CONSIDERATIONS FOR THE USE OF TOPOGRAPHIC LINEAMENTS IN SITING WATER WELLS IN THE PIEDMONT AND BLUE RIDGE PHYSIOGRAPHIC PROVINCES OF GEORGIA

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Department of Natural Resources

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Topographic Lineaments - Piedmont and Blue Ridge
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INTRODUCTION

GEORGIA'S WATER RESOURCES

North Georgia is blessed with an abundance of water. Rainfall is plentiful, and the area is drained by numerous streams and rivers that arise in its mountains. North Georgia's surface water has been harnessed for power generation and stored for industrial, municipal and recreational use by the construction of dams. Modern water systems deliver ample amounts of clean water directly to our homes and places of business using a combination of reservoirs, treatment plants and water lines. In 1990, surface water use was estimated to be greater than 590 million gallons per day (Fanning et al., 1992).

In addition to its surface-water supplies, north Georgia also has large reserves of ground water which can be tapped using water wells. Ninety-six million gallons per day of ground water were used in 1990 (Fanning et al., 1992). This represents only a fraction of the ground water available for use in the region. But with north Georgia's abundant surface-water supplies, why would anyone want to use ground water in this day and age?

The reason is that the population of north Georgia is growing at a rapid rate. Population was estimated at 3,300,000 in 1985, and an increase of 1,000,000 is projected by the year 2000 (Bachtel, 1987). This growth brings increased demand for water. Surface water resources are already heavily utilized. New sources will have to be found to supply future needs. Also, the cost of developing new water supplies will have to be carefully considered. In many cases, ground water supplies can be developed at a lower per unit cost than surface water.

Some of the benefits of developing ground water supplies include a simpler permitting process, lower water treatment cost, less susceptibility to pollution, smaller capital investment, and shorter development time. In addition, ground water development leaves the land free for other uses (Heath and Giese, 1980). Although surface water will continue to supply the bulk of water needs in north Georgia, in many cases ground water will represent the best option for additional water supplies.

WHY USE GROUND WATER?

Why hasn't north Georgia's supply of ground water been more extensively utilized? Because ground water in the region has an unearned reputation for being difficult to locate in large quantities and unreliable in times of drought.

For centuries, wells have been used for water supply in north Georgia. In the past, wells were dug by hand, down to the water table. Water was brought to the surface with a rope and bucket, or by means of a hand-turned crank. And how was the site for a well chosen? The well was simply dug close to the house for the sake of convenience. Sometimes the local dowser, or "water witch," chose a site using a forked stick. Some of these shallow wells yielded enough water; some did not.

The development of technology has changed the business of drilling water wells. Modern wells in north Georgia are drilled using powerful pneumatic rigs that can drill hundreds of feet through solid rock in a single day. Electric pumps can deliver water to the surface without the need for manual labor. These deeper wells rarely go dry in times of drought. And how is the modern well site chosen? Today many well sites are still chosen for convenience, or by the local dowser. Some of these wells yield enough water; some do not.

Well sites chosen for convenience rather than for sound geological reasons often do not produce large, sustainable amounts of water. Although generally adequate for household supply, these poorly sited, low-yielding wells help to perpetuate the idea that ground water is not a viable water-supply option where large yields are required for municipal, or industrial supply. Because ground water may represent the best, or only, option for many communities and industries in some areas of north Georgia, there has been concern over how to reliably locate adequate supplies.

In recent years, hydrogeologists have focused their attention on ways to define areas in which high well yields can be expected. This has entailed studying the geologic factors which influence the occurrence of ground water in the metamorphic and igneous rocks of north Georgia in order to recognize areas where such geologic factors produce good potential for high well yields. Using features observed on the land surface, geologists are able to concentrate their search for ground water in the areas with the best potential for high yields. There are numerous examples, among geologically sited wells, of yields in excess of 100 gallons per minute (gpm) sustainable for many years (Cressler et al., 1983). Every year the volume of geologic knowledge increases, further improving the probability of scientifically locating adequate and reliable sources of ground water in north Georgia.

The Geologic Survey Branch of the Georgia Environmental Protection Division initiated a program in 1987 to study the occurrence of ground water in North Georgia and to develop methods to site high-yielding wells using geological criteria. This paper summarizes some of those findings. The following discussion focuses on the use of topographic lineaments, one type of geologic feature, to aid in siting wells.

There are a number of definitions of lineaments, but all have certain things in common. Lineaments are linear features that are visible on aerial photographs or topographic maps. They can include such features as straight segments of streams, linear valleys, linear depressions, and aligned gaps in ridges. Most lineaments are negative, or topographically low, features; although sometimes straight ridges are also called lineaments. Cultural features, such as roads, do not qualify as lineaments.

This study focused primarily on lineaments visible on topographic maps, and their use in well siting in north Georgia. Evaluation of the site-selection criteria, for over 190 well sites in 36 counties in the Piedmont and Blue Ridge Physiographic Provinces, revealed some useful observations about the use of topographic lineaments in well siting. Although far from definitive, this paper outlines some of the practical considerations, positive and negative, inherent in this method of well siting. The use of lineaments in well siting has evolved over a number of years, in a number of geologic settings around the world. Although still being refined in the Southeast, this method can be useful to those attempting to locate sites for potentially high-yielding wells.

This publication was written for those who are not trained in geology or hydrogeology, but who will, nevertheless, be called upon to make well-siting decisions. These include well drillers, water system managers, engineers, and others in industry, government and the general public who are seeking to develop ground water supplies. Although not a "how-to" manual, it introduces the concepts behind well siting in crystalline-rock aquifers, particularly with regard to the use of lineaments. It also explores some of the issues which should be considered in any well-siting decision. Finally, it offers guidelines for selecting a registered professional geologist to aid in well siting and a well drilling contractor to drill the well.

AREA OF STUDY

The study area encompasses the Piedmont and Blue Ridge Physiographic Provinces (Figure 1). These Provinces extend across the greater part of 62 Georgia counties, an area of approximately 19,500 square miles. Data were collected from numerous well sites within this region; however, no attempt could be made to provide complete or equal coverage of all 62 counties within the study area. The largest cities located within the Piedmont and Blue Ridge include Atlanta, Athens, Carrollton, Cartersville, Decatur, Douglasville, Gainesville, Griffin, LaGrange, Marietta, Newnan, Roswell, and Toccoa.

PHYSIOGRAPHY AND SURFACE DRAINAGE

In Georgia, the Piedmont and Blue Ridge Physiographic Provinces are bounded on the west by the Emerson-Great Smoky Fault. The Piedmont is a rolling upland, bounded on the south by the Fall Line and on the north by the Blue Ridge. The Blue Ridge is a rugged upland, distinguished from the Piedmont Province chiefly on the basis of its greater topographic relief.

Most of the major river systems of Georgia arise in the Piedmont and Blue Ridge Physiographic Provinces. Major rivers which drain these provinces include the Chattahoochee, Flint, Ocmulgee, and Savannah Rivers and their tributaries.

GEOLOGY

The Blue Ridge and Piedmont Physiographic Provinces are underlain by geologically complex

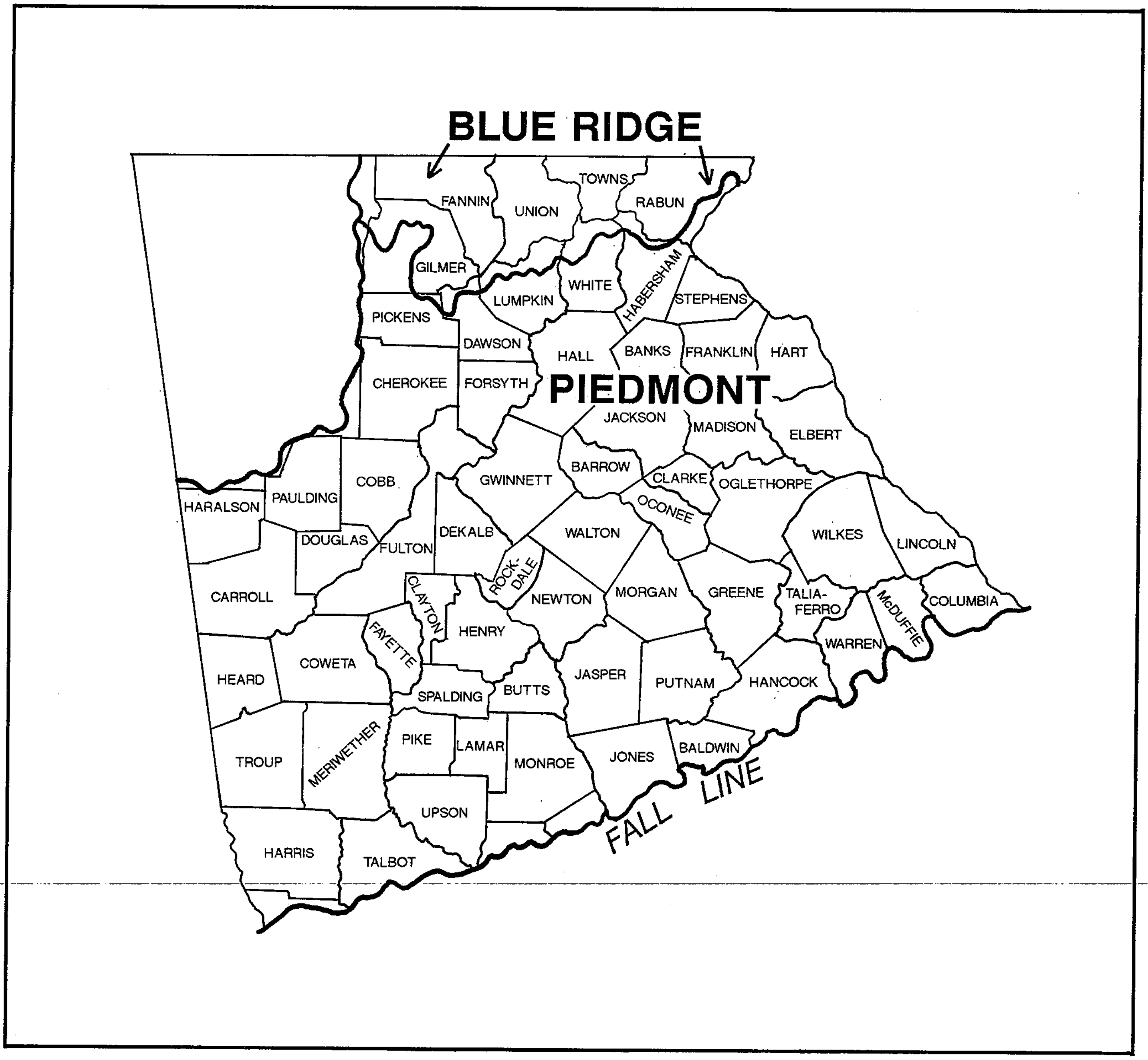


Figure 1. Location of study area showing extent of the Piedmont and Blue Ridge Physiographic Provinces.

metamorphic and igneous rocks. The most common rocks are gneisses and schists, into which igneous rocks, chiefly granite, have been intruded. Other intrusive rocks include pegmatite, and mafic and ultramafic intrusives. Thin dikes of diabase are also common and tend to cut across regional strike (Herrick and LeGrand, 1949). The rocks of the Piedmont and Blue Ridge have been extensively folded and faulted, further complicating the already complex geologic picture.

PREVIOUS WORK

In the search for ground water in north Georgia, it was recognized quite early that a relationship existed between topography and well yield. LeGrand (1967) used this relationship to develop a means of siting wells with an increased probability of large yield. He recommended a method of siting wells with regard to topographic setting combined with soil thickness. He noted that draws and valleys, combined with thick soil, produced higher yields than slopes and ridges with thin soil. By rating topographic setting and soil thickness independently, potential well sites could be ranked and compared.

Cressler et al. (1983), in a comprehensive study of ground water in the Greater Atlanta Region, described well yields as being influenced by various geologic features, some of which were expressed topographically. Among these were lithologic contacts, faults, and small-scale features such as joints, compositional layers, and foliation.

The study of lineaments as a class of topographic feature was developed by Lattman (1958), using aerial photographs. A study by Lattman and Parizek (1964) related well yield to proximity to single fracture traces and fracture trace intersections. The use of lineaments and fracture trace analysis rapidly gained acceptance as a method for identifying sites for potential high-yielding wells and has resulted in numerous other studies on the use of lineaments to locate areas where good well yields can be expected.

CRYSTALLINE-ROCK AQUIFERS

WHAT IS AN AQUIFER?

The concept of an aquifer is fundamental to the understanding of any method of well siting. An aquifer is a rock unit that stores water and transmits that water to wells. In sedimentary rock areas such as the Coastal Plain of south Georgia, rocks are formed of individual grains which have been cemented together. A great deal of pore space is left between these grains (Figure 2a). The porous nature of these rocks allows them to act much like giant sponges, taking in and storing great quantities of water in a process called recharge. Porous-rock aquifers yield the stored water easily to wells tapping the rocks.

The Piedmont and Blue Ridge Physiographic Provinces of north Georgia are composed of metamorphic and igneous, or crystalline, rocks. Most metamorphic and igneous rocks contain very little primary, or original, pore space. Weathering and fracturing, however, produce secondary openings in these rocks which allow them to store and transmit water. Thus, the deformational and weathering history of metamorphic and igneous rocks determine their properties as aquifers.

DEVELOPMENT OF CRYSTALLINE-ROCK AQUIFERS

To understand the nature of a crystalline rock aquifer, let us examine the "life history" of a crystalline rock. The earth is a dynamic place, and movements within its rocky crust result from enormous forces. When these forces act on rocks, tremendous strain results. Igneous rocks are formed when heat and pressure within the earth increase to the point at which materials of the earth's crust melt. The resulting liquid cools and crystallizes into solid rock as it comes nearer the surface of the earth. The rock textures that result are interlocking grains (Figure 2b). Metamorphic rocks are formed when sedimentary or igneous rocks are subjected to heat or pressure high enough to cause the grains of the rock to recrystallize. The resulting rocks also have a texture composed of interlocking grains (Figure 2c) and are often more dense and less porous than the original rock.

The conditions that produce crystalline rocks occur deep within the earth. Sooner or later, however, these rocks are exposed at the surface of the earth. They are pushed up and uncovered slowly through erosion of the overlying material. As these rocks approach the surface, weathering begins. Weathering is a complex series of processes which combine to cause rocks to decompose mechanically and chemically.

Mechanical weathering occurs when rocks are broken by physical forces. One type of mechanical weathering is expansion of rock due to unloading. As erosion lessens the confining pressure on rock which was once deep in the ground, the rock responds to the decrease in pressure by breaking into sheetlike layers parallel to the surface. Another important type of physical weathering is the expansion of water as it freezes. The freezing water acts as a wedge to break the rock apart.

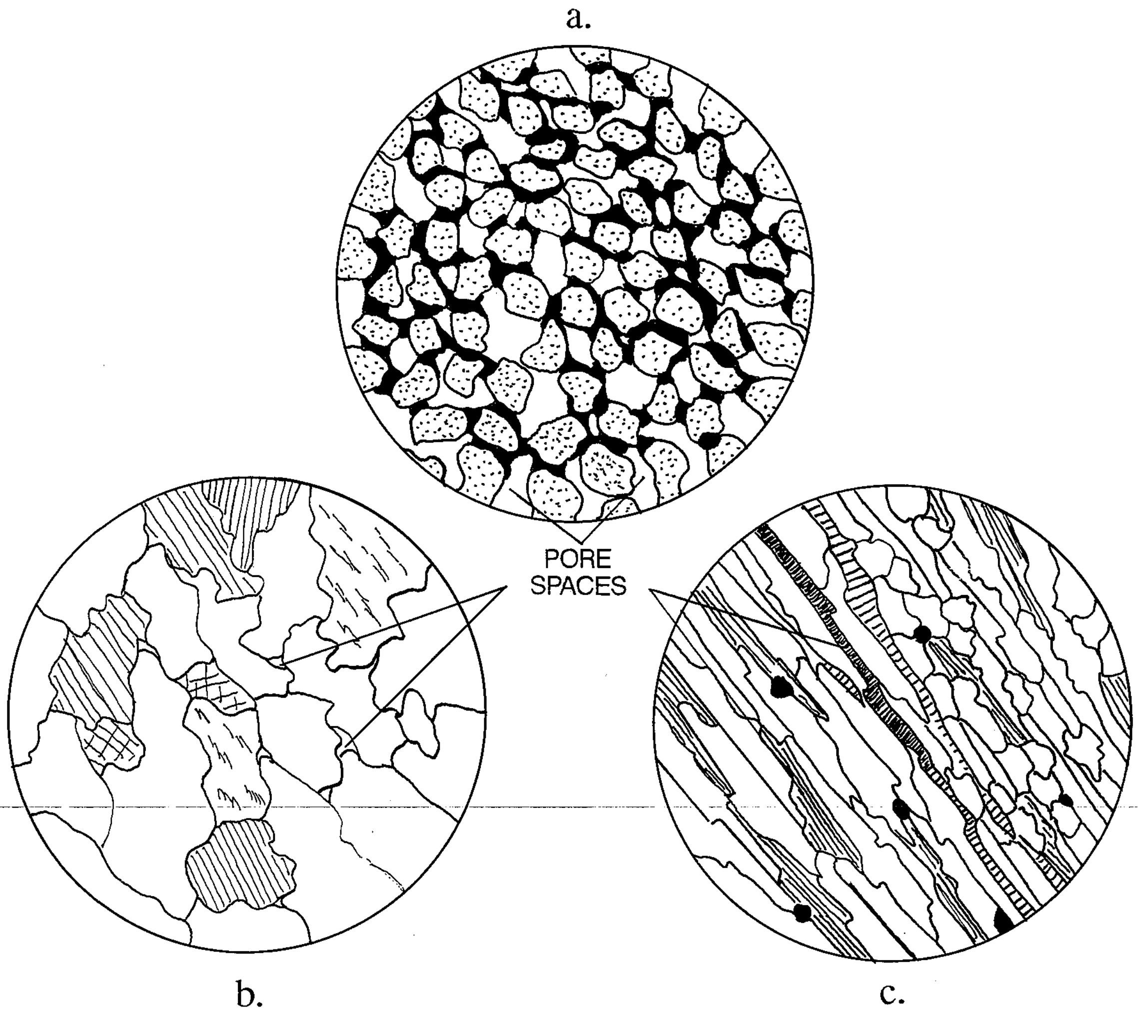


Figure 2. Representative rock textures: a. Sedimentary b. Igneous c. Metamorphic.

One type of chemical weathering occurs when rain water combines with other elements in the earth's atmosphere or in the soil to produce acids that chemically alter the rock. Chemical weathering changes the composition and texture of the rock, usually resulting in a more porous material than the original rock.

Mechanical and chemical weathering together produce soil and a mass of decayed rock called saprolite. The porous nature of soil and saprolite allows it to store water. In the Piedmont and Blue Ridge, where the rocks themselves are too dense to store significant quantities of water, the overlying soil and saprolite act as an important reservoir for ground water storage. They are, thus, a vital component of crystalline-rock aquifers. The depth and extent of this soil and saprolite reservoir determines, in large part, the amount of water a crystalline-rock aquifer will yield.

Weathering and development of saprolite generally proceed from the surface downwards. Weathering processes do not proceed uniformly in all directions, however. Many factors influence the rate of weathering, and, thus, the extent of saprolite development in any given area. Joints and faults, two types of fractures, are among these factors.

Joints are plane fractures or sets of parallel plane fractures in the rocks, along which there has been no movement. Intersecting joint sets produce angular blocks within a rock mass.

Faults are fractures along which there has been movement parallel to the break. Rocks on either side of the fault may have moved past each other horizontally or have been pushed up or dropped down relative to each other. Rocks in the vicinity of a fault may be broken or crushed.

Fractures such as joints and faults also provide paths of attack for both mechanical and chemical weathering. The more highly fractured a rock is the more surface area it presents to chemical weathering. Because of this, highly fractured areas often develop a thick layer of saprolite. The porous saprolite receives and stores water from precipitation which, in turn, allows more chemical weathering. Through progressive decomposition, weathering can also widen the openings of individual fractures.

Other types of openings in metamorphic and igneous rocks can also present opportunities for enhanced rates of chemical weathering. Metamorphic and igneous rocks may contain layers of varying mineral composition. Metamorphism can also produce a type of layering called foliation. These planar layers of varying composition present opportunities for chemical reactions. These features of the rock, along with fractures, are collectively called discontinuities.

Discontinuities are important in water well siting. They include any feature, at any scale, that interrupts the homogeneity of a rock mass. Discontinuities include variations in rock composition such as foliation, compositional layers, and lithologic contacts, as well as breaks in the rocks such as joints and faults. These features all have the potential to provide pathways for ground-water movement.

THE NATURE OF CRYSTALLINE-ROCK AQUIFERS

Crystalline-rock aquifers are a combination of a soil and saprolite reservoir that collects and stores recharge water from precipitation, and a network of discontinuities in less weathered bedrock that acts to deliver water to the well. When a well is drilled, these two components will influence the amount of water the well will yield over time. A larger soil and saprolite reservoir means that more water is potentially available to the well (Figure 3). This factor alone, however, can't guarantee a good well. A network of discontinuities intercepting the saprolite must also be present in order for the water to be delivered to the well. And, naturally, the more extensive this network is, the larger the area of saprolite reservoir the well will tap. Also, the well must intercept one or more of the individual discontinuities in this network, or there will be no pathway for water to enter the bore hole.

Thus, the areas with the greatest potential for high-yielding wells are those which are most permeable, which allow recharge and storage of ground water, and those areas which have a network of discontinuities to deliver water to the well. The difficulty in choosing such areas in metamorphic and igneous rocks of the Piedmont and Blue Ridge Physiographic Provinces is that most of the geologic factors which will determine the success of wells are covered by soil and vegetation and so are difficult to see and measure. Surface features such as topographic lineaments can provide valuable clues to the nature of the aquifer. Lineament analysis can help indicate areas with high well-yield potential when used in combination with field inspection of the local geology.

LINEAMENTS AND THEIR USE IN WELL SITING IN THE PIEDMONT AND BLUE RIDGE PHYSIOGRAPHIC PROVINCES

North Georgia is heavily wooded and possesses considerable relief developed on complexly folded and faulted metamorphic and igneous rocks. In this area, topographic lineament analysis com-

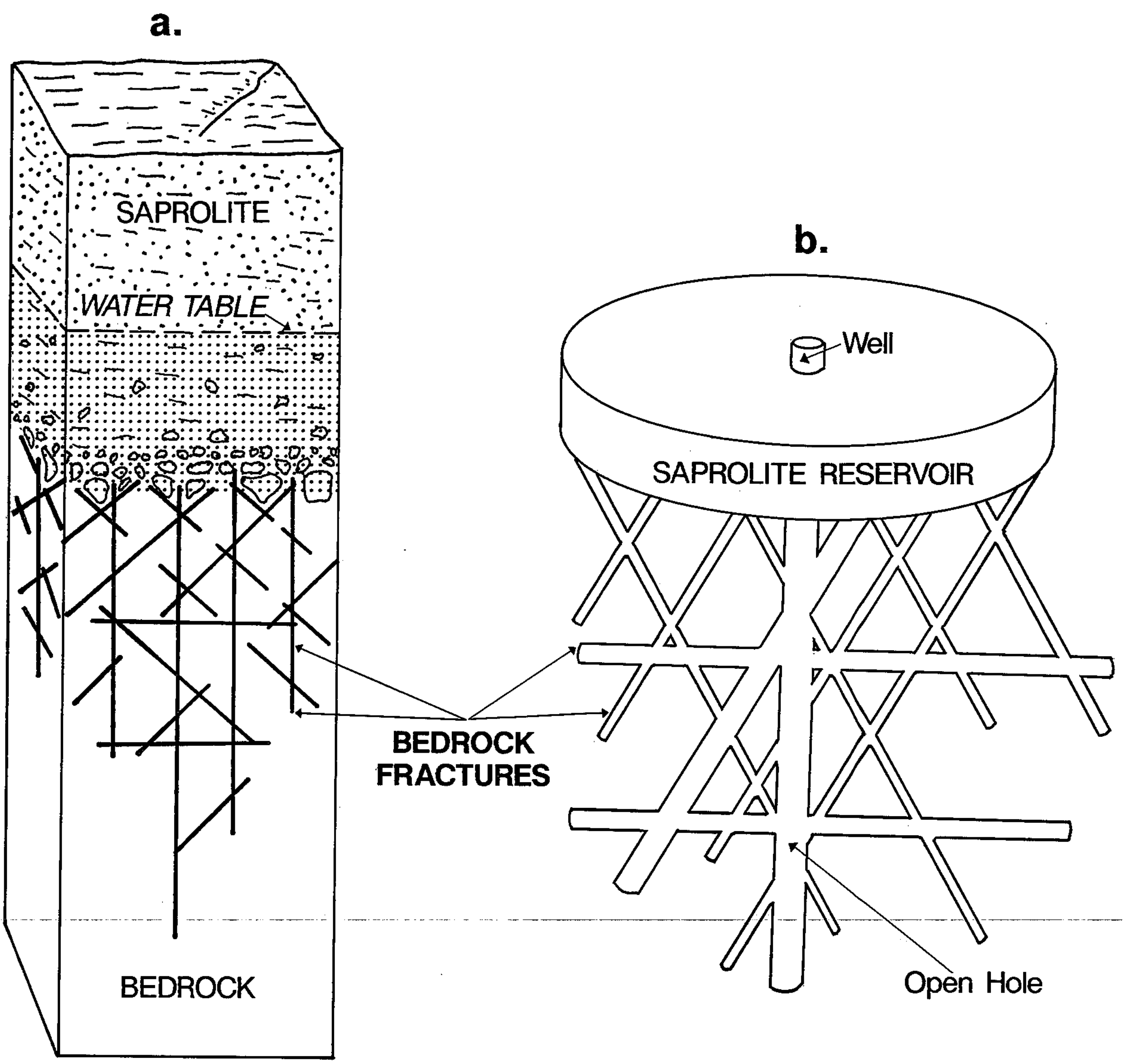


Figure 3. A typical crystalline-rock aquifer: (a) Schematic diagram showing saprolite and fracture network yielding water to a well (b). (After Heath and Giese, 1980.)

bined with geologic mapping, is a useful technique for well siting. In order to apply this technique successfully, it is necessary to learn to recognize lineaments on topographic maps and to understand the factors which control their formation.

RECOGNIZING LINEAMENTS ON TOPOGRAPHIC MAPS

Recognizing lineaments on topographic maps is not a matter of absolutes. In most cases, a lineament is evaluated by its relative appearance, that is, how it compares with other features of the surrounding topography. It should be kept in mind that learning to recognize lineaments on topographic maps is not an end in itself, but a means to focus a complete investigation.

The most common type of topographic lineament is a straight stream valley segment. All streams change direction many times over their length, but where a planar discontinuity intersects the land surface, a stream may conform to the discontinuity, resulting in a distinctly linear stream segment (Figure 4). Faults, joints, lithologic contacts, compositional layers or any other type of discontinuity can produce such straight stream segments.

Not all topographic lineaments are stream valley segments. Some lineaments will be linear valleys, or a series of aligned valleys, or aligned gaps in ridges. Breaks in slope or abrupt changes in the character of the topography may also be considered topographic lineaments. A lineament may be continuous across several topographic features. For example, a linear stream segment may be aligned with a gap in a ridge and with a linear valley across the ridge. Linear changes in natural vegetation are considered lineaments on aerial photographs, but they are not often visible on topographic maps.

Because locating wells at lineament intersections has the potential to improve well yields, recognizing these intersections on topographic maps is important. Intersections can be of two types: truncating, or "T"-shaped intersections and transcending, or "X"-shaped intersections. Well siting experience by the Georgia Geologic Survey tends to confirm that transcending intersections produce higher well yields than truncating intersections, but this observation has not been quantified.

In rare cases, there are certain cultural features visible on topographic maps which may be mistaken for lineaments. Examples include abandoned roads and channelized streams that can be mistaken for joint-controlled streams. Linear vegetational changes on topographic maps are often the result of land-clearing activity or fence lines. In most cases, inspection of the site will make clear the cultural origin of these features.

CONTROLS ON LINEAMENT FORMATION

Discontinuities

Discontinuities in rocks fall into two broad types, fractures and compositional differences. Many linear features in the Piedmont are caused by steeply dipping fractures in the rock, such as joints and fault zones. Other causes include differential weathering along lithologic contacts, tilted layers of varying composition, and foliation produced by metamorphism. All of these are discussed below.

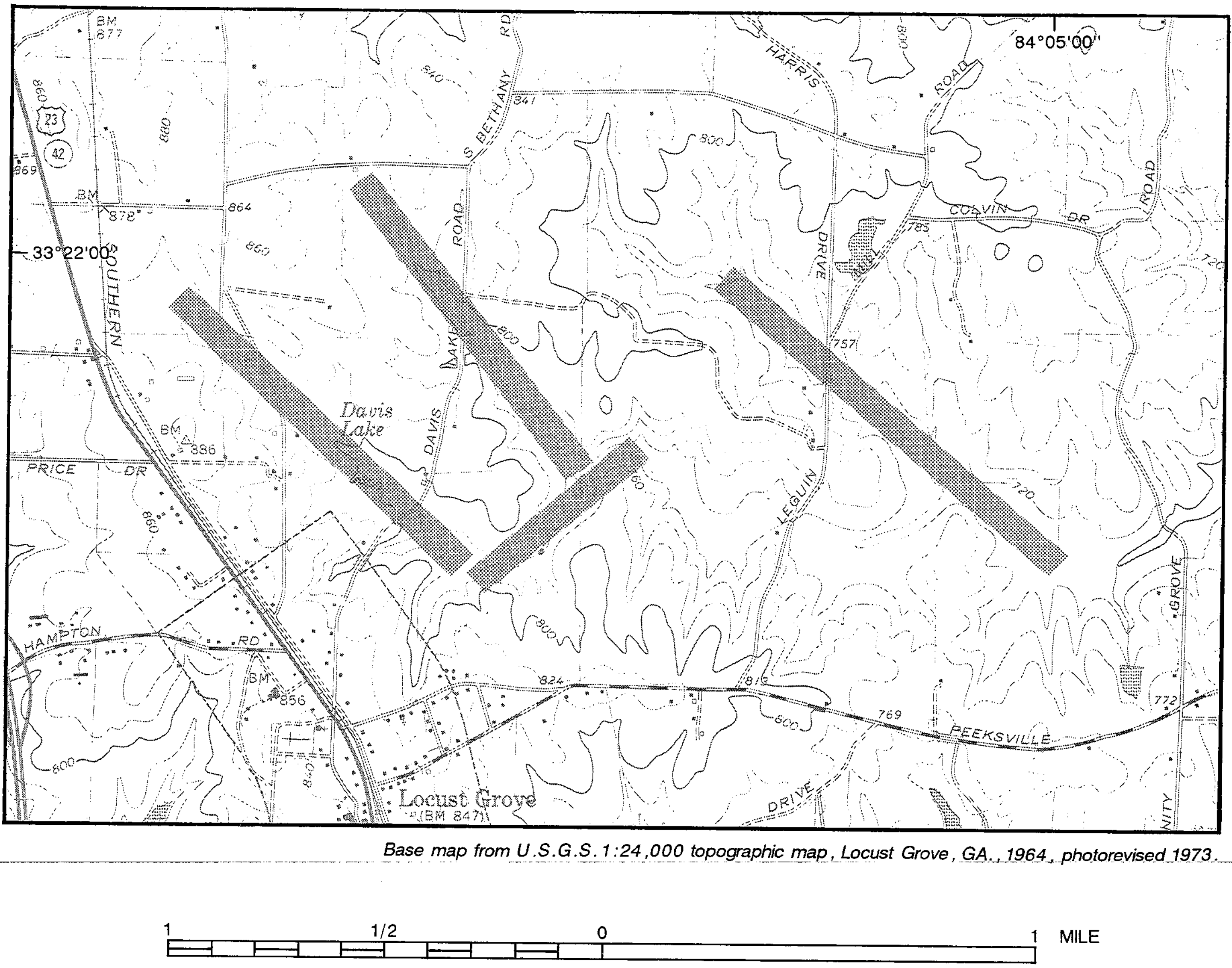
Joints

Joints are the most common type of fracture seen in rocks (Lahee, 1961). They are produced when rocks are subjected to compression, tension, or torsion. These stresses can be accompanied by emplacement of igneous rock masses, and are a part of the same processes which produce folding and faulting of rocks. Although intrusive igneous rocks can contain joints, well-developed jointing is more common in layered rocks (Figure 5).

The importance of joints in the development of topography is stated by Lahee (1961, p. 282). "In promoting erosion they [joints] are of the utmost importance, for they serve as channels for decomposition, they facilitate the wedge action of ice in disintegration...and they invite concentrated attack by abrasive agents." He further states that "...it has been demonstrated that the pattern of drainage and topography in a region often reveals a marked dependence upon the existing fracture systems."

Joints are produced in sets, all the joints in one set having approximately the same orientation. Sometimes a series, or set, of lineaments is developed on a joint set, all the lineaments having similar orientations. Because joints are so numerous and tend to be concentrated in a given area, it is common to see linear stream segments or linear valleys developed on an area of concentrated jointing. These areas may produce very high well yields because intensified weathering may produce a thick layer of soil and saprolite which will store water, and the joints provide a network of discontinuities to channel the water to wells.

Intersecting joint sets are often perpendicular to one another. Angular relationships between two or more lineaments or sets of lineaments, such as abrupt changes in the courses of streams, suggest joint control. Lahee (1961, p. 282) states that "...the elbow turns in many young streams are not



Base map from U.S.G.S. 1:24,000 topographic map, Locust Grove, GA., 1964, photorevised 1973.

CONTOUR INTERVAL 20 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 4. Representative straight stream valley segments. A Locust Grove municipal well located on the NE-trending segment yielded 180 gpm (air lift yield). Locust Grove topographic quadrangle.

Figure 5. Well-developed jointing in schist, Fulton County, Georgia.

infrequently due to a shift of the current from one joint set to another." Other causes could include a shift from a joint set to any other planar feature, such as compositional layering or lithologic contacts.

Faults

Abrupt offsets of drainages and streams, or abrupt changes in linear topography can sometimes indicate the presence of a fault (Cressler et al. 1983). But, although they typically contain broken rock, faults do not always produce lineaments, or result in increased well yields. The heat and pressure generated along a fault can produce rocks that are more dense and more resistant to weathering than the original rocks. In some cases, however, rocks of very different weathering characteristics are brought together along a fault, and enhanced weathering of the less resistant rock occurs. In such cases, weathering of the less resistant rock may produce a linear valley or depression along the trend of the fault, or there may be a change in the character of the topography across the fault. Faults that juxtapose different rock types may result in differential weathering, thus producing areas of enhanced permeability with good well-yield potential.

Lithologic Contacts

A lithologic contact is the surface between two contiguous rock masses of different lithologic character (Lahee, 1961). The two contiguous rock types often have very different physical and chemical characteristics, and these contacts can be areas of enhanced chemical weathering. In such cases, lithologic contact zones may be represented on the land surface by linear topographic depressions or linear changes in slope or topography (Figure 6). Wells drilled into the zone of enhanced weathering along the contact may produce higher well yields than those drilled into either of the less weathered rocks even a short distance from the contact.

The contact between a sheared gneiss and a garnet-feldspar-quartz-muscovite schist in Carroll County illustrates enhanced weathering and higher well yield, along a lithologic contact. The contact is visible on the topographic map as a linear stream valley, with a marked difference in the character of the topography on either side (Figure 7). The gneiss, on the northwest side of the valley, is massive and resists weathering, which produces rolling topography with rounded hills and pavement outcrops. There are few records of successful wells drilled in the gneiss. The schist, on the southeast side of the valley, is both layered and jointed, and it weathers more deeply. Topography developed on the schist is characterized by linear valleys. Outcrops for the most part are confined to road cuts and stream valleys. Wells completed in the schist are adequate for household supply. But one well near the contact, sited using geologic criteria, yielded in excess of 100 gpm (Crawford, personal communication).

Compositional Layering and Foliation

Although they are produced in different ways, compositional layering and foliation have similar effects on the weathering characteristics of rocks. Because these discontinuities are layers of varying mineral composition, they provide avenues for chemical weathering to proceed more rapidly in the less resistant layers (Figure 8). Compositional layering and foliation can be areally extensive and may produce large weathered zones with considerable potential for high yielding wells. However, the scale of such discontinuities is not large enough to produce topographic lineaments.

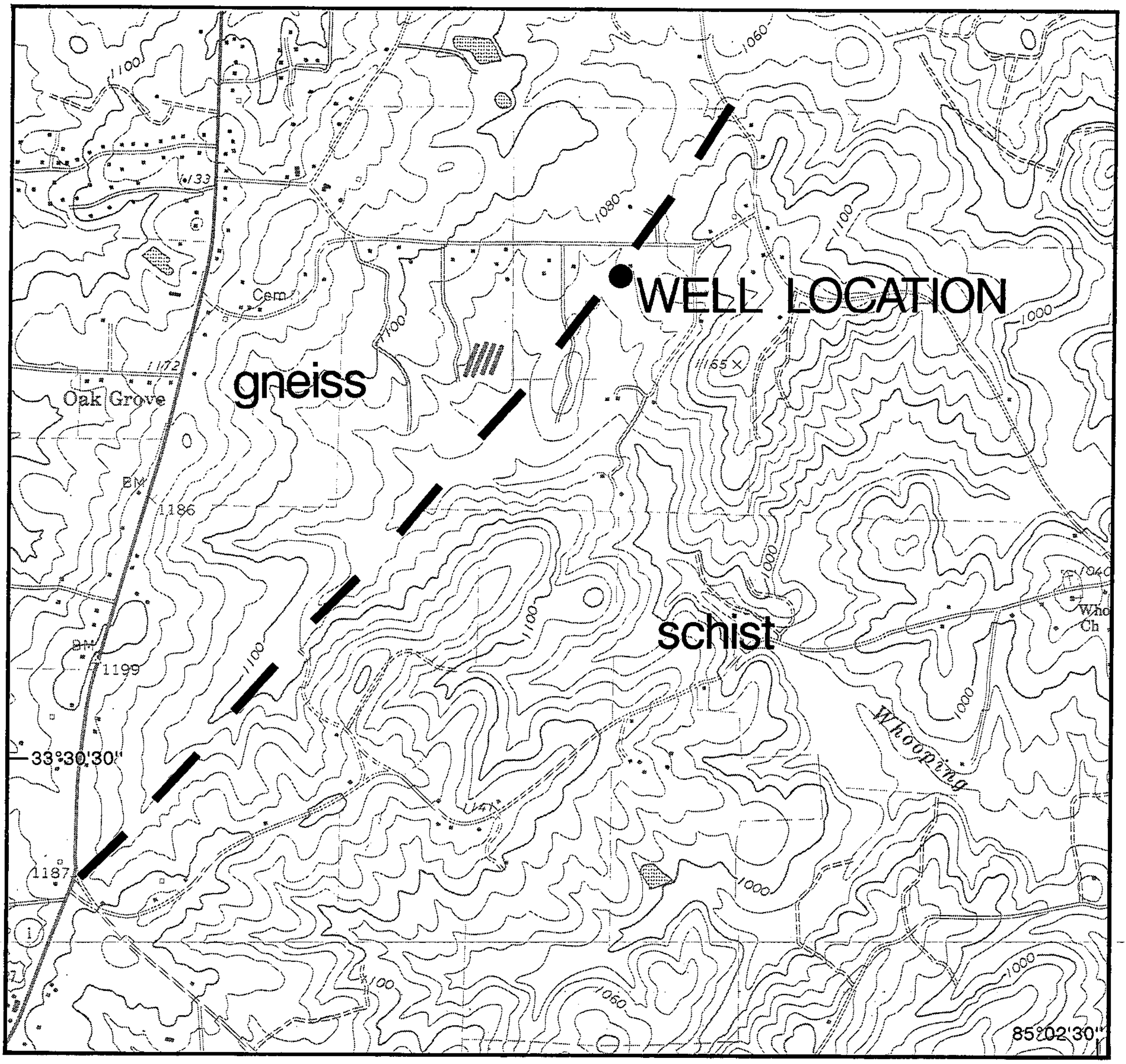
Rock Type

Rock type exerts a fundamental control on the development of topographic lineaments. First, it affects the probability that rocks will be layered or jointed, two factors that favor lineament development. Second, rock type determines the relative degree of weathering that the rocks will undergo.

Massive crystalline rocks, such as granite, produce fewer topographic lineaments than layered rocks. Massive rocks contain few discontinuities along which differential weathering can occur to produce lineaments. This is illustrated by studies of drainage patterns in massive igneous rocks. These rocks usually exhibit a dendritic drainage pattern, in which stream valleys have a randomly branched pattern (Figure 9a). The dendritic drainage pattern occurs in areas where structural control, such as jointing, faulting or inclined layering, is not well developed (Lahee, 1961). The dendritic drainage pattern common in massive rocks can be contrasted with that of jointed and foliated rocks such as schists, which tend to exhibit a rectangular drainage pattern (Figure 9b). This drainage pattern contains many topographic lineaments. Where stream courses are influenced by the regular patterns of jointing and/or layering that are common in these rocks, streams follow a few preferred orientations making obvious lineaments.

In the Piedmont and Blue Ridge Physiographic Provinces, the juxtaposition of numerous rock types often produces a complex drainage pattern which combines elements of several different drainage patterns. The development of lineaments in such areas, while influenced by rock type, is not

Figure 6. View across a linear topographic depression formed along the contact between a sheared gneiss and a garnet-feldspar-quartz-muscovite schist in Carroll County, Georgia.



Base map from U.S.G.S. 1:24,000 topographic map, Carrollton, GA., 1973, photorevised 1982.

1 1/2 0 1 MILE

CONTOUR INTERVAL 20 FEET

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Figure 7. A straight stream valley segment developed at the contact (dashed line) between a sheared gneiss and a garnet-feldspar-quartz-muscovite-schist. A well sited on this contact by T.J.Crawford yielded over 100 gpm. (Carrollton,GA topographic quadrangle)

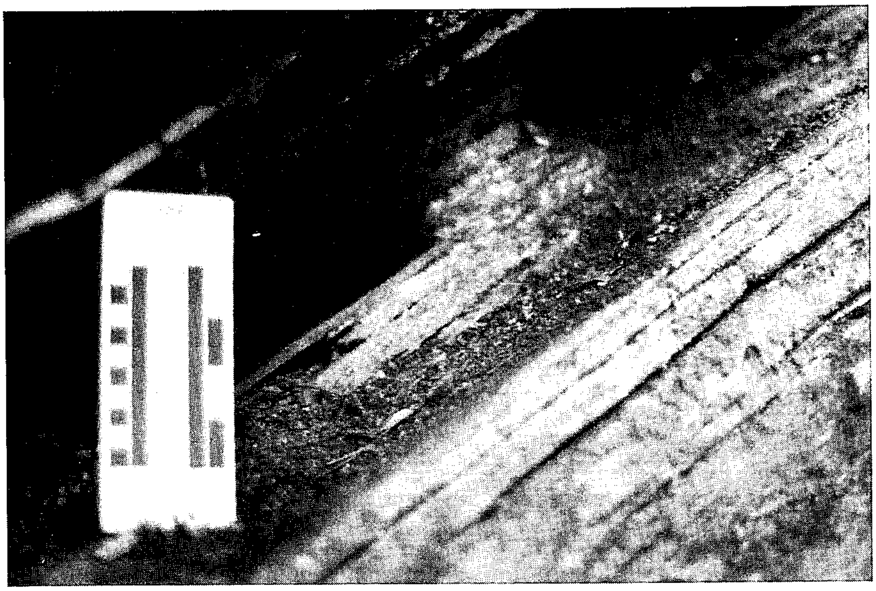
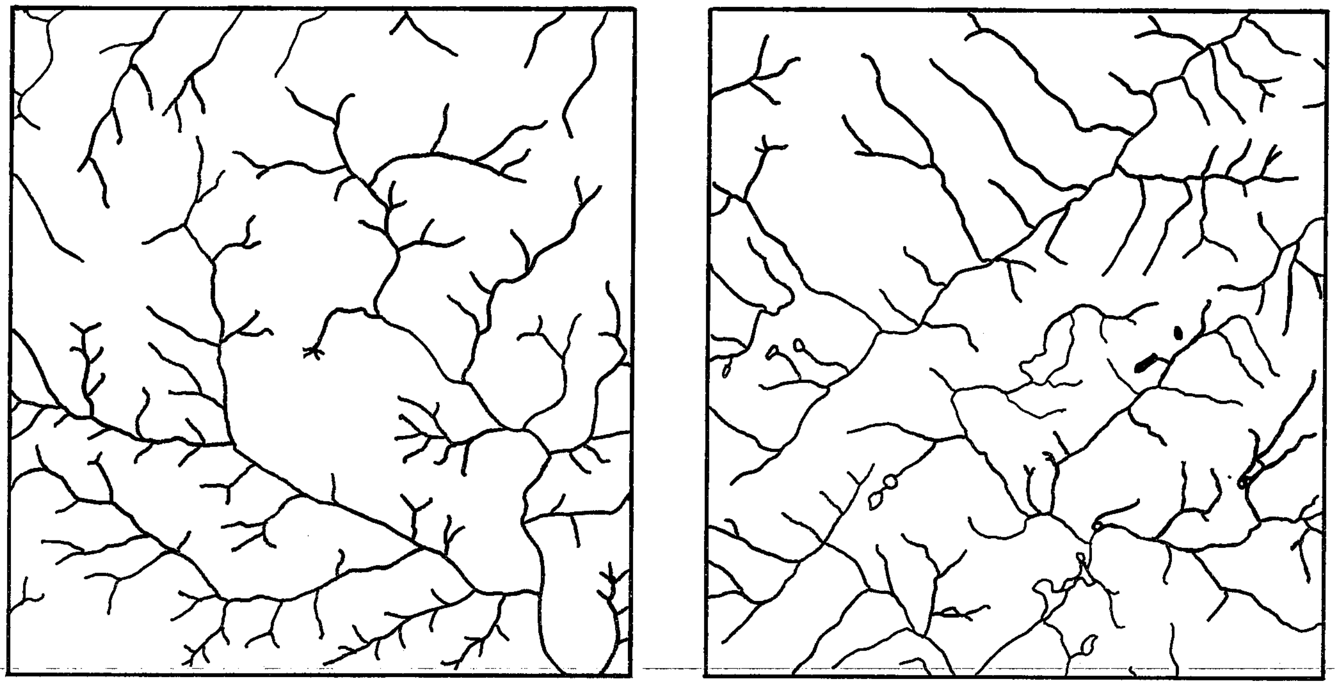


Figure 8. Differential weathering along compositional layering in schist, Fulton County, Georgia. The pedestal in the center of the photo is all that remains of the non-resistant layer.



a. b.

Figure 9. Drainage styles: a. Dendritic b. Rectangular.

straight forward.

Another way in which rock type affects the development of lineaments is through their varying susceptibility to weathering. Differential weathering occurs where adjacent rocks of different chemical composition and physical characteristics are exposed at the surface. Negative lineaments can form along the units which weather more readily than the surrounding rocks.

WELL SITING USING TOPOGRAPHIC LINEAMENTS

Many lineaments, such as the Warwoman Lineament in Rabun County, Georgia, are of such large scale that they are immediately visible even on satellite imagery. Others are so small or subtle that they can be verified only by field inspection. The prominence of lineaments on a topographic map is only one factor to consider when evaluating the well-yield potential of an area. One must also consider the size of the area from which a well derives its water, known as the recharge area, and the origin of the lineament.

In the Piedmont and Blue Ridge Physiographic Provinces, the size of recharge areas is highly variable. The recharge area includes all the soil and saprolite that supply ground water to a well via a network of discontinuities. The recharge area may extend only a few hundred feet from the well, in the case of very low-yielding wells. In areas with a sizeable network of discontinuities, the recharge area may include soil and saprolite hundreds to thousands of feet from the well.

In order to evaluate the size of the recharge area, the relationship of the lineament with a prominent discontinuity such as a well-developed joint set or a lithologic contact should be established. The area around the lineament should be geologically mapped to provide data on the orientation of such discontinuities. This is to insure that the linear feature seen on the topographic map is really the result of a geologic structure. When examining stream valley lineaments, for example, one should verify that the valley orientation is structurally controlled by measuring the orientations of nearby discontinuities and comparing them with the orientation of the stream valley segment (Figure 10). Recharge areas are usually identified by low-lying topography developed on deeply weathered rocks. Often such deeply weathered areas are near streams or drainages, with few, if any, outcrops. It is important to have enough structural data to allow interpolation across the area without outcrops.

Outcrops can provide other information important in selecting well sites. Information regarding the movement of water can be obtained from observing the spacing, persistence, and openness of joint sets. Spacing refers to the distance between joints; persistence describes the relative surface area of the individual fractures. Closely spaced, persistent joints will allow the movement of more water than widely spaced joints of limited extent. Joints which are open will allow the movement of more water than those which are closed. Staining on joint surfaces or weathering of the joint surfaces may indicate joint sets which have the potential to be water bearing. Any of these factors may influence a decision on well site selection.

Once a general area has been identified as a candidate well site, certain factors can be used to help maximize well yield. Identifying a topographic lineament and drilling in the center of it is not enough, although this technique is probably better than drilling at random.

The orientation of the discontinuities in the subsurface should be kept in mind when siting wells. Because the discontinuities control the direction of ground-water flow, wells should be sited in such a way that the discontinuities direct water towards, not away from, the well (Figure 11). Further, The inclination of the discontinuities will affect decisions concerning the depth of the well.

Stream valleys also direct surface water downwards from the valley's head and inward from its walls. For this reason the most water will be available to wells which are located near the center of valleys, close to the valley floor (Figure 12).

WATER QUALITY ISSUES

The overall quality of ground water in north Georgia is quite good; however, there are two major factors which can adversely affect the quality of ground water. One is the type of rock and degree of weathering, and the other is man-made pollution within the recharge area of the well.

Rocks in the Piedmont and Blue Ridge Physiographic Provinces can yield natural concentrations of iron, sulfate or manganese high enough to be objectionable. It is not always possible to determine before a well is drilled whether the water will contain high levels of these constituents. Information on the quality of water from other wells in the area is helpful. A Georgia registered professional geologist (P.G.) with well-siting experience in the area should be able to offer advice on avoiding potential water quality problems.

An important part of selecting a potential well site is assessing the possibility of man-made pollution. A careful examination of the surrounding

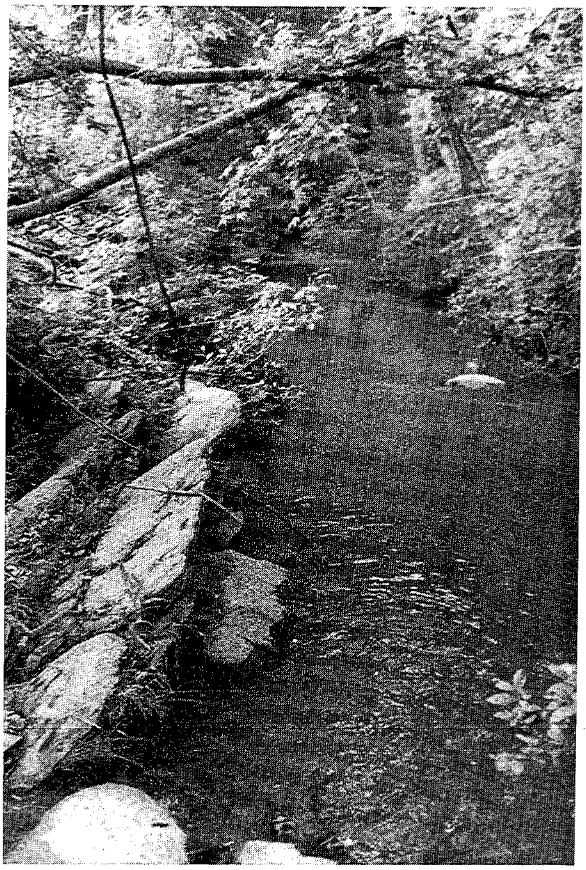


Figure 10. A structurally controlled stream segment, Lamar County, Georgia. The stream flows parallel to the joint set visible at lower left, and subparallel to the strike of the foliation.

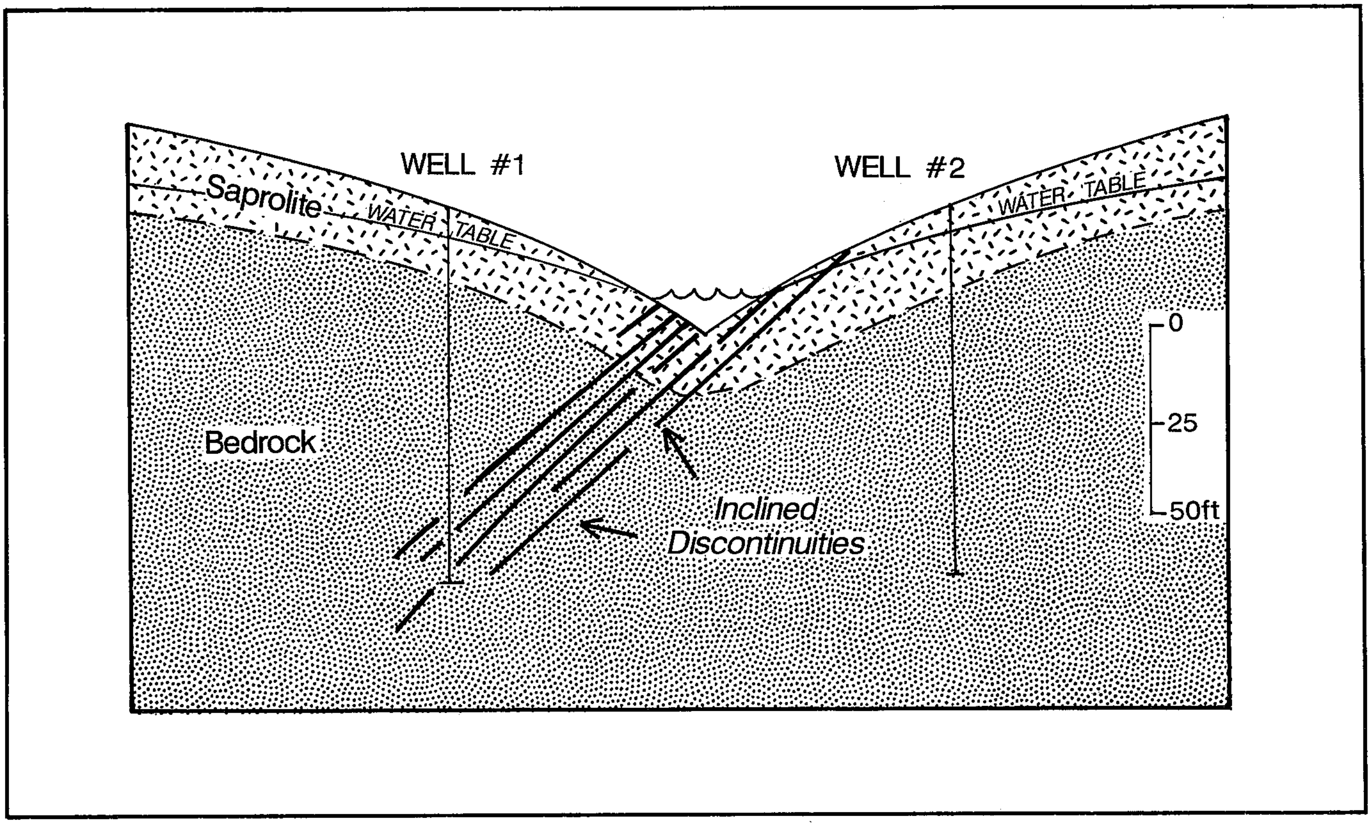


Figure 11. Placement of wells with respect to discontinuities. Well 1 intercepts discontinuities at approximately 100 ft depth. Well 2 does not intercept discontinuities.

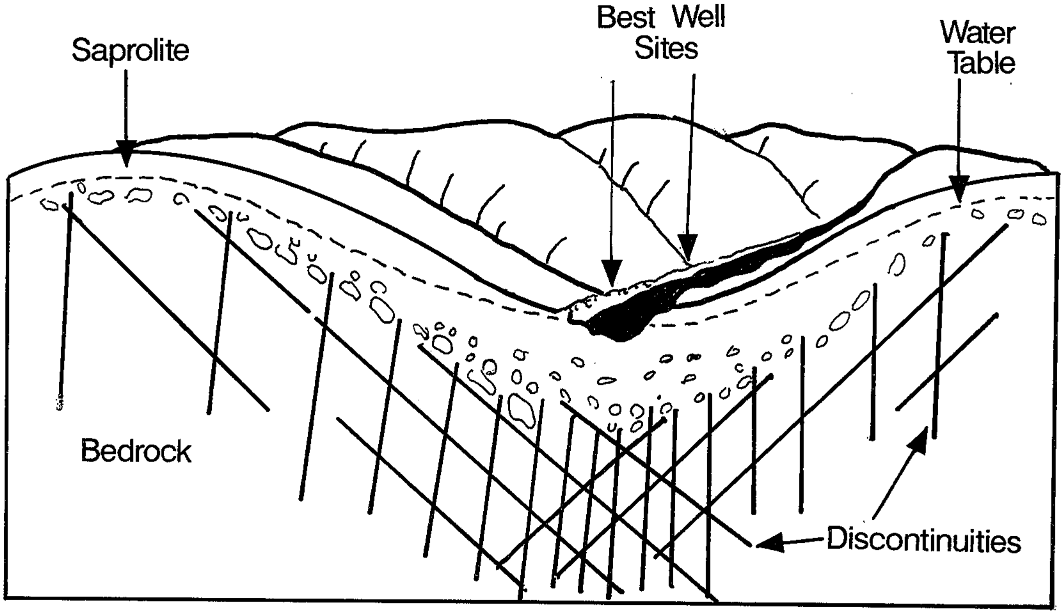


Figure 12. Proper well placement for maximum yield within a drainage basin. After Heath and Giese, 1980.

area should be made in order to discover whether activities such as farming, waste disposal, or industry are likely to contribute pollutants to the ground water. It is often helpful to speak with long-time residents of the area who may remember past activities of which there is no longer any obvious evidence.

The future quality of ground water should also be considered. In addition to steps taken to site wells away from present sources of pollution, it will be necessary to safeguard the vicinity of new wells from potential pollution.

PRACTICAL CONSIDERATIONS FOR WELL SITING USING LINEAMENTS

Locating wells in the vicinity of topographic lineaments has been shown empirically to improve well yields. Although lineament analysis cannot predict the actual yield of a well, it can be a valuable means to reduce the risk of drilling a low-yielding well. One researcher has described the risk of a dry hole as 1 chance in 4 for randomly located wells, and 1 in 72 for wells located on fractures or lineaments (Snipes, 1981). There is some evidence that wells sited on the intersections of fractures produce higher yields than those located on single fractures (Schmitt, 1988). Intersecting lineaments are indicative of these intersecting fractures.

Lineament analysis is a useful tool for locating high-yielding wells. It has become increasingly popular as a means for choosing well sites. It should be noted, however, that there are some drawbacks to relying exclusively on these techniques when siting wells.

Lineament analysis can indirectly indicate geologic characteristics which favor high well yield. However, many potentially high-yielding well sites will be overlooked or misinterpreted by relying on lineament analysis alone. For example, lineament analysis will give no indications of horizontal stress-relief fractures of the type documented by Cressler et al. (1983), or distinguish rock types whose weathering characteristics produce higher-than-average well yields. Additionally, simple proximity to lineaments does not assure the maximum well yield. For instance, in many cases, drilling slightly to one side or the other of a lineament can produce very different well yields, depending, in part, on the direction in which the discontinuities are inclined. Knowledge of the detailed geology of the well site is critical for gaining the maximum benefit from the use of lineaments in well siting.

Lineaments analysis does not address water quality issues. The chemical and mineral composition of a rock can adversely affect the quality of the water that it produces. Common water-quality problems in igneous and metamorphic rocks include high natural concentrations of iron, sulfate and manganese. Inspection of the rocks in the vicinity of the proposed wells can screen out potential well sites where water quality may be of concern.

USE OF WELL-SITING PROFESSIONALS

The drilling of a water well requires a certain amount of expense and risk. The best way to reduce this risk, and perhaps the overall cost, is to seek qualified professional assistance in selecting and drilling a well site.

The services of a Georgia registered professional geologist, one who has experience in locating well sites in your area, can be an excellent investment, particularly where large well yields are required. A qualified professional geologist will take into account all the pertinent geologic factors in order to obtain the highest and most reliable well yield.

Should you decide to hire a professional, it is important to assess their experience and success in locating wells in your area. The geologist should have a knowledge of the local geology. All the factors mentioned in this paper should be taken into consideration, including topography, local drainage patterns, rock types, depth of weathering, geologic structure, and all discontinuities. In addition, a professional geologist will take care to choose well sites that are not located near potential sources of contamination.

Once the well sites have been selected, the geologist will mark the sites using a stake or other marker. It is very important that all parties involved, including the well drilling contractor, realize that the well must be drilled at the point specified. In cases where well sites are chosen to intercept a specific discontinuity, even a few feet one way or the other can adversely affect well yield.

It is preferable that the geologist be available for advice during the drilling of the well. The professional geologist that you choose should have an understanding of drilling techniques and a good rapport with your well driller. Most registered geologists who specialize in well siting maintain professional relationships with one or more licensed well drilling contractors.

The geologist should be able to inform the driller about the drilling conditions he is likely to encounter and be ready to advise on the best drilling method for the area. The well driller should have confidence in the ability of the geologist to make decisions regarding the progress of drilling, setting of casing, and whether it may (or may not) be necessary to abandon the hole. Unless the geologist is knowledgeable and has the confidence of the well driller, the best well sites may be abandoned before high-yielding zones are reached. Conversely, the geologist should know when to save the client money by curtailing drilling at a site that proves to have less potential than expected.

It is well to note that all geologists offering professional services to the public in Georgia must hold a professional geologist's license issued by the state of Georgia. In a like manner, all water well contractors must hold a valid State license and must construct all wells in accordance with the provisions of the Georgia Water Well Standards Act.

COST CONSIDERATIONS

When deciding whether to develop ground water or surface water to meet the needs of a community or industry, one of the most important factors to consider is cost. There are many components to the total cost of a water system, and they differ depending on which resource is utilized. When considering ground water as a source of water supply, the following should be taken into account. Professional assistance in selecting drilling sites can be viewed as a one-time expenditure which may ultimately eliminate costly mistakes. It represents a good investment in risk reduction. A low-yielding well costs just as much to drill as a high-yielding well, often more. High-yielding wells cost less on a per-gallon-obtained basis than do low-yielding wells. The cost of a professional geologist's assistance should be more than offset by paying for fewer feet of hole per gallon of yield. Even though some well sites will cost more to drill than others, the difference in cost between them may be minimal when compared to the difference in yield.

Most individual homeowners and businesses developing ground water supplies will be restricted to well sites on their own property. Industries and local governments requiring large well yields, however, may find it necessary to look beyond their own property in order to obtain the needed amount of water. Obtaining legal access to the property on which the well site is located may entail buying or leasing of property. In many cases rights-of-way must also be considered. It may be necessary to obtain easements from adjacent property owners for physical access to the site or for the construction of water or power lines to the site.

Physical access to the drilling site may require the removal of trees and undergrowth, heavy equipment rental, and in some cases, road construction. Often the well sites with the most potential are the most difficult to access. Difficulty of access, and the attendant expense, must be weighed against the yield potential of the well, and the possibility of a "dry hole" in a more easily reached site. Even if some unsuccessful wells are drilled during ground-water development, the overall cost of a surface-water system may far outweigh that of a ground-water system.

Well construction represents a considerable part of the cost of developing a ground water supply. When choosing a licensed well-drilling contractor, cost-per-foot should not be the only consideration. A well-drilling contractor with considerable experience in your particular area, and one who is willing to rely on the recommendation of professional geologists when choosing a well site, may be a bargain at a somewhat higher price than competitors who are not experienced in the area or are less willing to accept advice.

Other expenses include a suitable pump, the cost of water lines, and the cost of getting power to the well site. A well house is usually constructed for security. Testing for both water quality and well capacity are additional expenses.

The cost of water treatment must also be considered. In many cases, ground water quality is such that it may be used for virtually any purpose with little or no treatment. The cost advantages of such a situation are obvious. In some areas, however, higher-than-normal concentrations of such natural substances as iron or sulfate require treatment. Man-made pollutants can also find their way into ground water and require treatment.

Usually, several wells are required to supply the needs of a community or industry. However, it may be feasible to add wells to a system only as they are needed. In this way, ground water can supply the growing water needs of a community without a large up-front investment.

Potential water users are reminded that a ground-water withdrawal permit is required to withdraw more than 100,000 gallons or more of water per day. Wells used for community water supplies must also have a permit and must meet standards set by the Georgia Safe Drinking Water Act. Water use and drinking water permits are issued by the Water Resources Management Branch of the Environmental Protection Division of the Georgia Department of Natural Resources in Atlanta.

SUMMARY

Aquifers in the Piedmont and Blue Ridge Physiographic Provinces are complex systems composed of a subsurface reservoir of porous soil and saprolite overlying a network of discontinuities in relatively non-porous metamorphic and igneous rocks. Discontinuities in the rocks serve to channel water from the overlying soil/saprolite reservoir to water wells which intercept the discontinuities. Obtaining large well yields in the Piedmont/Blue Ridge depends on selecting well sites which have both an adequate soil and saprolite reservoir and a network of discontinuities in the less weathered rock to facilitate water movement.

Topographic lineament analysis has evolved as an indirect means of locating areas with good well-yield potential in crystalline rock aquifers. Surface lineaments can reveal the presence of such underground features as faults, joints, lithologic contacts and compositional layering which may channel water to wells.

There are both positive and negative aspects to the use of topographic lineaments in well siting. Lineament analysis as part of a well- siting methodology can greatly enhance the probability of drilling a high-yielding well. However, reliance strictly on lineament analysis is not recommended. There are many other geologic factors which influence well yield, and all of them should be considered in making well siting decisions.

On-site verification of the nature of topographic lineaments is necessary in order to maximize well yields. Considerations in the siting of wells include rock type, depth of weathering, proximity to discontinuities, extent of discontinuities, position within the drainage basin, and presence of potential pollutants within the recharge area of the well.

Careful attention to geologic factors can significantly reduce the risk of drilling a low-yielding well, and, thus, can reduce the overall cost of developing a ground-water system. Georgia registered professional geologists with well-siting experience can provide valuable guidance in this regard. Cooperation between the licensed well drilling contractor and the geologist is essential. Even small deviations from the chosen well site or drilling depth can result in lowered well yields.

When deciding whether to develop a ground water system, there area number of cost factors to consider. They include siting assistance, property acquisition, access, drilling, pumping system, water lines, and possibly, water treatment.

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