Structural control of spring locations in the northern Shenandoah Valley, Virginia and West Virginia: interpretation of geologic controls on ground-water flow paths in folded and faulted carbonate rocks

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ABSTRACT

New and revised detailed geologic mapping by the U.S. Geological Survey in the Paleozoic carbonate rocks of the northern Shenandoah Valley of Virginia and West Virginia is providing a geologic framework with sufficient spatial resolution for testing correlation of ground-water flow paths to geologic setting. Thrust faults, cross faults, and major folds in the valley serve as directional controls on ground-water flow, and combined with lithologic units produce physical compartments for ground-water storage and flow. Strike-parallel ground-water flow is interrupted by compartment-bounding cross faults that may either direct water across strike or force flow towards the surface, often producing springs. Flow-paths are complex and the compartments are leaky. Support for these ideas include: 1) results of multidisciplinary hydrogeologic studies at the U.S. Geological Survey, Lewisport, WV Science Center which indicate strong anisotropy in ground-water flow directions and correlation between test well-transmissivity and geologic structures, including faults and folds; 2) New geologic mapping in the Middletown, Winchester, Stephens City, Stephenson, Inwood, and White Hall 1:24,000 quadrangles suggests that spring location, magnitude, combined with lithologic units produce physical compartments for ground-water storage and flow. Strike-parallel ground-water flow is interrupted by compartment-bounding cross faults that may either direct

INTRODUCTION

Communities in the northern Shenandoah Valley of Virginia and West Virginia depend heavily on ground water extracted from both karstic carbonate rocks and fractured siliclastic rock aquifers. The ground-water resource is facing pressure as populations in the valley rapidly increase. Berkeley County, WV (Fig. 1) is the fastest growing county in the state and Frederick and Clarke Counties, VA also house rapidly expanding populations and industries. To meet the water resource demands, the karst aquifer in the region must be developed. Local land-use managers are in need of detailed geologic and hydrogeologic information to make informed decisions concerning source-water protection and land use related to subsidence.

The study area is in the Shenandoah Valley region of the Valley and Ridge Physiographic Province. Approximately 10,000 ft of Middle Cambrian to Upper Ordovician sedimentary rocks are near the surface and are overlain by Pleistocene and Holocene surficial deposits. The Shenandoah Valley can geologically be divided into two regions: (1) shale, graywacke, and limestone of the Ordovician Martinsburg Formation in the central part (along the axis of the Massanutten syncline), and (2) Cambrian and Ordovician carbonate rocks to the east and west. The carbonate rocks are bounded on the east by the metamorphic rocks of the Blue Ridge and on the west by the North Mountain fault zone which separates them from mixed siliciclastic and carbonate rocks of the Valley and Ridge. All of the rocks in the area were folded and faulted during the late Paleozoic Alleghenian orogeny. The terrain of the Shenandoah Valley generally is gently to moderately rolling with low relief. The springs are fairly common in areas underlain by carbonate rocks. Rocks of the carbonate aquifer system underlying the northern Shenandoah Valley range from Middle Cambrian to Late Ordovician in age and consist of carbonate and clastic lithologies.

The carbonate aquifer system in the northern Shenandoah Valley is recharged by infiltration of precipitation across the area. In areas with appreciable accumulations of recharge, substantial quantities of ground water can be stored in the aquifer and the dominant direction of ground-water flow may be normal to strike toward adjacent valley bottoms and streams (Bailey and Lee, 1991). However, relict bedding structures in regolith and open bedding planes in bedrock may result in a dominant direction of ground-water flow. The study area is a potential karstic system and karstic features and associated springs may be found. This study is intended to provide information to aid in understanding the geologic controls on spring locations. The geologic setting of the area of study is that of an east-trending anticline/syncline couplet.

A structurally interesting aspect of this part of the Shenandoah Valley is that folds on the east side of the Massanutten syncline and the west side of the valley, and to the northeast on the east side of the valley. These trends hold until a major topographic incursion or cross strike structure (fault) is encountered which enables the water to move across the strike of bedding towards regional drains, such as the Opequon Creek, Shenandoah River. Examples of this bedding/lithologic control on local flow are the southwest plunging Buffalo Marsh and Welltown synclines. Both synclines have well-developed karst features in them and the ground-water flow direction is presumably similar to that of their axes to the southwest before turning sharply to the east towards the center of the main valley. Both of these synclines have well-developed karst features in them and the ground-water flow direction is presumably similar to that of their axes to the southwest before turning sharply to the east towards the center of the main valley. Both of these synclines have well-developed karst features in them and the ground-water flow direction is presumably similar to that of their axes to the southwest before turning sharply to the east towards the center of the main valley.

In places faults interrupt the bedding-controlled flow. These faults act as barriers to flow or as potential conduits to flow across strike. When contrasting lithologies are juxtaposed by faulting, ground water may pool and be forced to the surface creating a spring. An example of the later is at Vaucluse Spring (Fig. 4.6) where the Conococheague and Stonehenge Limestones are faulted against the Rockdale Run formation near the nose of a south-plunging anticline/syncline couplet.

Two other large springs, Fay Spring and Sempeles Spring, issue from a newly mapped fault intersection with, and offset of the Edinburg Limestone-Martinsburg Formation contact in the case of Fay and the New Market Limestone-Freewater Station Dolomite contact at Sempeles Spring (Fig. 5). Either the fault is a barrier to ground-water flow, collecting strike parallel flow from the northeast, or is acting as a conduit and drain for the area of the Welltown syncline to the north. Hopefully dye tracing can be done in this area in the near future to help delineate the ground-water basins contributing to these springs, which will help clarify the hydrogeologic model.

A structurally interesting aspect of this part of the Shenandoah Valley is that folds on the east side of the Massanutten syncline predominantly plunge to the north and folds on the west side plunge to the south (Fig. 3). This means that bedding trends to guide ground-water flow is parallel to strike in some areas. Burton and others (2002, p. 256) studied ground-water flow in moderately dipping siliciclastic rocks in a local watershed in the Shenandoah Valley of Virginia. Conclusions reached by this study are that ground-water flow paths parallel to the dip direction in well-developed bedding-plane partings in fractured bedrock have higher proportions of young water than for flows parallel to the strike direction. This result may also apply to moderately dipping carbonate rocks in the study area (Fig. 2). The bedrock in the Valley has very low permeability and therefore bedding orientation controls ground-water flow by acting as a barrier to water flowing down the hydrologic gradient and across the strike of the bedding. The retardation of cross-strike flow is especially pronounced in areas where the bedding typically dips at steep angles.