INFLUENCE OF FOLIATION FRACTURE SYSTEMS ON WATER AVAILABILITY IN THE LAWRENCEVILLE, GEORGIA, AREA

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Abstract. The city of Lawrenceville, Georgia, pumps ground water mainly from wells completed in a system of productive fractures formed parallel to foliation and compositional layering in layered crystalline rocks. Much less production is obtained from planar, more steeply dipping joints intersecting boreholes. The combination of subhorizontal sets of foliation fractures and a well-developed network of steeply dipping joints that connect these fractures to regolith source water creates a fracture system that can sustain large well yields ranging from 100 to 400 gallons per minute (gal/min). Joints and joint sets generally are low yielding and produce water ranging from 1 to 5 gal/min, and in few cases as high as 30 to 35 gal/min where the joint opening is created from dissolution of a pre-existing mineral infilling. Fractures formed from weathering along foliation planes yield water ranging from 1 to 15 gal/min for individual foliation partings and ranging from 50 to 100 gal/min for larger openings. The model presented in this paper indicates that a "weathering wedge" or a zone of weathered rock either originates from the outcrop area or develops from steeply dipping joint systems transmitting water into the bedrock, or a combination of these two. Once a ground-water flow path is established, progressive differential weathering along foliation planes and layering forms zones of increased bedrock permeability. Where foliation fracture systems dominate the flow system, this model could be used to better understand ground-water availability and recharge to bedrock.

INTRODUCTION

Crystalline rock aquifers in the Piedmont physiographic province have the potential for supplying large amounts of potable water for supplemental, or sole-source supply to small communities in areas of increased bedrock permeability. Use of these aquifers is limited mainly because of the poor understanding of the fracture systems that convey water to wells. To determine specific lithologic and structural controls on the development of water-producing fracture systems in the area, a study was conducted in cooperation between the U.S. Geological Survey (USGS) and the city of Lawrenceville (Chapman and others, 1999). In Lawrenceville (Fig. 1), ground water is derived almost exclusively from high-yielding "foliation fractures," which are recharged from the overlying regolith. This paper describes lithologic and structural controls on the development of water-bearing foliation-fracture systems and presents a conceptual model of ground-water availability based on geologic and hydrologic data that were collected as part of the cooperative study.

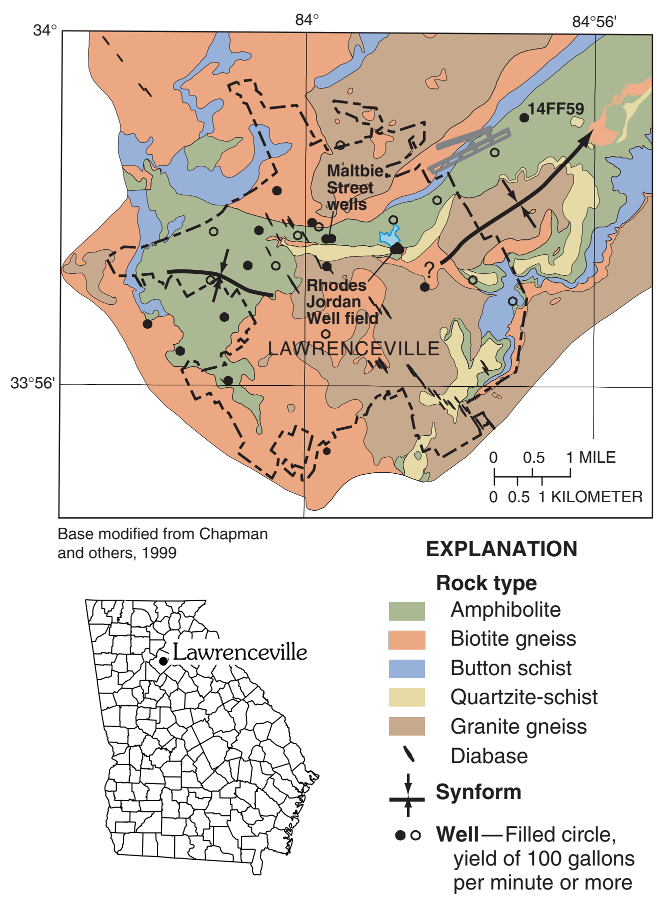

Figure 1. Geologic map of the Lawrenceville area showing lithologic units and large-scale geologic features.

Method of Study

During the study, emphasis was placed on developing a relation between the lithology mapped at land surface and subsurface fractures, so that surface-mapping data could be more readily used to develop ground-water resources in the Piedmont region. Detailed surface geologic mapping was conducted to define major lithologic units and structural controls. To define the characteristics of water-bearing fractures, borehole geophysical logs were collected in 32 bedrock wells and pumping tests were conducted in 10 wells. The depth and nature of fracture openings were determined mainly from optical and acoustic televiewer logs and downhole camera surveys.

Yield from individual fractures or fracture zones was estimated by correlating increases in yield recorded during drilling, to the measured depths of the water-bearing fractures. Individual fracture yield was confirmed in selected wells using flow-meter surveys and packer testing.

FOLIATION-FRACTURE SYSTEMS

Using borehole imaging data and correlating these data to individual fracture yield, two main systems of water-bearing fractures were observed in the Lawrenceville area: (1) openings along foliation planes and layering, which make up a system of discontinuous, but high-yielding, fractures (termed foliation fractures herein); and (2) zones of intense jointing and open joints, which make up a series of mostly steeply dipping low-yielding fractures. Water-bearing fractures also occur as a result of dissolution of pre-existing crosscutting mineralized joints, which create irregular openings that cross foliation and layering.

Foliation-fracture systems are comprised of discrete fractures formed along bedrock foliation and layering. Although these fractures are not continuous throughout the area, they appear to be developed along large-scale geologic features (such as pervasive or extensive foliation or folds); and, thus, their extent may be estimated if geologic structure and lithology are mapped. Individual fractures within the foliation-fracture system range from partial openings to foliation partings, to large water-bearing foliation fractures with apertures as large as 10 to 12 inches. In many cases, the foliation fracture at its point of intersection with the well bore has a variable aperture that conforms to undulatory foliation planes in the rock. This indicates that fractures of this type probably are undulatory and thicken and thin along their length. Wells that penetrate foliation fracture systems derive water from single to multiple dominant fractures to groups of water-bearing foliation partings along weathered bedrock zones.

Foliation fractures appear to provide the largest yields to bedrock wells in the Lawrenceville area, with some of the larger fractures yielding as much as several hundred gallons per minute (gal/min). Individual foliation partings yield water in the 1- to 15-gal/min range and in a few cases more than 30 gal/min, compared to a range of 1 to 5 gal/min for open water-bearing joints. The difference in yield between foliation fractures and joints likely is because most of the foliation fractures are formed along relatively flat-lying lithologic units that extend along contact zones and tap into numerous steeply dipping joints and joint sets. Hence, the foliation fractures connect a large network of steeply dipping joints and have the capacity to transmit large amounts of water into open boreholes.

The presence of at least one large fracture between foliation planes or compositional layers seems necessary to produce well yields of greater than 50 gal/min. Conversely, the scarcity or even absence of joints in the bedrock does not always preclude high well yields. For example, wells penetrating the amphibolite mass west of Lawrenceville (Fig. 1) yield water, almost exclusively, from foliation and compositional layering fractures. In wells in this area, joints are relatively scarce and are not water bearing, except for one well where several open joints were observed.

Influence of Lithology

Lithology strongly controls the occurrence and distribution of fractures near Lawrenceville. On a borehole scale, lithologic control was directly observed by the presence of fracture openings at lithologic contacts in multilayered rocks or at contacts between major lithologic units, confirming earlier observations made by Cressler and others, (1983) and Herrick and Legrand (1949). At the outcrop scale, productive foliation fractures appear to be limited to, and form along the strike of layered rocks consisting mostly of amphibolite, biotite gneiss, and button schist (Fig. 1). The discontinuous nature of foliation fractures probably is controlled by the weathering characteristics of individual layers in the bedrock. Along strike, lithologic units have compositional and textural changes that also lead to differences in the weathering characteristics and the depth and degree to which these fractures are developed. The feldspar-dominant biotite gneiss is particularly susceptible to deep weathering. Foliation fractures were not observed in boreholes penetrating massive, weakly foliated rocks, such as granite gneiss (Fig. 1). The granite gneiss is quartz rich, making this rock type less prone to differential weathering.

Lithology also affects mechanical properties that, in turn, control the degree of jointing from post-metamorphic brittle deformation. Ductile lithologies, such as the button schist unit, exhibit less abundant jointing in outcrops than do the brittle rocks because of their ability to absorb more strain; conversely, more brittle lithologies (such as quartzite) exhibit abundant jointing. In layered rocks, the resulting joint systems can be extremely complex and change intensity from one rock type to another, commonly producing layers of jointed rock that are overlain by unjointed rock. The joint systems appear to be less complex in massive rocks.

Influence of Structural Features

Small-scale structures and large-scale geologic features combine to influence occurrence and distribution of ground water in the bedrock to varying degrees and scales. Small-scale structures include foliation planes, joints, and folds. The small-scale structural features form weaknesses along which ground-water flow can further enhance fracture openings in the bedrock. If bedrock is massive and has no foliation planes, joints, or other weaknesses along which weathering can occur, then ground-water availability will be less than if abundant structural features are present in the rock.

Small-scale structures influence ground-water flow locally, whereas larger-scale geologic features influence subregional flow patterns within a drainage basin or possibly, several basins. Dips along the north and northwest limb of the synformal feature located east of Lawrenceville (Fig. 1) range from 10 to 20 degrees, thus allowing fractures formed along contacts to be extensive and to receive recharge across wide areas. Large-scale structures also may concentrate and localize ground-water flow where they are confined to a single basin such as in the amphibolite mass west of Lawrenceville (Fig. 1).

CONCEPTUAL HYDROGEOLOGIC MODEL

A conceptual hydrogeologic model explaining the system of productive foliation fractures that contribute to high well yields in the Lawrenceville area is referred to herein as a “weathering wedge model” (Fig. 2). This model was conceived mainly from the strong relation observed between bedrock fractures in boreholes and the surface outcrop of lithologic units. The weathering wedge is a zone of weathered rock either developed along a lithologic or structural feature originating in the outcrop area or from steeply dipping joint systems transmitting water into the bedrock or a combination of these two. Differential weathering occurs along foliation planes, rock contacts and other lithologic and structural features in the bedrock. As a result of differential weathering, weaknesses eventually form in the bedrock that in turn separate to create physical openings in response to tectonic stresses such as stress-relief or buckling from compressive forces (although tectonic processes may not necessarily be needed to produce these features).

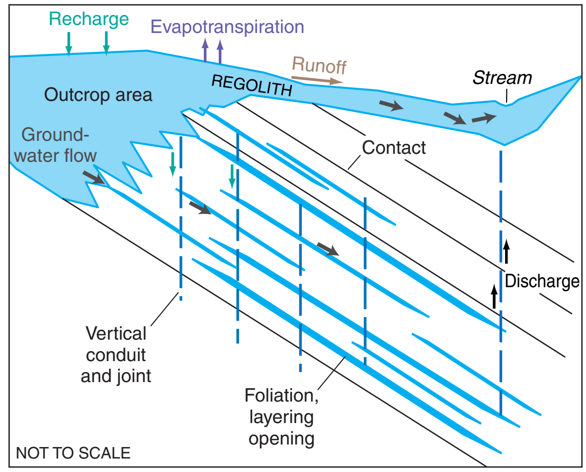

Figure 2. The weathering wedge model shows an inclined sequence of layered crystalline rocks that are exposed to deep chemical and physical weathering at the outcrop. *In situ* weathering of the bedrock causes progressive weathering along rock foliation and layering and produces downdip productive fracture openings. The fracture openings are recharged laterally from the outcrop or through vertical conduits or joint sets, further breaking up the rock.

Differential weathering from the outcrop area in a down-dip direction seems to best explain the high yields obtained at the Rhodes Jordan Well Field, Maltbie Street, and at the 14FF59 well site (Fig. 1). Joints and joint systems also may influence the development and extent of weathering wedges in the bedrock locally. In upland areas, joints and joint systems probably provide avenues that allow weathering to progresses into the bedrock and along rock layering. Open high-angle joints accompany many of the high-yielding foliation fractures observed in boreholes, thus indicating the potential importance of joints on the development of foliation fracture systems.

Recharge to foliation fracture systems is possible either directly from the outcrop area (lateral) or from discrete joint systems that allow vertical leakage into the deeper bedrock (Fig. 2). Down dip from the outcrop area, steeply dipping joints connect the system of deeper foliation fractures to the regolith. Once a circulation pattern is established, continued ground-water flow and progressive weathering cause development of the system of fractures parallel to foliation or layering. This results in a ground-water flow system that is confined or semiconfined across most of the flowpath, and that can discharge only through steeply dipping joint systems. The general hydraulic behavior of flowing wells in the Lawrenceville area seems to confirm the weathering wedge model; many of the wells flow at rates of 10 gal/min to more than 50 gal/min. Flowmeter surveys also confirm hydraulic confinement in the system of foliation fractures at some wells; several surveys revealed artesian pressure in deep fractures that causes water to flow up through open boreholes and exit out of lower-head, shallow fractures and fracture zones.

CONCLUSIONS

Large ground-water yields obtained in the Lawrenceville, Ga., area appear to be the result of a system of foliation fractures formed along flat-lying lithologic units, combined with a well-developed net-work of steeply dipping joints that connect horizontal fractures to regolith source water. Without the combination of subhorizontal fracture systems and vertical joints, the yields would be low, as evidenced by the low-yield wells in the weakly foliated granite gneiss in the Lawrenceville area.

It is likely that large ground-water yields can be obtained in other parts of the Georgia Piedmont that have similar lithology and structure to that of Lawrenceville. Lithology and structure are the primary factors that must be considered when attempting to tap into productive systems of foliation fractures. The extent of these fracture systems probably is only limited to the larger-scale geologic features that ultimately control the distribution of rocks over subregional areas and on the depth and degree of weathering developed in the bedrock.

Where foliation fractures dominate the flow system, the conceptual weathering wedge model can be used to explain ground-water flow and recharge to these systems. Geologic mapping combined with subsurface geophysical logging are the main sources of information needed to identify foliation fracture systems. These techniques also are used to locate other systematic geologic controls, such as jointing and lithologic contacts, affecting the ground-water occurrence and availability in an area of study.

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