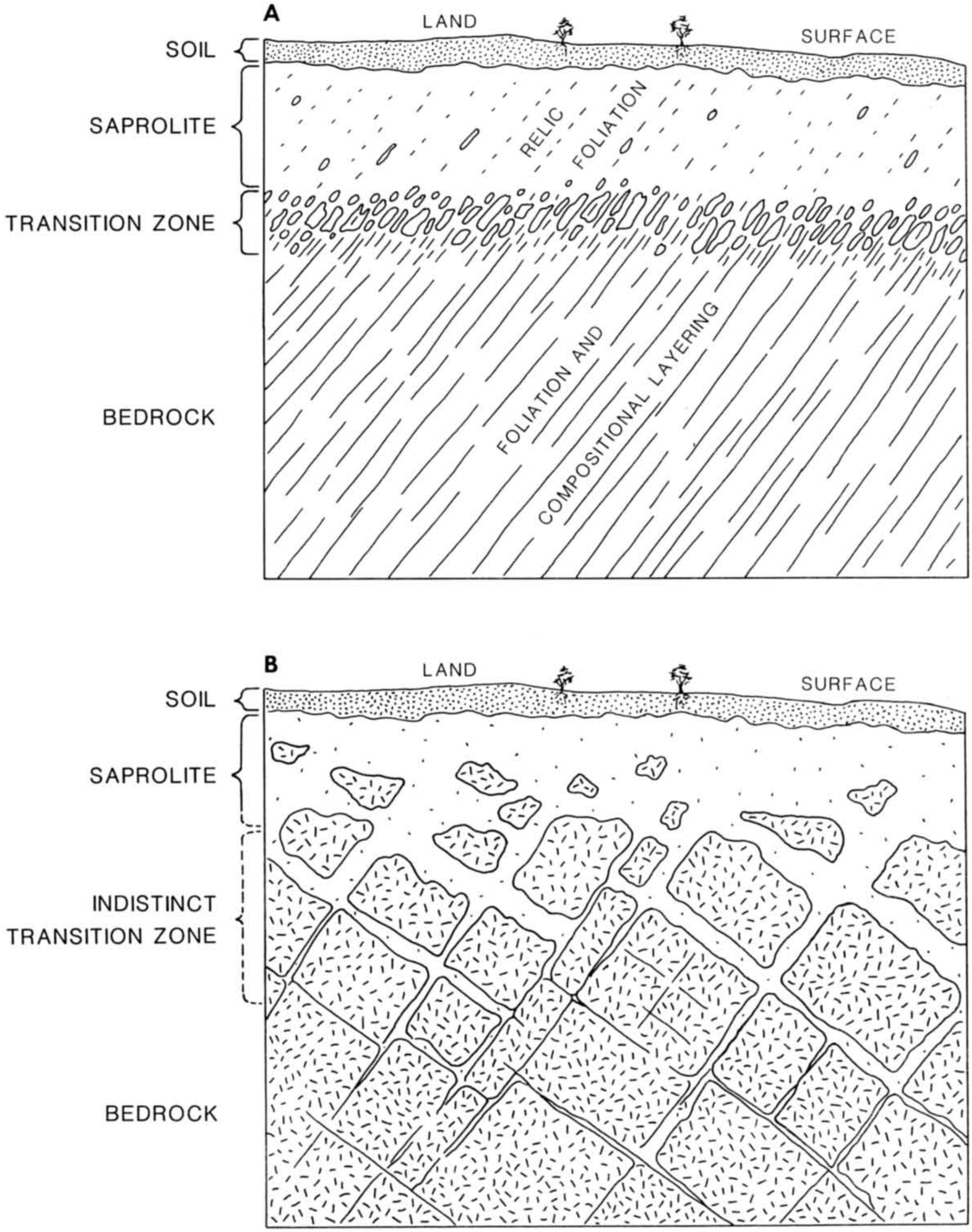

Figure 2. -- Conceptual variations of transition zone definition due to rock type.
A) Development of distinct transition zone on highly foliated schists, gneisses, and slates.
B) Development of an indistinct transition zone on massive bedrock.

Table 1. -- Properties of regolith at three well locations in the Piedmont northwest of Greensboro, North Carolina.

Well pair	Total thickness regolith (feet)	Thickness soil and saprolite (feet)	Thickness transition zone (feet)	Saturated thickness regolith (March 3, 1989)	Topography
Gu-383, AH-13	45.9	35.8	10.1	29.6	side of draw
Gu-385, AH-4	65.7	48.1	17.6	48.1	side of draw
Gu-386, AH-1	46.2	27.9	18.3	28.3	side of draw
AVERAGE	52.6	37.3	15.3	35.3	

Stewart (1964) and Stewart and others (1964) tested saprolite cores from the Georgia Nuclear Laboratory area for variables including porosity and permeability. It is apparent from those data that porosity, although variable, changes only slightly with depth through the saprolite profile until the transition zone is reached, where porosity begins to decrease (Fig. 3). The highest permeability values are present near the surface and within the transition zone (Fig. 3).

The high permeability of the transition zone is probably due to incomplete weathering in the lower regolith. Chemical alteration of the bedrock has progressed to a stage of minute fracturing of the crystalline rock, yet it has not progressed so far that the rock minerals all have been altered to clays, which would clog the tiny fractures. An idealized weathering profile by Nutter and Otton shown in Figure 4 illustrates the effect of degree of weathering on permeability.

The presence of a zone of high permeability on top of the bedrock may create a zone of concentrated flow within the ground-water system. Well drillers may find water at relatively shallow depth, yet complete a dry hole after setting casing through the regolith and transition zone and into the unweathered bedrock. If this happens, the ground water probably is present and moving primarily within the transition zone, but there is probably poor connection between the regolith reservoir, the bedrock fracture system, and the well.

A hypothesis that can be derived from the above observations can be stated simply as follows:

> The transition zone between bedrock and saprolite is a high-flow zone of ground water. If the ground water is contaminated, the zone will serve as a conduit of rapid movement for that contaminated water.

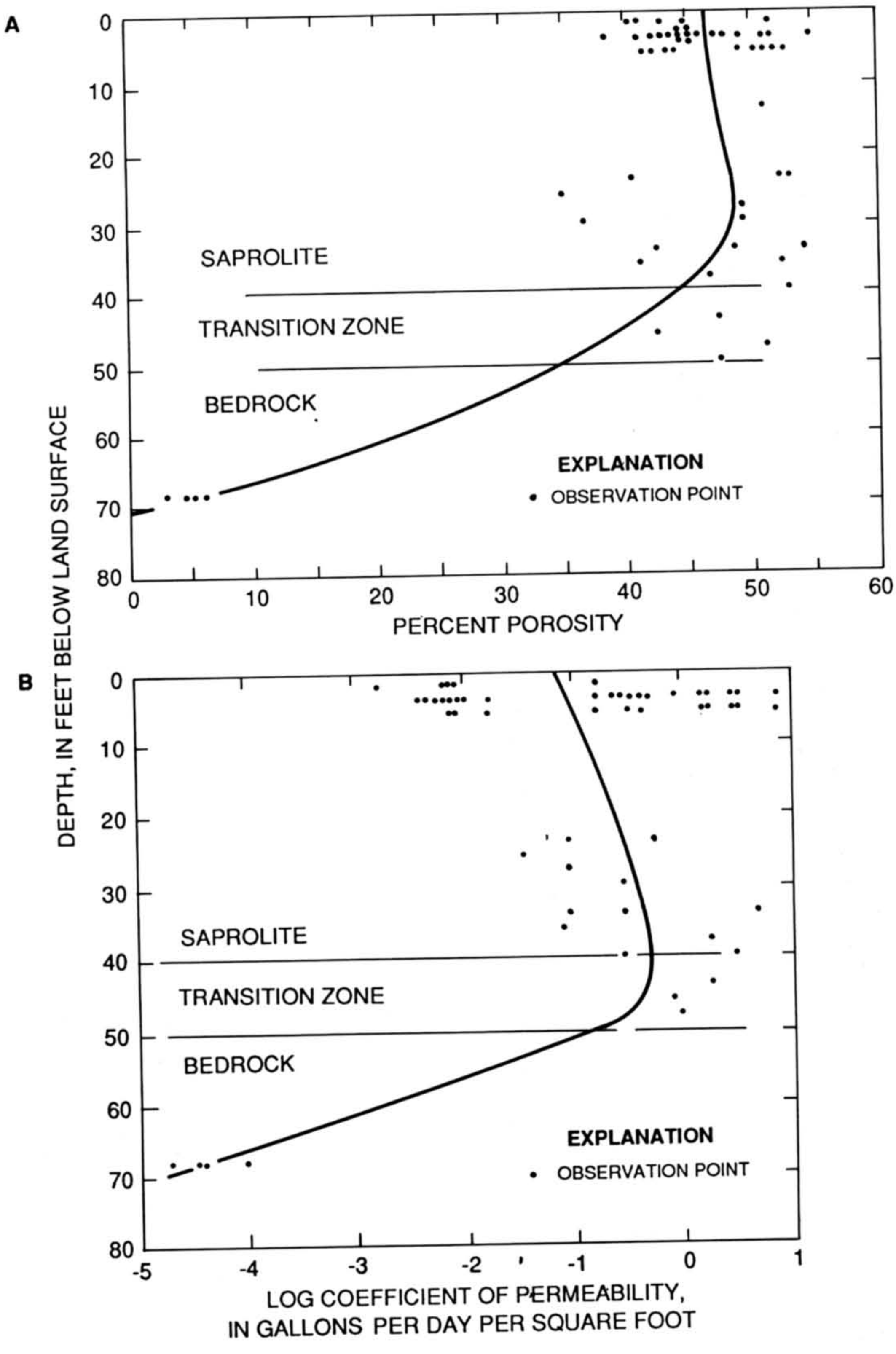

Figure 3. -- Relations between porosity, depth (A), and permeability (B) for samples from the Georgia Nuclear Laboratory area (data from Stewart, 1964, and Stewart et al., 1964).

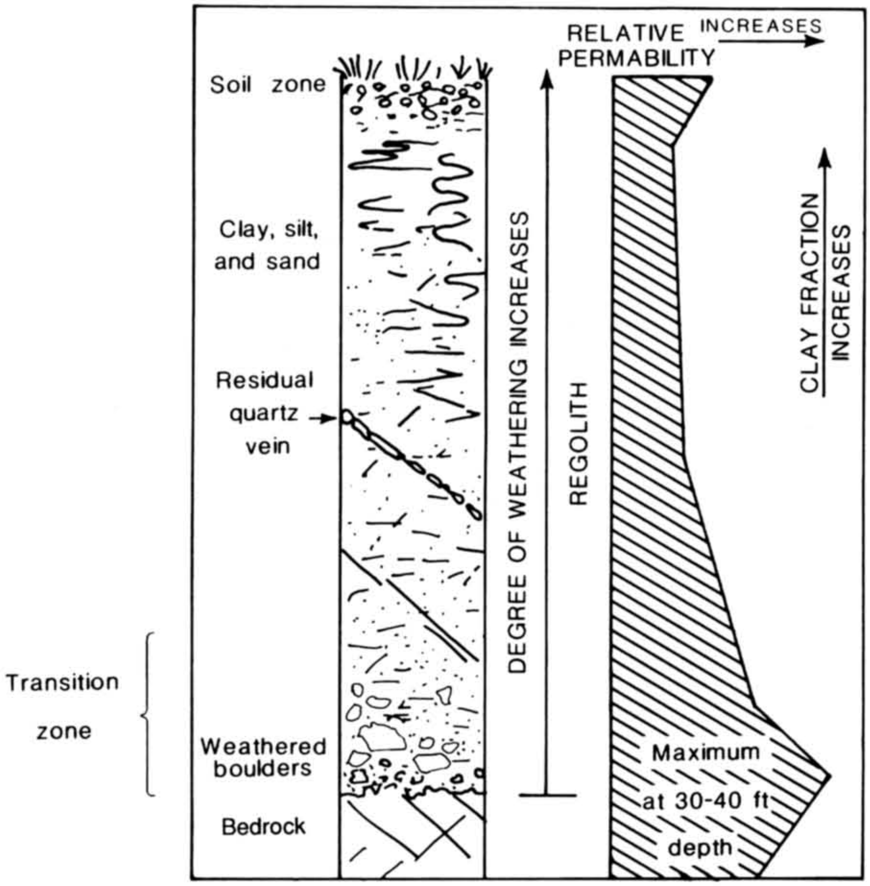

Figure 4. -- An idealized weathering profile through the regolith and relative permeability (after Nutter and Otton, 1969).

The concept of this hypothesis is shown in Figure 5. In this illustration the transition zone is shown as a conduit for landfill leachate that will eventually discharge at a local stream that is incised into the transition zone.

Figure 5 also illustrates how the thickness of the transition zone, as presented in Table 1, might be determined. The depth of the bored well, completed to auger refusal, indicates the thickness of soil and saprolite. The depth to unweathered rock, as approximated by the casing depth in the drilled well, gives the total regolith thickness. By subtracting casing depth in the bored well from casing depth in the drilled well, an estimate of the thickness of the transition zone is obtained.

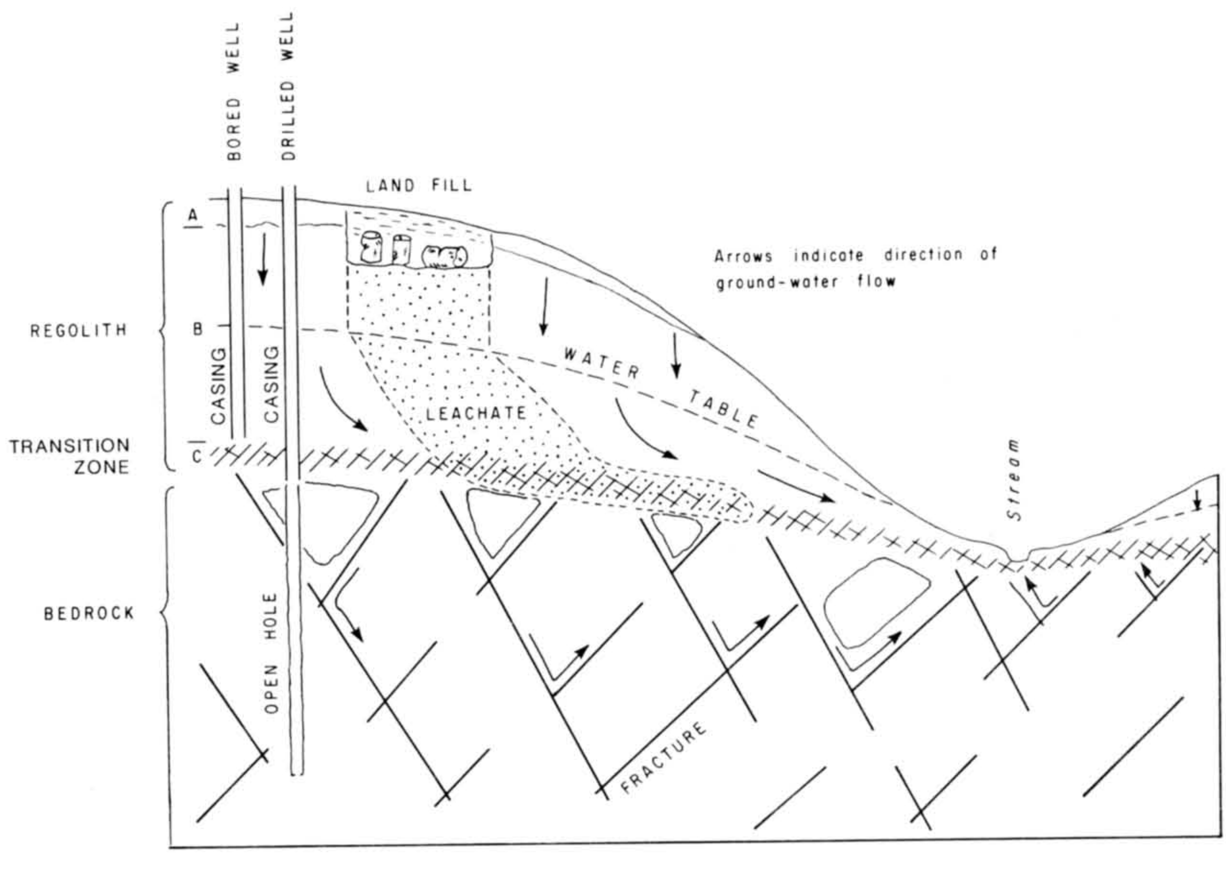

Figure 5. -- Diagram showing the transition zone between bedrock and saprolite functioning as a primary transmitter of contaminated ground water.

POTENTIAL FOR CONTAMINANT MOVEMENT IN THE TRANSITION ZONE

Some initial tests have been made of the hypothesis that the transition zone is a principal conduit for the movement of ground water and, therefore, ground-water contaminants. One of the authors (Daniel) was among the first investigators to focus on the transition zone and has done some initial test drilling, well construction, and well logging to define the characteristics of this zone.

Borehole geophysical log data were collected in June 1983 from five bedrock wells located at a test site in Guilford County, North Carolina, by Daniel and Sharpless (1983). Well depths ranged from 200 to 275 feet. The borehole geophysical data from these five wells were collected in order to refine current knowledge of subsurface geology and hydrologic parameters in the test-site area. The data collected included natural gamma-ray logs, neutron-porosity logs, temperature logs, televiewer logs, and caliper logs. Temperature logs also were collected at all five well sites in March 1985.

Well-log data collected at the test site agree with the results of other well-log studies conducted in other sections of the Piedmont (Stewart, 1962). The bulk of the material in the upper 40 and 50 feet penetrated by these wells is unconsolidated regolith. The gamma-ray logs identified clay-rich zones in the saprolite, as well as zones of feldspars and micaceous minerals in bedrock. The temperature logs were evaluated in order to (1) obtain geothermal-gradient profiles in the bedrock wells and (2) determine to what extent temperature profiles in an open borehole might delineate zones of ground-water entrance or movement. Nutter and Otton (1969) conducted a similar evaluation of temperature logs collected from wells located in the Maryland Piedmont detecting seasonal effects of temperature change on ground water in the first 60 feet below land surface.

The upper segments of temperature profile logs collected at well Gu-383 at the Greensboro-High Point test site in June 1983 and in March 1985 are shown in Figure 6. Note the pronounced cool-water temperature zone at the top of the log of June 1983. Only slight cool-water temperature deflections were detected on temperature logs collected in March 1985 (Fig. 6). Initial comparisons of recorded surface-water temperature data collected in North Carolina for the winter of 1982-83 (Gunter and others, 1984) and for the winter of 1984-85 indicate that the winter of 1982-83 may have been slightly cooler than the winter of 1984-85. The temperature profile in figure 6 may indicate that warmer water recharged the ground-water system more in 1985 than in 1983. It is interesting to note that the uppermost portions of the temperature curves (from the water surface to 20 feet) have opposite slopes. These near-surface temperature curves may be indicative of the most recent water to recharge the ground-water system. Also, temperatures below the transition zone are almost equal indicating less mixing. However, these few temperature profiles are not enough to delineate zones of ground-water movement. Additional study is needed in the Piedmont province in order to determine to what extent seasonal variations do affect ground-water temperatures and if the subsurface temperatures can provide evidence of greater flow in the transition zone than in the other zones.

One possible approach would be to run temperature logs monthly over a 1- to 2-year span at an established test site with a known regolith-bedrock profile. Another approach is to place thermocouples in key boreholes at the test site to record ground-water temperatures at various borehole depths for various time periods. These approaches might provide enough temperature-profile information to test the hypothesis that differential flow within the regolith and fractured-rock system can be detected by ground-water temperature profiles under favorable climatic conditions.

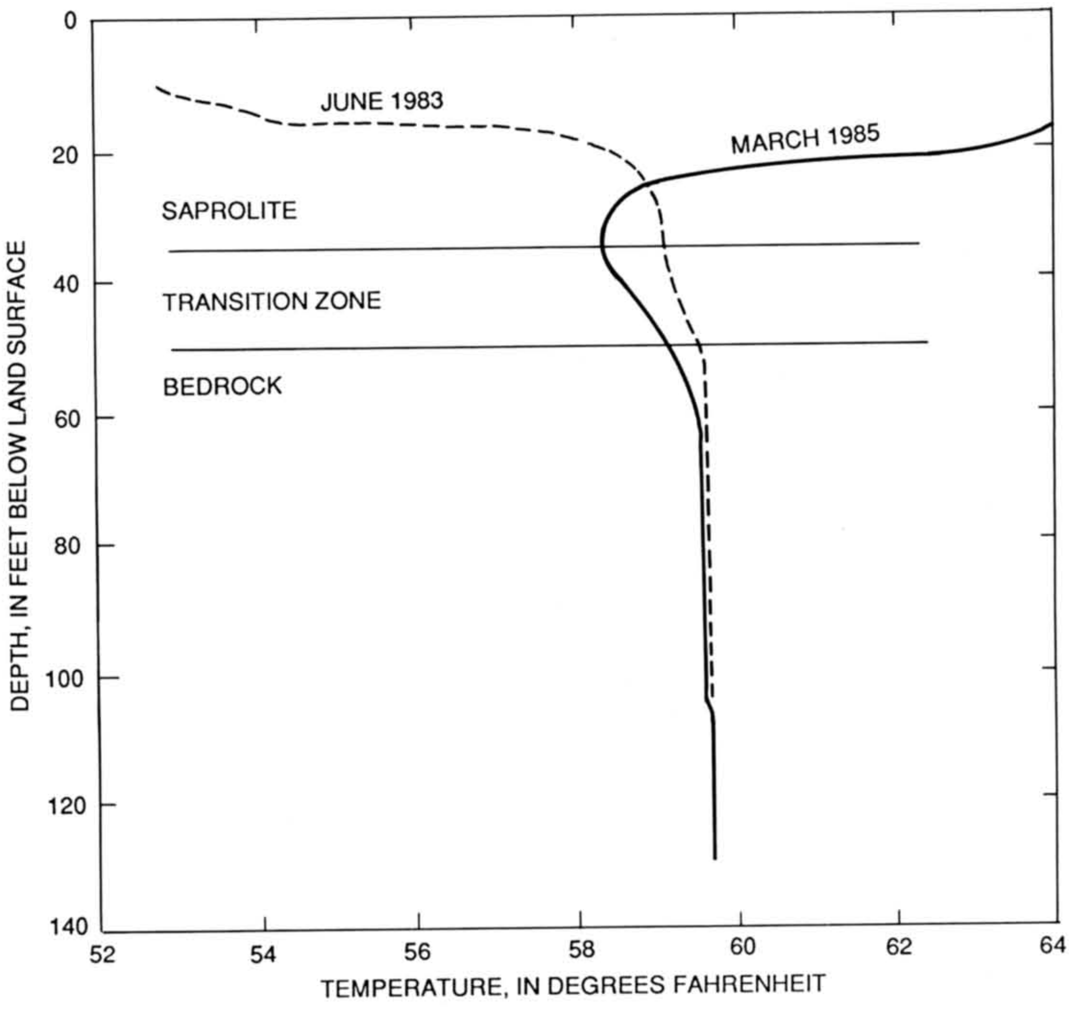

Figure 6. -- Temperature logs for well Gu-383 located at the Greensboro-High Point Regional Airport study area, June 1983 and March 1985.

CONCLUSIONS

Current understanding of the Piedmont ground-water flow system and some preliminary study results have led to formulation of the hypothesis that the transition zone serves as a high-flow zone of ground water. If the ground water is contaminated, the zone will serve as a conduit of rapid movement for that contaminated water. Further study is needed to test the hypothesis that this zone is a conduit for contamination and how the characteristics of the zone vary in different geologic settings.

Data from Stewart (1964) and Stewart and others (1964) show a high permeability transition zone in Georgia. Careful augering of wells in the Guilford County, North Carolina, test area showed a transition zone approximately 15 feet thick. Temperature logs might serve as a useful tool to provide evidence of higher flow in the transition zone than in the regolith and bedrock.

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