From "Digital Mapping Techniques '11–12—Workshop Proceedings"
U.S. Geological Survey Open-File Report 2014–1167
*http://pubs.usgs.gov/of/2014/1167//*

# Using High-Resolution Digital Terrain Models to Improve Bedrock and Surficial Geologic Mapping in Virginia

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## Abstract

Shaded relief maps generated from elevation control data associated with high-resolution orthoimagery have been used to improve 1:24,000-scale geologic mapping in Virginia. These shaded relief maps have been demonstrated to be useful in delineating geologic, geomorphic, and geologic hazard features, especially in highly vegetated areas. Features such as terraces, sinkholes, fault scarps and landslide deposits are often difficult to detect on the ground, on topographic maps or on aerial photos, and may only be visible on shaded relief maps derived from high-resolution digital terrain models (DTMs).

In the Elkton West 7.5-minute quadrangle, located in the Valley and Ridge Province near the southern end of Massanutten Mountain, areas underlain by residuum, mountain slope colluvium, and older debris-flow deposits are not evident on a standard 1:24,000-scale topographic map with a 40-foot (ft) contour interval. These geologic map units can, however, be identified on the shaded relief map due to subtle differences in slope pattern and dissection. The map also allows for accurate delineation of modern flood-plain and terrace deposits along the South Fork of the Shenandoah River. In the Providence Forge 7.5-minute quadrangle, located in the Coastal Plain Province east of Richmond, the shaded relief map enables correlation of Pleistocene terraces and underlying marine and nearshore facies of older stratigraphic units, previously difficult to resolve. Scarp and terrace morphology, which generally follows consistent elevations, can be further refined by extending the use of shaded relief maps across the Coastal Plain. Other features such as fault lineaments and the extents of mined-out areas in pits and quarries also are revealed using the shaded relief maps.

Many States now use bare-earth light detection and ranging (LiDAR) elevation data, but, at present, Virginia lacks comprehensive LiDAR coverage. However, the DTMs generated from high-resolution orthoimagery have proven to be a useful alternative in delineating geologic features when LiDAR data are unavailable, and the DTMs are substantially more useful than standard 7.5-minute topographic maps.

## Methodology

The Virginia Base Mapping Program (VBMP) was initiated in 2001 to develop orthoimagery for the entire Commonwealth of Virginia. The purpose of this program was to create a consistent, accurate base map that all State, local, and Federal government agencies could use for spatial data applications. As a part of the VBMP, the Sanborn Map Company, under contract to the Virginia Geographic Information Network (VGIN), a part of the Virginia Information Technology Agency (VITA), also developed DTMs primarily for the purpose of orthorectification of imagery. This product was made available in addition to the source imagery for the purposes of planning and hydrographic analysis.

In the VBMP DTM data, the terrain is represented by masspoints and breaklines. For areas mapped to 1 inch = 200 ft, the aerial imagery was collected at a 1:14,400 scale at a flying height of 7,200 ft above the mean terrain. For areas mapped to 1 inch = 100 ft mapping standards, the aerial imagery was collected at 1:7,200 scale at a flying height of 3,600 ft above the mean terrain. Ground control is used to support the orthophoto mapping by either placing air target panels on existing permanent monuments or photographic identification of strategic points. The coordinates were collected via ground survey techniques. Aerial triangulation was performed on softcopy workstations using high-accuracy stereo plotters and software with a fully analytical triangulation adjustment. The data were photogrammetrically stereo-compiled to North American Datum 1983; Virginia State Plane North or South Zone, as applicable (VGIN, 2007). All DTMs were developed from the imagery acquired in 2006 or 2007, using high-accuracy stereo plotters and traditional manual photogrammetric techniques for generating the breaklines and masspoints.

Division of Geology and Mineral Resources (DGMR) staff use VBMP DTM data (masspoints and breaklines) delivered in Microstation CAD .DGN format to create Triangulated Irregular Networks (TINs) in ArcGIS's 3D Analyst for the purpose of representing surface morphology. The Elkton West 7.5-minute quadrangle was chosen as a test case to see if the data could prove useful for surficial mapping projects (fig. 1). A raster hillshade of the Elkton West quadrangle was generated in ArcGIS's Spatial Analyst. After it was determined that this product was useful for mapping purposes, raster hillshades were generated for other quadrangles.

## Geomorphic Features From Surficial Mapping in Elkton West 7.5-Minute Quadrangle

The surficial geologic map of the Elkton West 7.5-minute quadrangle was mapped by Matt Heller and Scott Eaton in 2008 for the STATEMAP cooperative mapping program (Heller and Eaton, 2010). They relied on a variety of sources and methods, including field work, topographic maps, soils maps, and aerial photography. A preliminary map was produced that showed the general distribution of the surficial deposits in the quadrangle. This map was extensively revised and improved when the raster hillshade for the quadrangle became available. The boundaries of surficial deposits, such as alluvial fans, debris flows, and ancient terrace surfaces, were refined with the higher-resolution provided by the DTM hillshade (fig. 2). Heller and Eaton (2010) also were able to better subdivide terrace and debris-flow deposits by relative age (fig. 3). In addition, smaller and subtle surficial deposits were identified and included on the map.

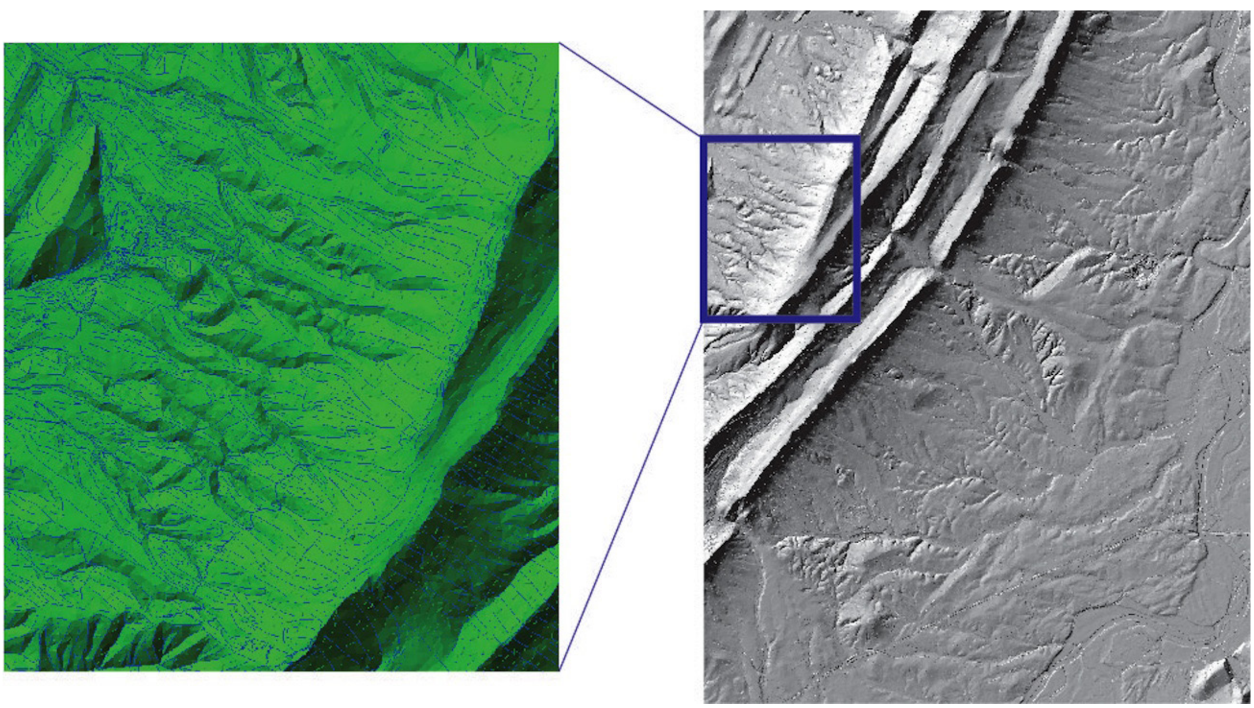

**Figure 1.** A TIN for a portion of the Elkton West 7.5-minute quadrangle generated from masspoints and breaklines is shown on the left. The blue dots represent masspoints, which are regularly spaced. The blue lines are breaklines, representing ridges, valley bottoms, and some types of infrastructure, such as roadways. The DTM hillshade of Elkton West 7.5-minute quadrangle is shown on the right. The DTM was created in ArcGIS's Spatial Analyst.

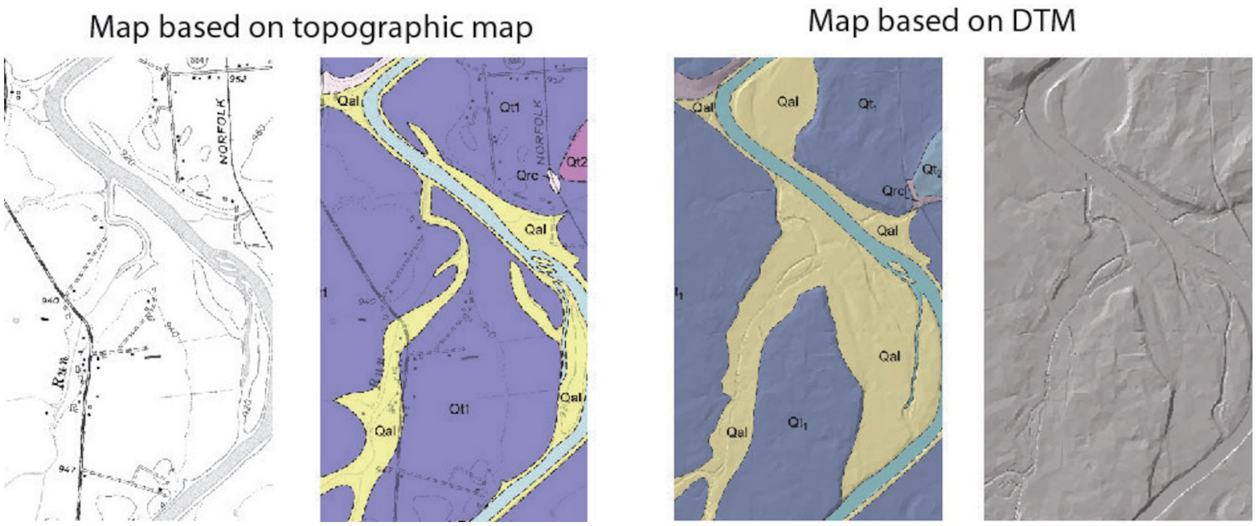


**Figure 2.** An example of a refinement that the DTM hillshade provided is visible in the comparison of the alluvium as mapped from the topographic and soils maps (second image from left) and the alluvium as mapped from the DTM hillshade (third image from left). One can see that the alluvium is much more extensive on the map based on the DTM hillshade. This revision was confirmed in the field.

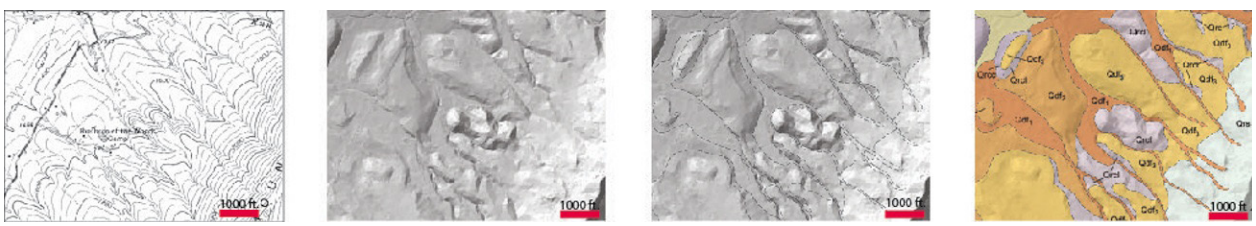


**Figure 3.** Three generations of debris-flow deposits (shown in shades of yellow and orange on the right-most image) and areas of residuum (gray areas) are distinguishable on the DTM hillshade; interpreted geologic contacts are shown on the DMT image that is second from the right. These deposits are difficult to distinguish from one another on the topographic map (left-most image).

## Features From Coastal Plain Mapping in Providence Forge 7.5-Minute Quadrangle

Mapping in the Providence Forge 7.5-minute quadrangle has also benefited from detailed elevation data collected for rectification of Virginia's orthoimagery. Shaded relief maps generated from these elevation data enable correlation of Pleistocene terraces and underlying marine and nearshore facies of older stratigraphic units, previously difficult to resolve. Scarp and terrace morphology, which generally follow consistent elevations, can be further refined with the use of shaded relief maps.

The surface raster (the DTM) developed for this quadrangle was classified using the natural breaks (Jenks) method in ArcGIS. The natural breaks classification scheme works well with these data because it selects the most suitable class ranges by finding clusters of similar elevations over the entire range of the data set. Several terrace scarps are visible on the natural-breaks shaded DTM (fig. 4). One of the most prominent terraces has a flat surface ranging up to 48 ft elevation. This corresponds to the elevation for the Shirley Alloformation (Qsh) identified elsewhere on the Coastal Plain using traditional mapping techniques (Mixon and others, 1989). In Figure 5, the terraces corresponding to the Chuckatuck Alloformation (Qc), Tabb Alloformation, Sedgefield Member (Qts), and the Shirley Alloformation (Qsh) are identified. This has been confirmed by field work, including geologic borings (Gilmer and Berquist, 2011).

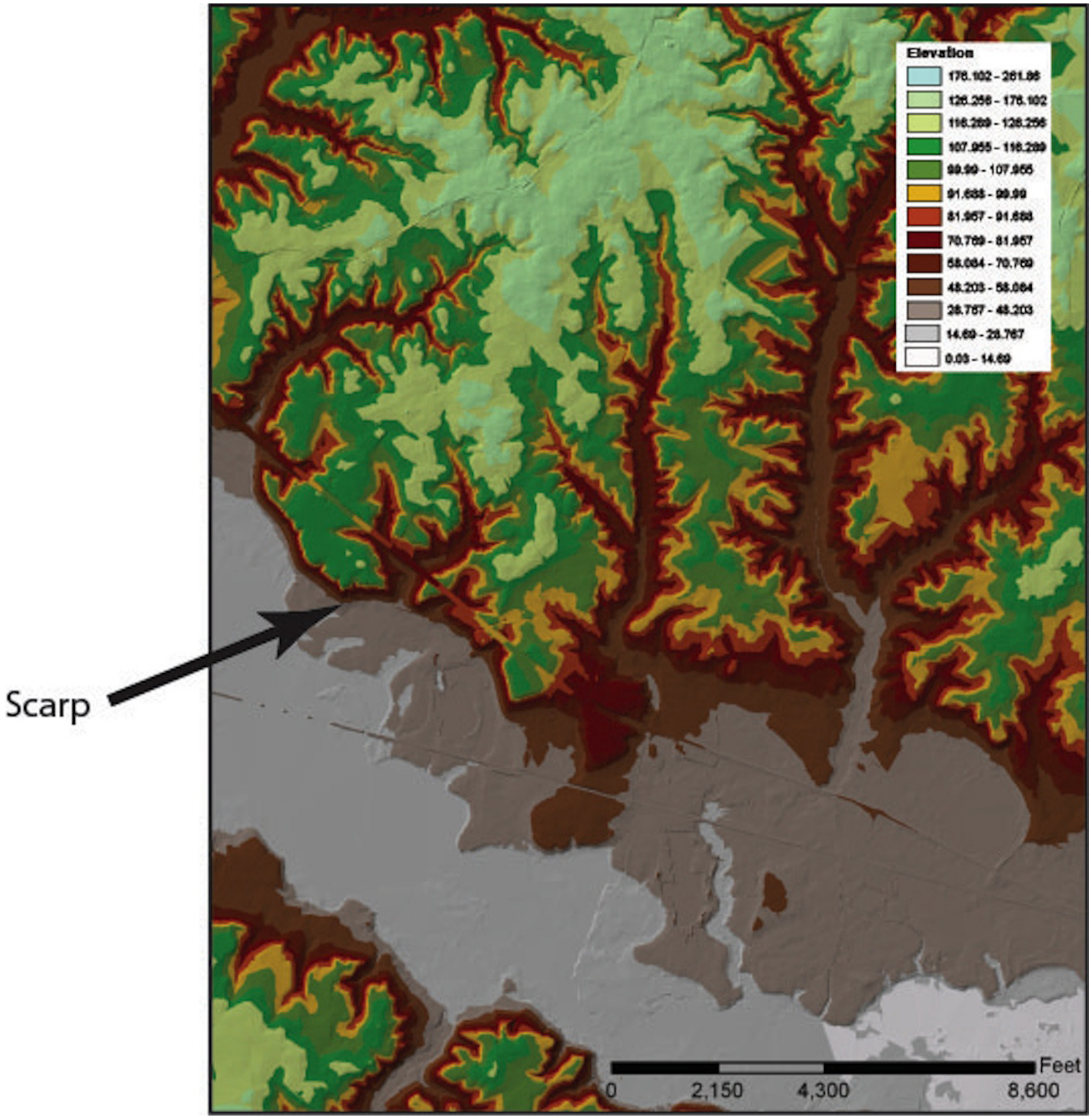


**Figure 4.** DTM created in ArcGIS and shaded by color ramps using the natural breaks classification scheme, showing several terrace scarps. Elevations are in feet above sea level. Shirley Alloformation occurs beneath the 48-ft level, shown here in light brown.

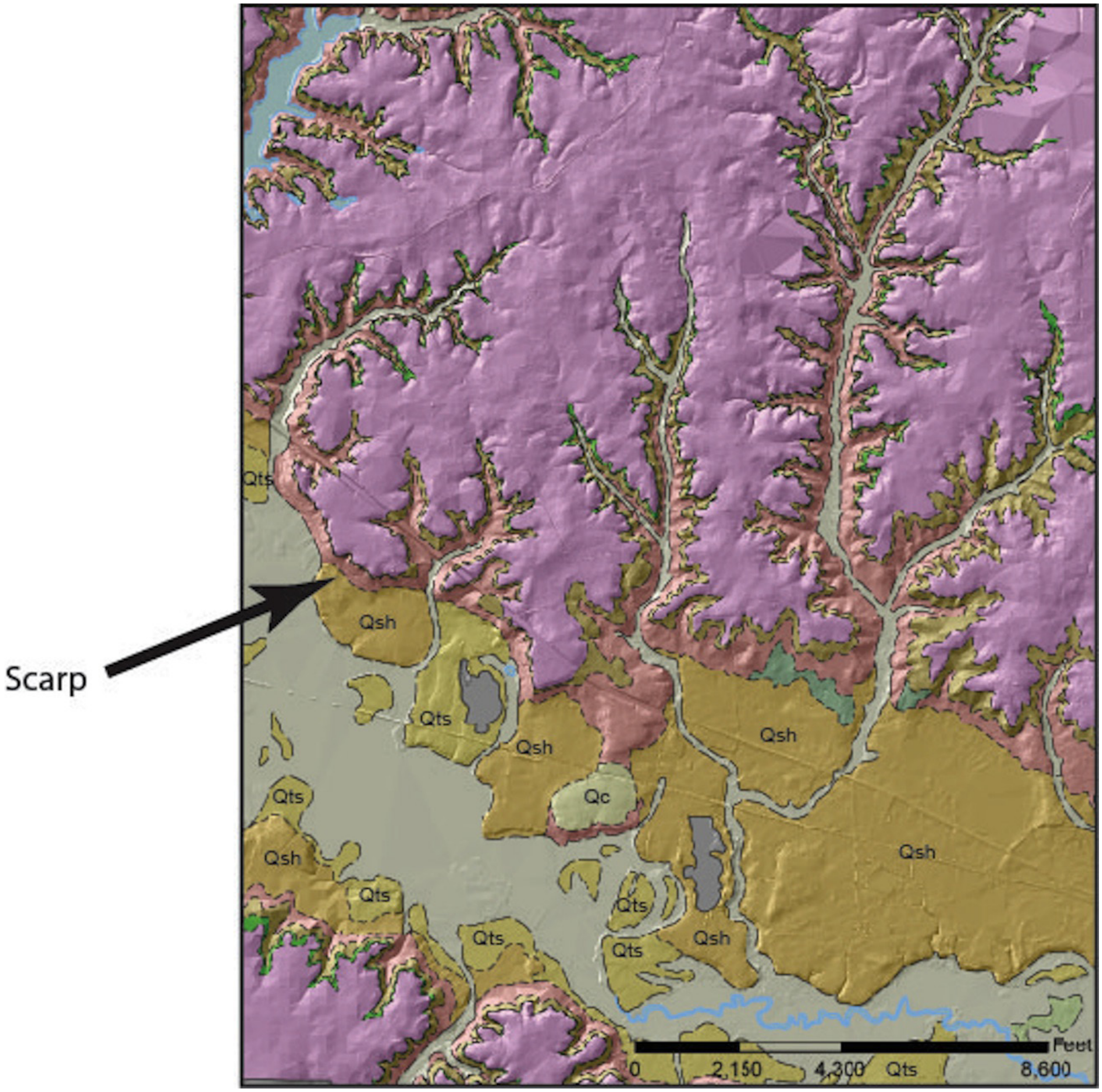


**Figure 5.** Terraces corresponding to the Chuckatuck Alloformation (Qc; yellow areas), Tabb Alloformation, Sedgefield Member (Qts; pale orange) and the Shirley Alloformation (Qsh; orange) were identified on the DTM and confirmed by field work, including hand augering and geologic borings.

## Limitations of DTMs Created From Orthoimagery Data

Although DTMs created from orthoimagery data are extremely useful for identifying features, they do have significant limitations. Their primary purpose is to rectify imagery, not to serve as a basemap for geologic mapping. This must be considered when attempting to do any quantitative analyses using the DTMs. DTMs created from orthoimagery data are not as detailed as DTMs generated from LiDAR data.

Areas with densely spaced infrastructure, such as roads, railroads, and buildings, have many more breaklines and masspoints than areas with little development and, therefore, show more detail. Also, areas with significant changes in slope, such as ridges and areas with significant hydrography, have more breaklines than areas that are flat-lying or lack streams or lakes. Therefore, some areas have more elevation control than others (fig. 6). This makes it difficult to quantify the accuracy of the DTM generated from elevation control data associated with the orthoimagery.

Another challenge DGMR faced in using the DTMs is that in some quadrangles the data collected for elevation ground control is at different scales. For example, the portion of Providence Forge quadrangle in New Kent County is at a scale of 1 inch = 100 ft, whereas the portion in Charles City County is at a scale of 1 inch = 200 ft. This variation in scale can cause edge effect errors, leaving some areas without useful data. In many cases, nothing substitutes for "boots-on-the-ground" field work. Features such as narrow debris flows are sometimes not resolvable on the DTM hillshade or the topographic map. Only field traverses enable the geologist to map the true extent of these features.

## Conclusions

High-resolution DTMs have been very useful to DGMR geologists for delineating both geomorphic and geologic features. DGMR now examines the DTMs for every mapping project. The higher-resolution and more current information provided by this tool enable the geologist to plan their field work in order to evaluate observations made from these DTMs. In an ideal world, LiDAR data would provide this service and enable much more quantitative analysis of an area, but LiDAR data are not available for most areas. The DTMs based on elevation control from orthoimagery are a good substitute until we can obtain statewide LiDAR coverage.

## Additional Information

Additional information is available on the poster presented at the DMT meeting (fig. 7) or by contacting the authors.

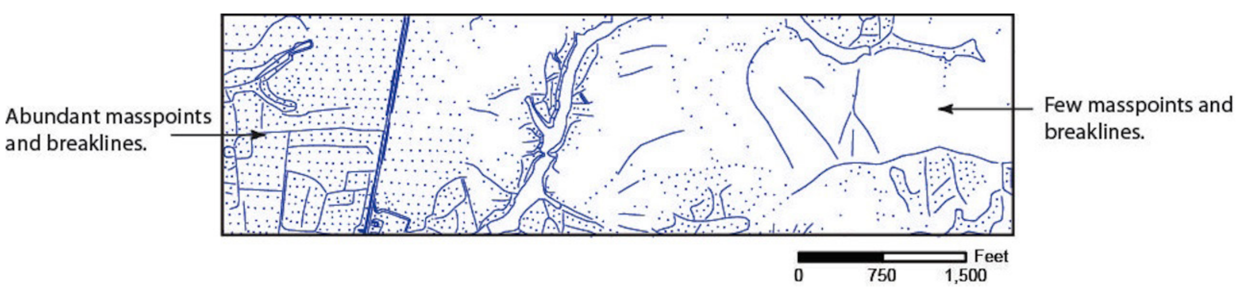


**Figure 6.** Masspoints and breaklines for a part of the Providence Forge quadrangle.

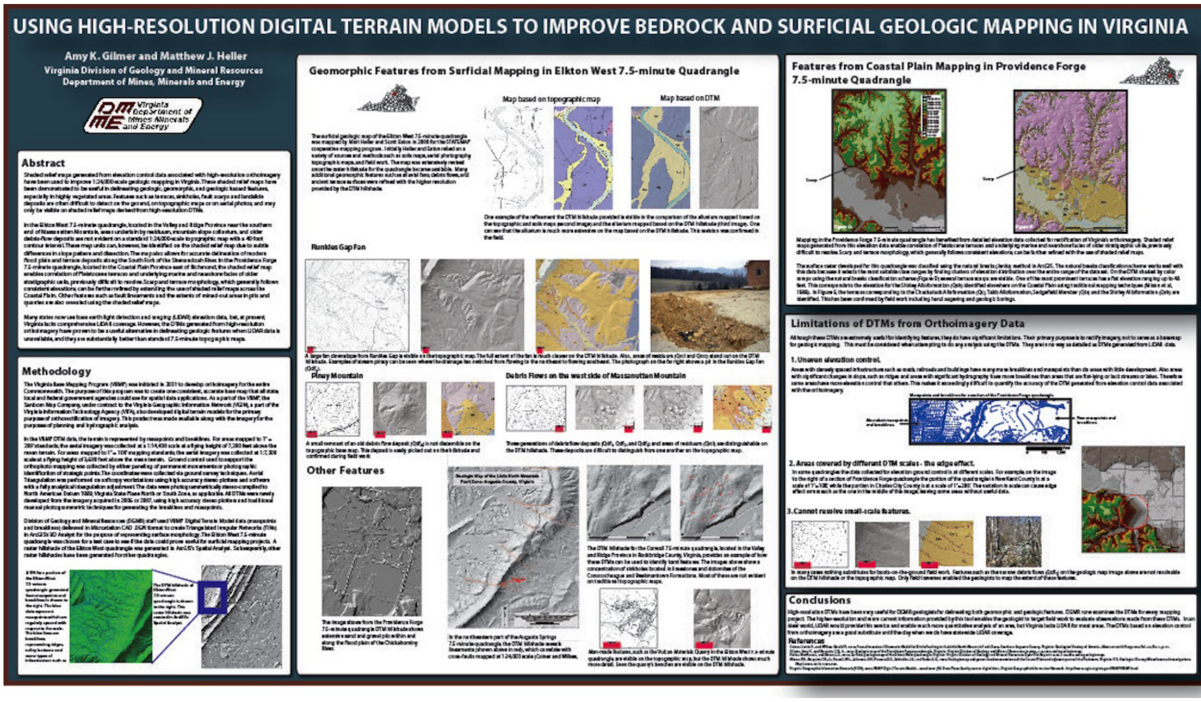


**Figure 7.** Poster entitled “Using High-Resolution Digital Terrain Models to Improve Bedrock and Surficial Geologic Mapping in Virginia,” presented at the Digital Mapping Techniques 2011 workshop in Williamsburg, Virginia. A high-resolution version of this poster is available for download at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT11_Gilmer.pdf*.

## References

Gilmer, A.K., and Berquist, C.R., Jr., 2011, Geologic map of the Providence Forge quadrangle, Virginia: Virginia Division of Geology and Mineral Resources Open File Report 11–07, scale 1:24,000, *https://www.dmme.virginia.gov/commerce/ProductDetails.aspx?productID=2615*.

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