The Depth to Gas-bearing Shale Units in Western Otsego County

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Abstract

Otsego County is underlain by two significant gas shale units—the Marcellus shale and the Utica Shale. Both of these units contain substantial quantities of natural gas, and gas development companies are now targeting these units for exploitation. Development of this gas play hinges on hydraulic fracturing (hydrofracking), a technique which utilizes directional drilling (often called horizontal drilling), to increase permeability, and thus drain gas from the unit. The New York State Department of Environmental Conservation has recently issued a draft Supplemental Generic Environmental Impact Statement which outlines general case scenarios where no location specific Environmental Impact Statement is required. Some well site locations will require a special environmental assessment, namely in places where the target gas shale unit is less than 2000 feet below the ground surface, or where there is less than 1000 feet of separation between the target unit and a known drinking water aquifer. Thus, knowledge of the depth to target shale units is of fundamental importance.

I present a model for the depth to the Marcellus and Utica shales in Otsego County along its western border, essentially following the Butternut Valley. I combine digital geologic data from the New York State Museum, well log data from online digital records at Empire State Oil and Gas Information System, and topographic data from the United States Geologic Survey digital spatial data server to develop a calibrated model of the subsurface stratigraphy beneath western Otsego County. The results of the model delineate an area north of which an additional environmental assessment will be required. Citizens and landowners in western Otsego County may find the model useful for planning purposes.

The stratigraphic model depends strongly on the gentle southwesterly inclination (that is, the *dip*) of geologic formations underlying Otsego County. Determining the dip of geologic layers is most often performed in the field, where bedding surfaces provide suitable locations to measure the orientation of the layers. In regions where sedimentary layers dip gently (1° or less) obtaining reliable field measurements can be challenging, especially where layers are poorly exposed. In such cases, the orientation of rock layers can be derived from the combination of geologic maps of formation contacts and topography. Each layer can be treated as a dipping plane, and by measuring three points on the plane, a solution to a planar equation will yield the bed orientation. I implement this model in a spreadsheet, plotting topography extracted from digital data, solving for the strike and dip of formation contacts, and utilizing equations to extend formation contacts into the subsurface. I compare the model results to well log records as a test of model assumptions and as a means of calibrating the model (mainly the dip angle). The results highlight the necessity of coupling well log with surface geologic data to adequately refine the model.

Data Sources and References:

Empire State Oil and Gas Information System: http://esogis.nysm.nysed.gov//

US Geological Survey's National Map data server: http://seamless.usgs.gov/

New York State Museum's digital geologic map: http://tin.er.usgs.gov/geology/state/state.php?state=NY

DRAFT Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs, New York State Department of Environmental Conservation, Division of Mineral Resources, September 2009.

Paul Bourke, *Equation of a plane*, http://local.wasp.uwa.edu.au/~pbourke/geometry/planeeq/ , 1989, last accessed January 14, 2010.

Anonymous, *Intersection of two planes,* routine to compute the line of intersection, accessed Jan. 14, 2010, http://members.tripod.com/vector_applications/xtion_of_two_planes/index.html.

In the NYS DEC's own words…

"3.2.3 Projects Requiring Site-Specific SEQRA Determinations

The Department proposes that site-specific environmental assessments and SEQRA determinations be required for the high-volume hydraulic fracturing projects listed below, regardless of the target formation, the number of wells drilled on the pad and whether the wells are vertical or horizontal.

1) Any proposed high-volume hydraulic fracturing where the top of the target fracture zone is shallower than 2,000 feet along the entire proposed length of the wellbore;
2) Any proposed high-volume hydraulic fracturing where the top of the target fracture zone at any point along the entire proposed length of the wellbore is less than 1,000 feet below the base of a known fresh water supply;…

6.1.5.2 Subsurface Pathways

As explained in Chapter 5 and detailed in Appendix 11, ICF's analysis showed that hydraulic fracturing does not present a reasonably foreseeable risk of significant adverse environmental impacts to potential freshwater aquifers by movement of fracturing fluids out of the target fracture formation through subsurface pathways when certain natural conditions exist. To guide review and acceptability, these conditions include:

- Maximum depth to the bottom of a potential aquifer ≤ 1,000 feet;
- Minimum depth of the target fracture zone ≥ 2,000 feet;
- Average hydraulic conductivity of intervening strata ≤ 1 x 10^{-5} cm/sec; and
- Average porosity of intervening strata ≥ 10%. "

Verbatim from:

DRAFT Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program Well Permit Issuance for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs, **New York State Department of Environmental Conservation**, September 2009.

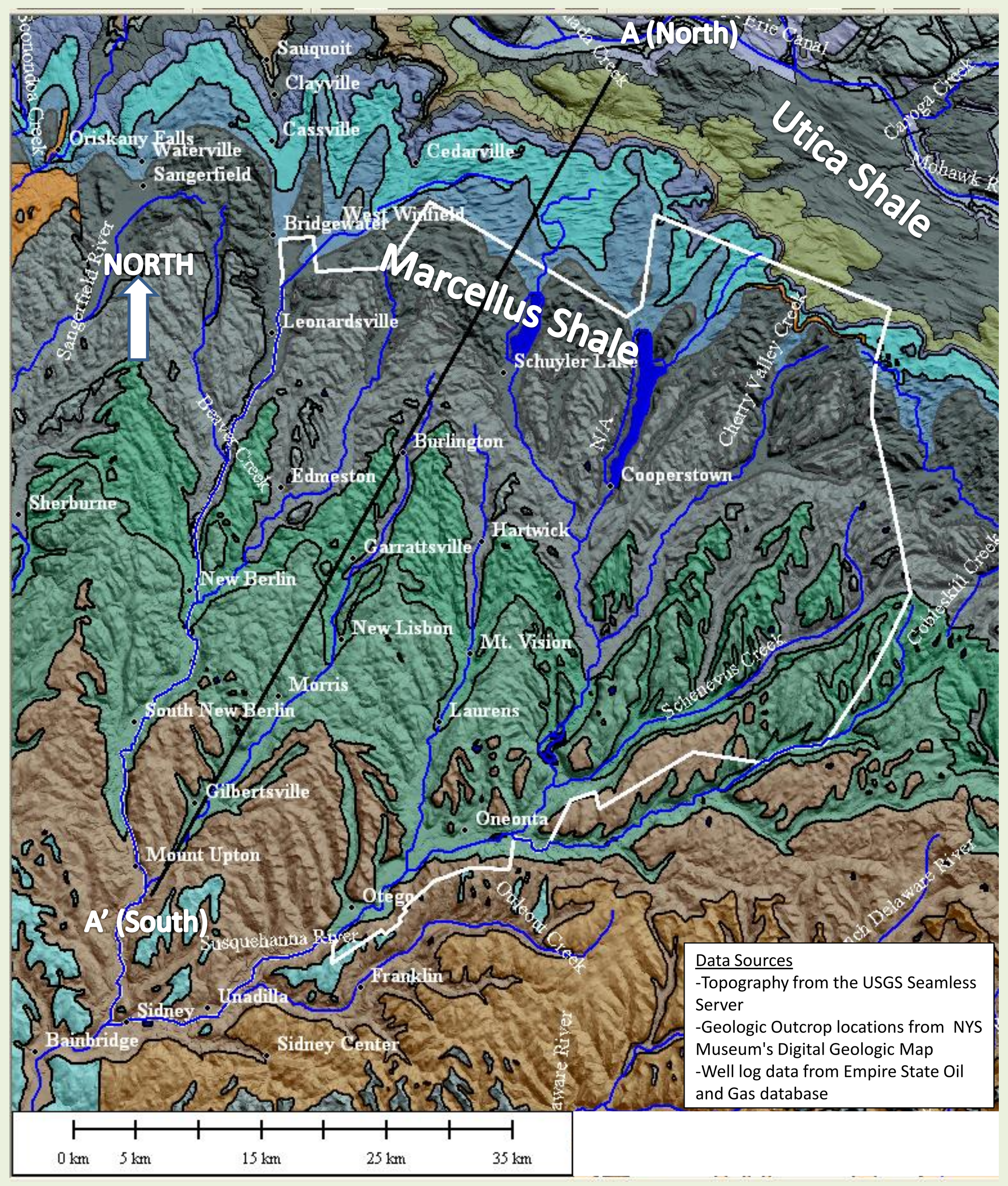


Figure 1 Geologic Map of Otsego County, overlain onto topography. Black line is cross section line for Figure 2 at right. Rock legend is provided below. White outline delineates Otsego County. UTM projection.

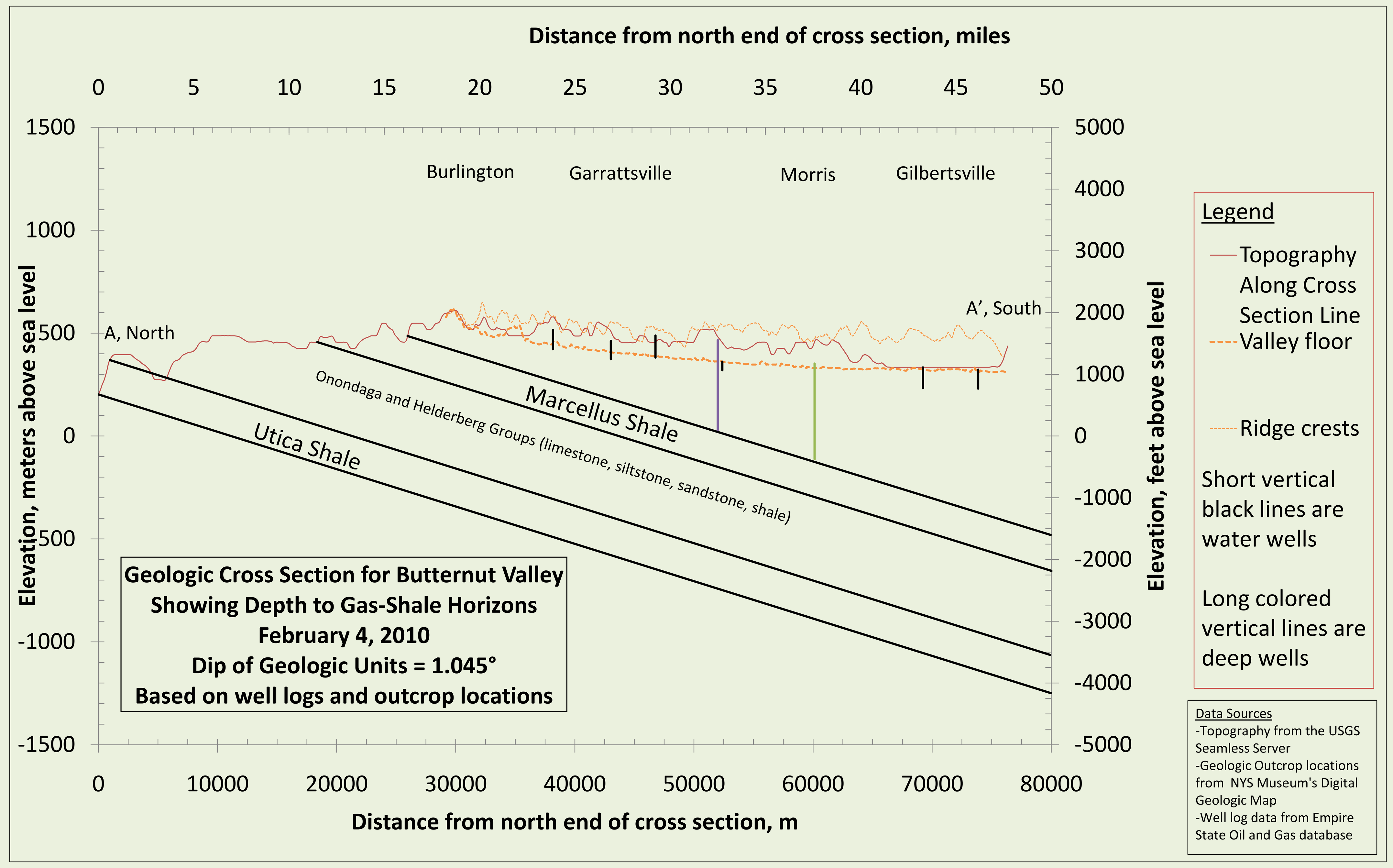
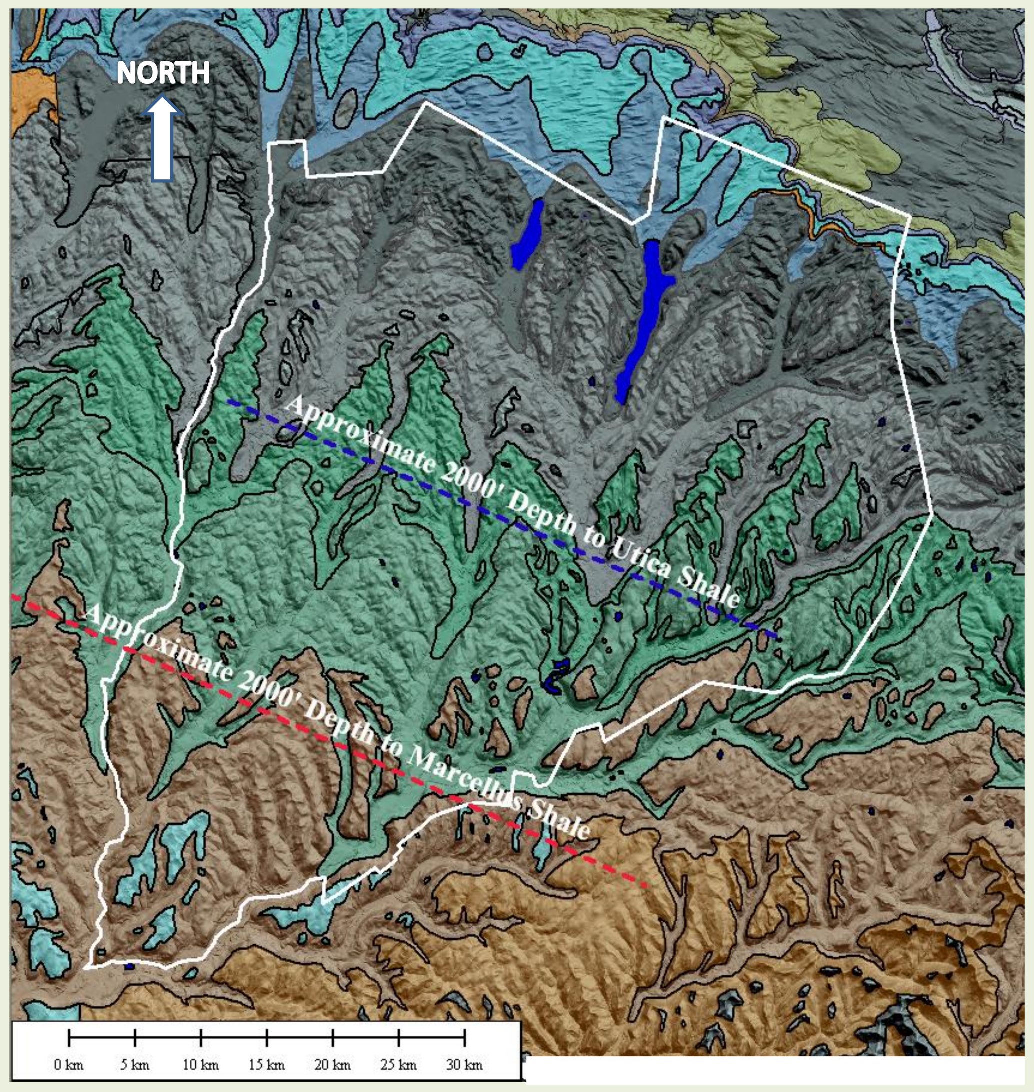


Figure 2 Geologic cross section, highlighting the Marcellus and Utica shales underlying Otsego County. Contacts were drawn with a linear equation (dip angle = 1.045º) extending from their respective outcrop locations at the surface. The dip angle can easily be adjusted in a spreadsheet. The original dips that were used were derived from the three-point method, described below. Deep wells provided a test of this method—essentially validating the 3-point method. Initial estimates were 1-2º based on the 3-point method. Well logs provided a tighter constraint on the dip angle.



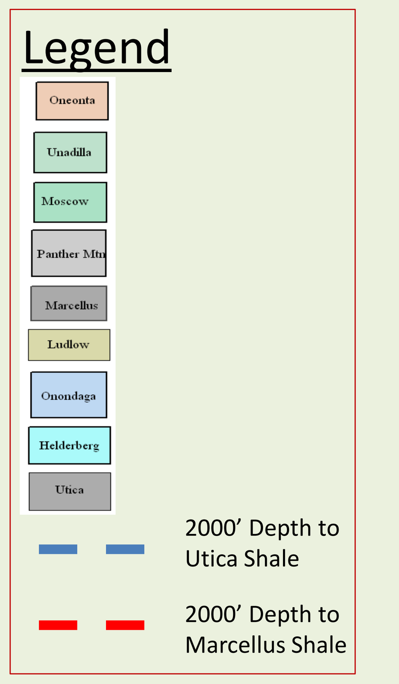


Figure 3 Geologic Map showing the approximate location of the the 2000' depth to the Utica and Marcellus shale units. Both units dip southwest, so the shale units shallow to the northeast of each line.

Key points to this paper

1) **Some parts of Otsego County will likely have additional environmental considerations before horizontal drilling can happen. Depending on the target shale unit, a significant portion of Otsego County will require site specific environmental assessments.**
2) **3-Point rock layer orientation determination using geologic and topographic data in a GIS along with spreadsheet calculations can provide a good first order characterization of subsurface stratigraphy.**

Description of 3-point method to determine rock layer orientation

Notice the long skinny gray fingers extending down the valleys in the geologic map (Figure 3)? This pattern of geologic contacts that extend down valleys and rise up on ridges can be used to find the orientation of the rock layers. We start with the assumption that the rock layer can be approximated by a plane.

1. First, select three points along a contact. This is simple to do in a GIS.
2. Then, fit a plane to the three point coordinates, using the vector cross product. This yields a plane equation: Ax + By + Cz + D = 0, where A, B, and C represent a vector normal to the plane.
3. The plane is then intersected with an arbitrary horizontal plane whose unit normal is (0,0,1). Using the vector cross product of the surface normals yield a line of intersection which represents the strike of the rock layer.
4. The resultant vector (i, j, k) can be used to determine the azimuth of the strike.

The standard equation of a plane in terms of 3 dimensional coordinates is:

$$Ax + By + Cz + D = 0$$

One can determine $\langle A, B, C \rangle$ if three points $(x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3)$, on the plane are known:

$$A = y_1(z_2 - z_3) + y_2(z_3 - z_1) + y_3(z_1 - z_2)$$
$$B = z_1(x_2 - x_3) + z_2(x_3 - x_1) + z_3(x_1 - x_2)$$
$$C = x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)$$
$$-D = x_1(y_2 z_3 - y_3 z_2) + x_2(y_3 z_1 - y_1 z_3) + x_3(y_1 z_2 - y_2 z_1)$$

INPUT POINTS (UTM Coordinates)					OUTPUT	
Pt id	x	y	z		**Strike**	**Dip**
1	489714.9	4722282	547.202		**116.8**	**1.074**
2	483739.9	4713509	349.835		degrees	degrees
3	492549	4708235	335.936			

Where subscripts refer to points 1, 2, and 3.

Intersecting the dipping plane with a horizontal plane yields a line X of intersection (the strike):

$$X = (Bx1 + Cx0)i \quad , \quad (Ax1 + Cx0)j \quad , \quad (Ax0 + Bx0)k$$
$$X = Bi, Aj, 0k$$

Finally, the strike $= \sin^{-1}\left(\frac{A}{(A^2+B^2)^{1/2}}\right) + pi/2$

The dip $= \cos^{-1}\left(\frac{C}{(A^2+B^2+C^2)^{1/2}}\right)$

Map View of Strike Line as a Unit Vector