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superseded by a paper in the
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See also earlier Proceedings (1997-2010)
http://ngmdb.usgs.gov/info/dmt/

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 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 contour interval. These 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 are also 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 is unavailable, and they are substantially better than standard 7.5-minute topographic maps.

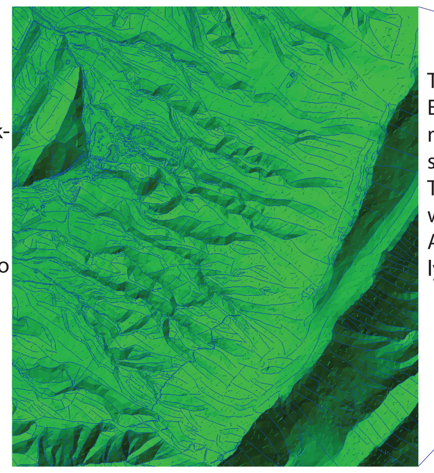
Methodology

The Virginia Base Mapping Program (VBMP) was initiated in 2001 to develop orthoimagery for the entire Commonwealth. The purpose of this program was to create one 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 digital terrain models for the primary purpose of orthorectification of imagery. This product was made available along with the imagery for the purposes of planning and hydrographic analysis.

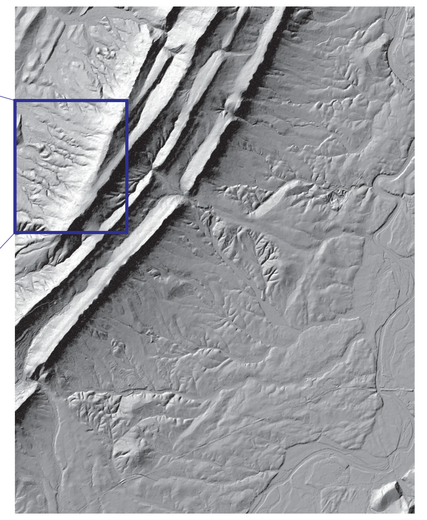
In the VBMP DTM data, the terrain is represented by masspoints and breaklines. For areas mapped to 1″= 200′ standards, the aerial imagery was collected at a 1:14,400 scale at a flying height of 7,200 feet above the mean terrain. For areas mapped to 1″= 100′ mapping standards, the aerial imagery was collected at 1:7,200 scale at a flying height of 3,600 feet above the mean terrain. Ground control used to support the orthophoto mapping was collected by either paneling of 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. All DTMs were newly 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 used VBMP Digital Terrain Model 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 for a test case to see if the data could prove useful for surficial mapping projects. A raster hillshade of the Elkton West quadrangle was generated in ArcGIS's Spatial Analyst. Subsequently, other raster hillshades have been generated for other quadrangles.

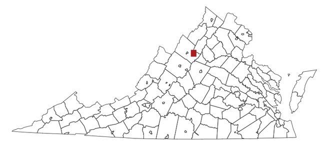
A TIN for a portion of the Elkton West 7.5-minute quadrangle generated from masspoints and breaklines is shown to the right. The blue dots represent masspoints which are regularly spaced with respect to the scale. The blue lines are breaklines, representing ridges, valley bottoms and some types of infrastructure such as roadways.



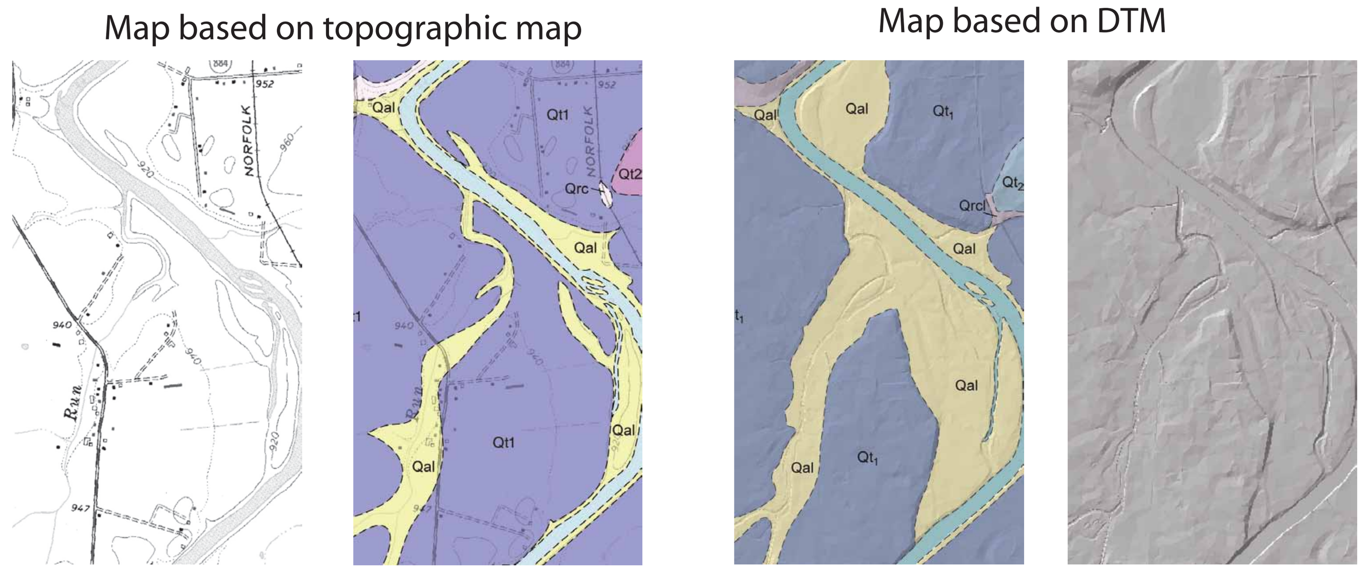
The DTM hillshade of Elkton West 7.5-minute quadrangle is shown to the right. This raster hillshade was created in ArcGIS's Spatial Analyst.



Geomorphic Features from Surficial Mapping in Elkton West 7.5-minute Quadrangle

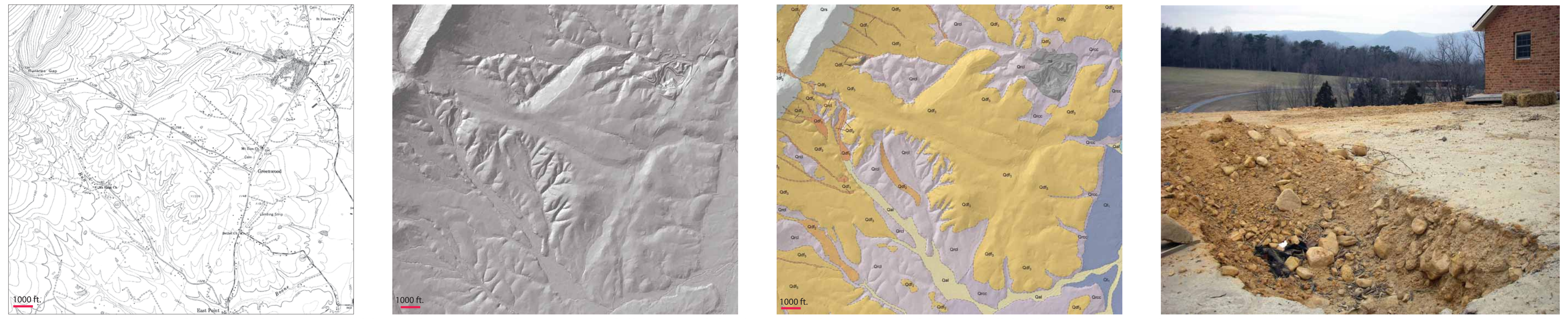


The surficial geologic map of the Elkton West 7.5-minute quadrangle was mapped by Matt Heller and Scott Eaton in 2008 for the STATEMAP cooperative mapping program. Initially, Heller and Eaton relied on a variety of sources and methods such as soils maps, aerial photography, topographic maps, and field work. The map was extensively revised once the raster hillshade for the quadrangle became available. Many additional geomorphic features such as alluvial fans, debris flows, and ancient terrace surfaces were refined with the higher resolution provided by the DTM hillshade.



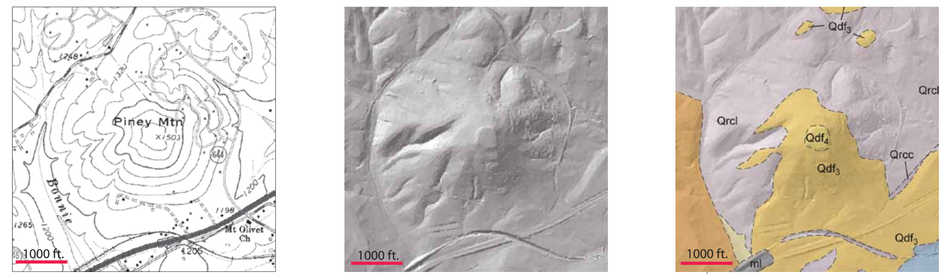
One example of the refinement the DTM hillshade provided is visible in the comparison of the alluvium mapped based on the topographic and soils maps (second image) and the alluvium mapped based on the DTM hillshade (third image). One can see that the alluvium is much more extensive on the map based on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

Runkles Gap Fan



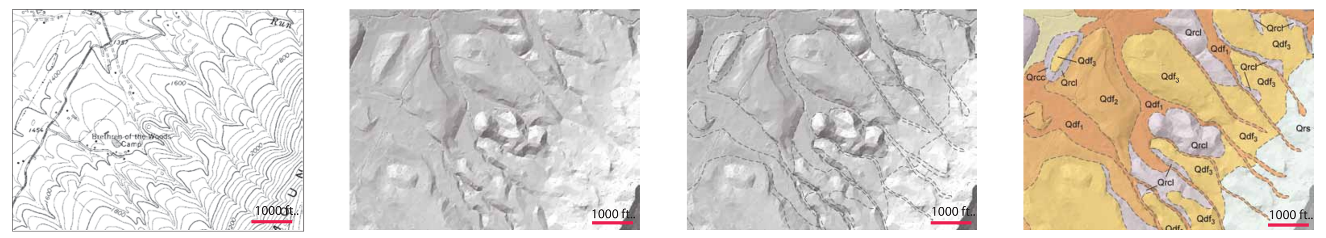
A large fan downslope from Runkles Gap is visible on the topographic map. The full extent of the fan is much clearer on the DTM hillshade. Also, areas of residuum (Qrcl and Qrcc) stand out on the DTM hillshade. Examples of stream piracy can be seen where the drainage has switched from flowing to the northeast to flowing southeast. The photograph on the far right shows a pit in the Runkles Gap Fan (Qdf_3).

Piney Mountain



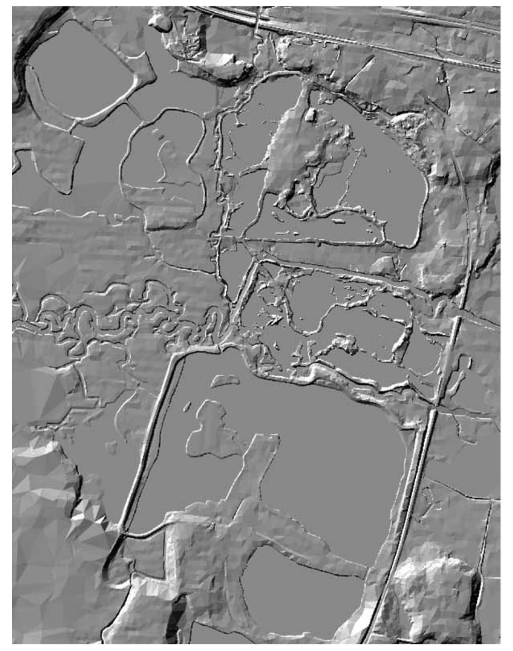
A small remnant of an old debris flow deposit (Qdf_4) is not discernible on the topographic base map. This deposit is easily picked out on the hillshade and confirmed during field work.

Debris Flows on the west side of Massanutten Mountain

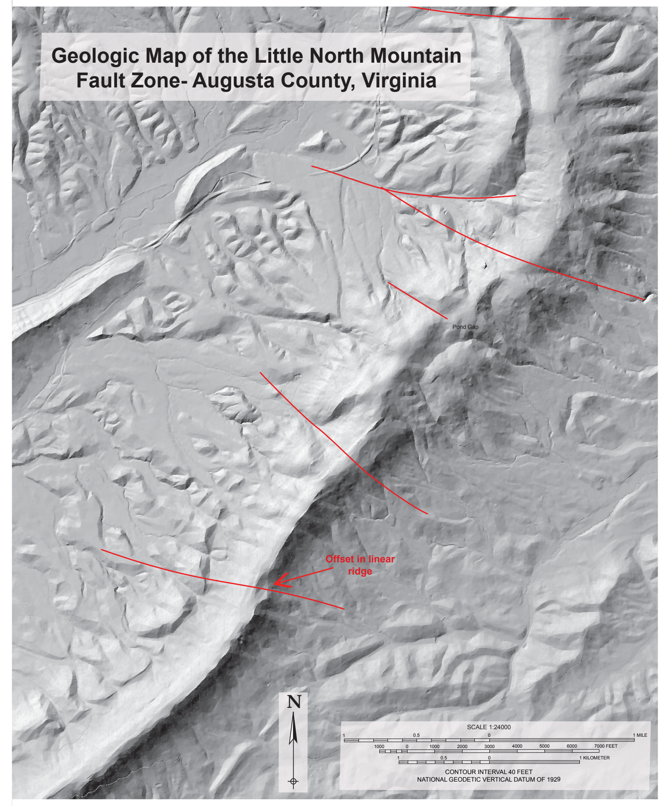


Three generations of debris flow deposits (Qdf_1, Qdf_2, and Qdf_3) and areas of residuum (Qrcl) are distinguishable on the DTM hillshade. These deposits are difficult to distinguish from one another on the topographic map.

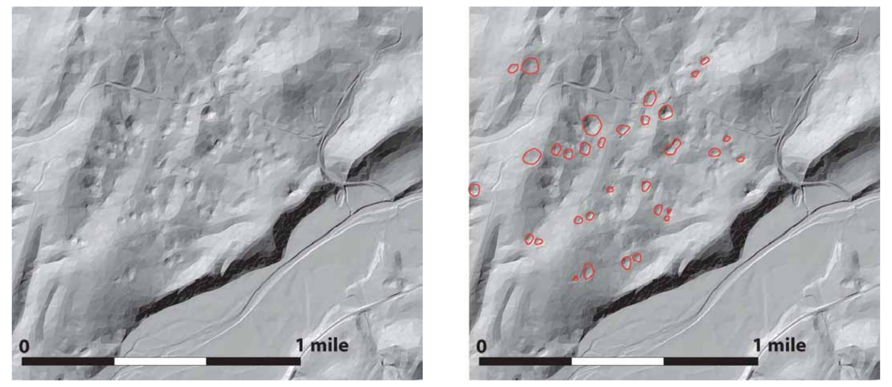
Other Features



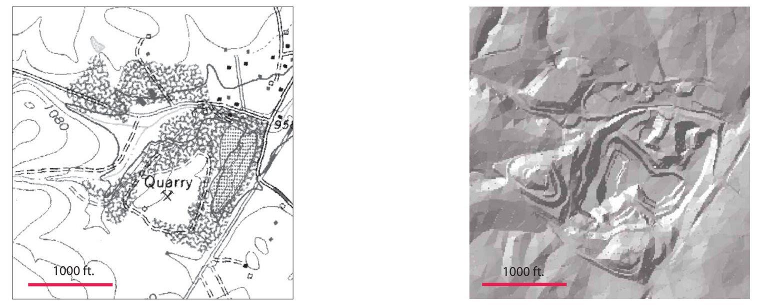
The image above from the Providence Forge 7.5-minute quadrangle DTM hillshade shows extensive sand and gravel pits within and along the flood plain of the Chickahominy River.



In the northeastern part of the Augusta Springs 7.5-minute quadrangle, the DTM hillshade reveals lineaments (shown above in red), which correlate with cross-faults mapped at 1:24,000 scale (Coiner and Wilkes, 2010).

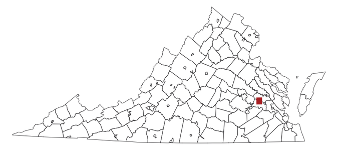


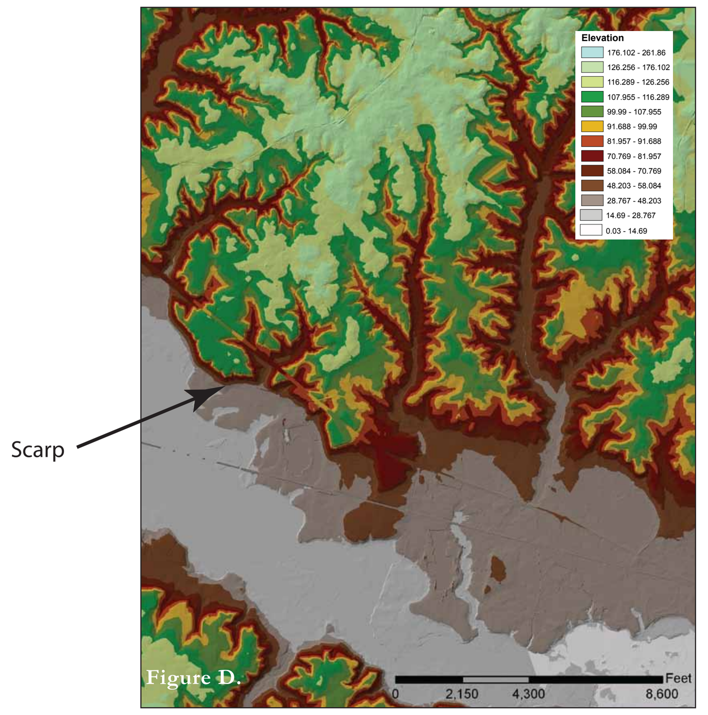
The DTM hillshade for the Corwall 7.5-minute quadrangle, located in the Valley and Ridge Province in Rockbridge County, Virginia, provides an example of how these DTMs can be used to identify karst features. The images above show a concentration of sinkholes located in limestones and dolomites of the Conococheague and Beekmantown Formations. Most of these are not evident on traditional topographic maps.

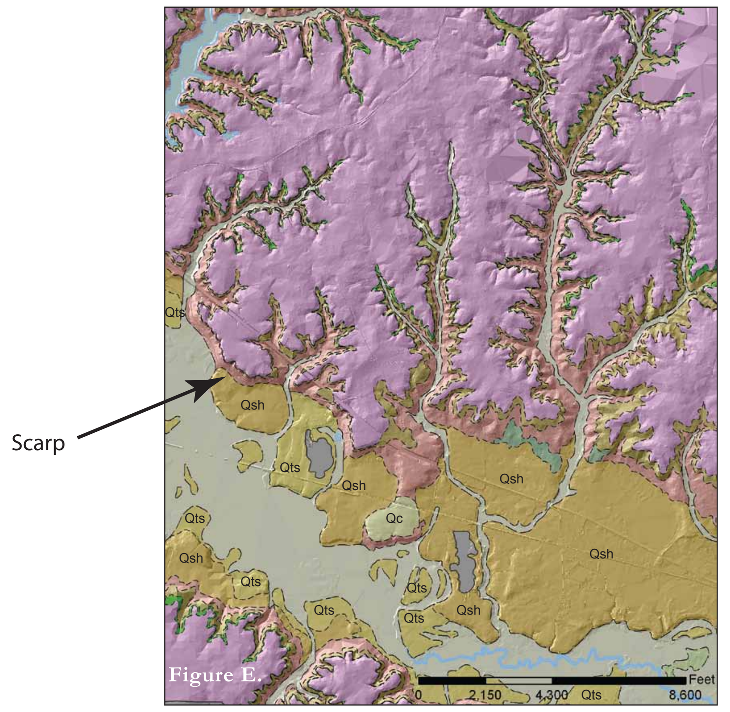


Man-made features, such as the Vulcan Materials Quarry in the Elkton West 7.5-minute quadrangle, are visible on the topographic map, but the DTM hillshade shows much more detail. Even the quarry's benches are visible on the DTM hillshade.

Features from Coastal Plain Mapping in Providence Forge 7.5-minute Quadrangle







Mapping in the Providence Forge 7.5-minute quadrangle has benefited from detailed elevation data collected for rectification of Virginia's orthoimagery. Shaded relief maps generated from this 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 follows consistent elevations, can be further refined with the use of shaded relief maps.

The surface raster developed for this quadrangle was classified using the natural breaks (Jenks) method in ArcGIS. The natural breaks classification scheme works well with this data because it selects the most suitable class ranges by finding clusters of elevation distribution over the entire range of the data set. On the DTM shaded by color ramps using the natural breaks classification scheme (Figure D) several terrace scarps are visible. One of the most prominent terraces has a flat elevation ranging up to 48 feet. This corresponds to the elevation for the Shirley Alloformation (Qsh) identified elsewhere on the Coastal Plain using traditional mapping techniques (Mixon et al., 1989). In Figure E, 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 hand augering and geologic borings.

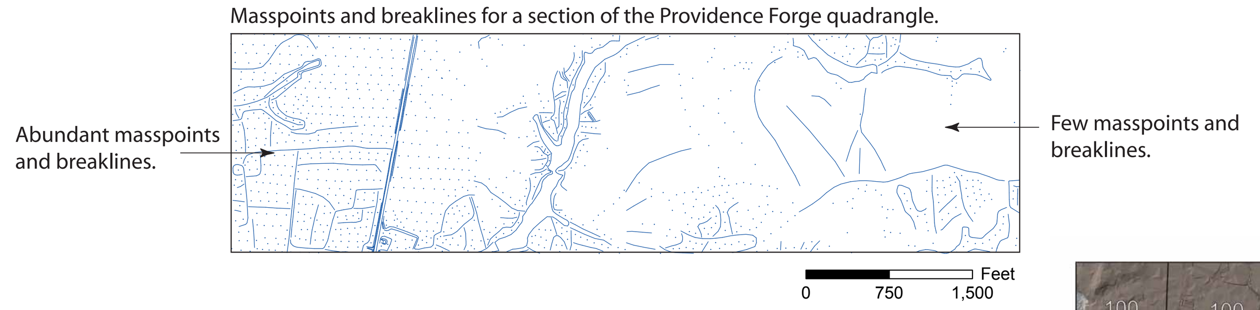
Limitations of DTMs from Orthoimagery Data

Although these DTMs 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 analysis using the DTMs. They are in no way as detailed as DTMs generated from LiDAR data.

1. Uneven elevation control.

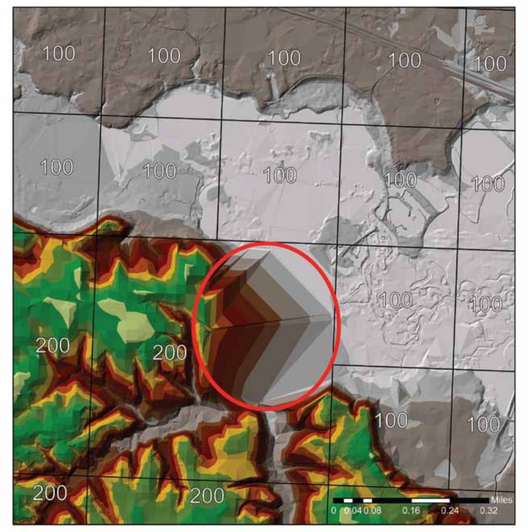
Areas with densely spaced infrastructure such as roads, railroads and buildings have many more breaklines and masspoints than do areas with little development. Also areas with significant changes in slope, such as ridges and areas with significant hydrography have more breaklines than areas that are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

Masspoints and breaklines for a section of the Providence Forge quadrangle.

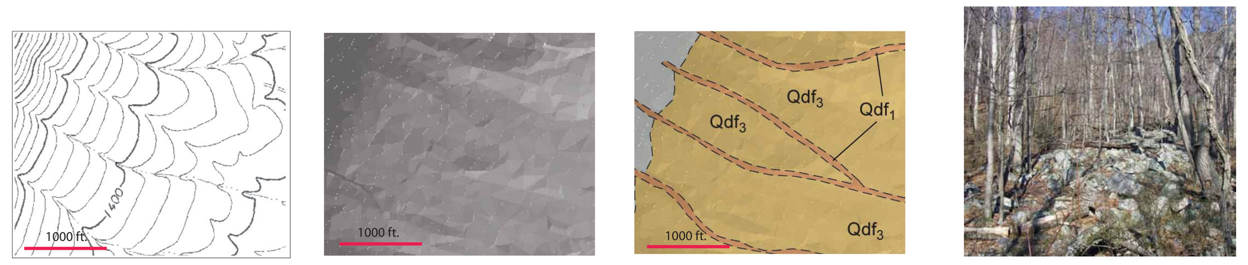


2. Areas covered by different DTM scales - the edge effect.

In some quadrangles the data collected for elevation ground control is at different scales. For example, on the image to the right of a section of Providence Forge quadrangle the portion of the quadrangle in New Kent County is at a scale of 1″=100′, while the portion in Charles City County is at a scale of 1″=200′. The variation in scale can cause edge effect errors such as the one in the middle of the image, leaving some areas without useful data.



3. Cannot resolve small-scale features.



In many cases nothing substitutes for boots-on-the-ground field work. Features such as the narrow debris flows (Qdf_1) on the geologic map image above are not resolvable on the DTM hillshade or the topographic map. Only field traverses enabled the geologists to map the extent of these features.

Conclusions

High-resolution DTMs have been very useful for 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 enables the geologist to target field work to evaluate observations made from these DTMs. In an ideal world, LiDAR would provide this service and enable much more quantitative analysis of an area, but Virginia lacks LiDAR for most areas. The DTMs based on elevation control from orthoimagery are a good substitute until the day when we do have statewide LiDAR coverage.

References

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Mixon, R.B., Berquist, C.R., Jr., Newell, W.L., Johnson, G.H., Powars, D.S., Schindler, J.S., and Rader, E.K., 1989, Geologic map and generalized cross sections of the Coastal Plain and adjacent parts of the Piedmont, Virginia: U.S. Geological Survey Miscellaneous Investigations Map I-2033, scale 1:250,000.

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