CHAPTER V

GEOLOGIC CROSS SECTIONS, MAPS, AND PLANS

After geologic samples have been properly collected and logged, the resultant information is used to construct geologic maps and cross sections. These maps and sections will provide a graphical account of the area geology that can then be used, along with other data, to develop a site-specific description of the proposed permit and adjacent area (See Chapter VI). All such maps and sections must be prepared and certified by a qualified individual approved by the Commissioner. The following sections describe the methods of construction and the types of maps and sections that may be required.

A. CONSTRUCTION AND CORRECTION TECHNIQUES

Because of the lack of detailed geologic mapping in the West Virginia coal field, most cross sections and maps will have to be prepared by the applicant using information collected during the geologic sampling program. This section briefly describes methods of calculating and correcting for inclined strata.

1. Determination of Strike and Dip

Strike and dip can be measured through a variety of methods, both by direct field measurement and by calculation. However, because the majority of the West Virginia coal field consists of essentially horizontal rock (<10°), the indirect method is preferable because it is not affected by minor undulations in the bedding. The easiest method of calculation is the three-point method. The three-point method utilizes three points that lie at different elevations on one bedding surface, such as the bottom of a coal seam. This bedding surface must be consistent throughout the area and be positively identified in each drill hole or outcrop. The calculation of strike and dip also requires that the distances and directions between the three points be known, along with the differences in elevation. The lateral distances can normally be determined from a topographic map and elevations from methods described in section B.l of Chapter 3.

<u>*EXAMPLE*</u>

Figure V- 1 illustrates a three-point problem using the elevation of the bottom of the coal seam taken from drill holes A, B, and C. The strike is found by locating a point D, where the coal would have the same elevation as drill hole B (intermediate elevation), and is on the line joining the highest and lowest coal elevations, drill holes C and A. The point D can be located by solving the equation:

$$\text{length of } \overline{AD} = \text{length of } \overline{AC} \times \frac{\text{difference in elevation between A and B}}{\text{difference in elevation between A and C}}$$

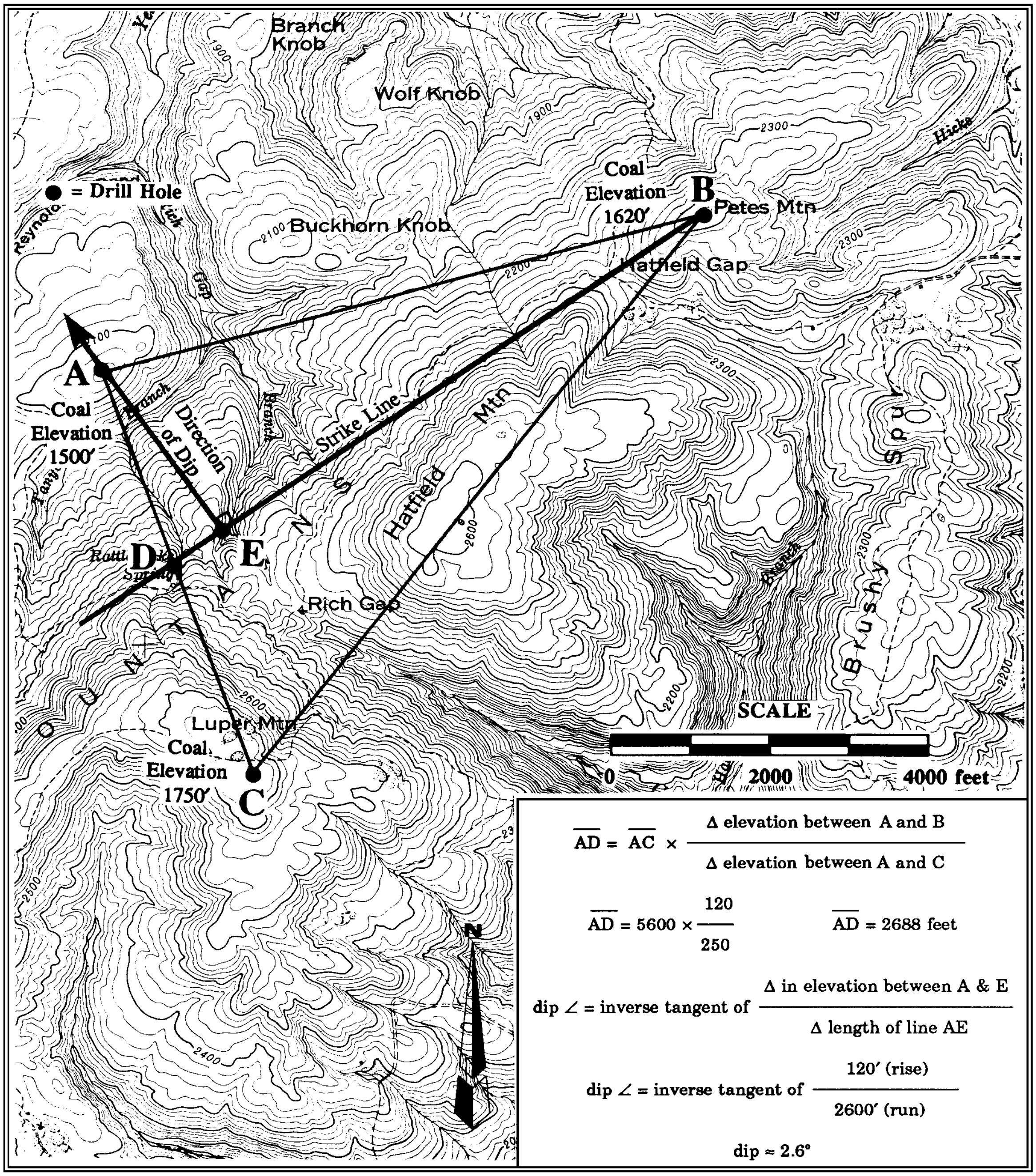


Figure V-1.-Example of Strike and Dip Calculations Using a Three-Point Problem

The strike is now shown as line BD. To determine dip, a new point E is established at some distance that will create a perpendicular line to the lowest elevation point A. Once this line AE is established, dip angle can be calculated by the following equation:

$$\text{dip} \angle = \text{inverse tangent of } \frac{\text{difference in elevation between A and E (rise)}}{\text{length of line AE (run)}}$$

2. Correction for Strike and Dip

Where geologic strata are dipping off the horizontal, corrections must be made before drill hole data can be projected to the surface as a cropline. Also, drill hole data that are outside the plane or line of a geologic cross section, can be extrapolated into that cross section, if it is first adjusted for the area strike and dip. However, this extrapolation should only be used in areas of consistent stratigraphy and over relatively short distances. In areas of complex stratigraphy or structure, a fence diagram should be used instead of extrapolation techniques. The following formulas can be used to determine the vertical rise or fall of a coal seam or drill hole over a known horizontal distance.

EXAMPLE 1

Where the true strike and dip are known, the rise or fall of a coal seam in any direction from a point of known elevation can be calculated using the following formula:

sin α x true dip angle = adjusted dip angle

Where α = the angle between the true strike and the direction of concern

Once the adjusted dip angle is known, a simple cross section can be used to project the coal seam to its surface outcrop. Several such cross sections can be used to define the coal outcrop line. However, in cross sections using vertical exaggeration to better illustrate the local topography, the dip must be converted from degrees to slope. Once the slope is known, a slope line is projected to the surface in the same manner as described above. Figure V-2 illustrates the use of this method for the determination of coal outcrop elevations.

EXAMPLE 2

For geologic cross sections where additional drill hole data are available, but not in the actual plane of the cross section, a correction factor must be determined prior to use in

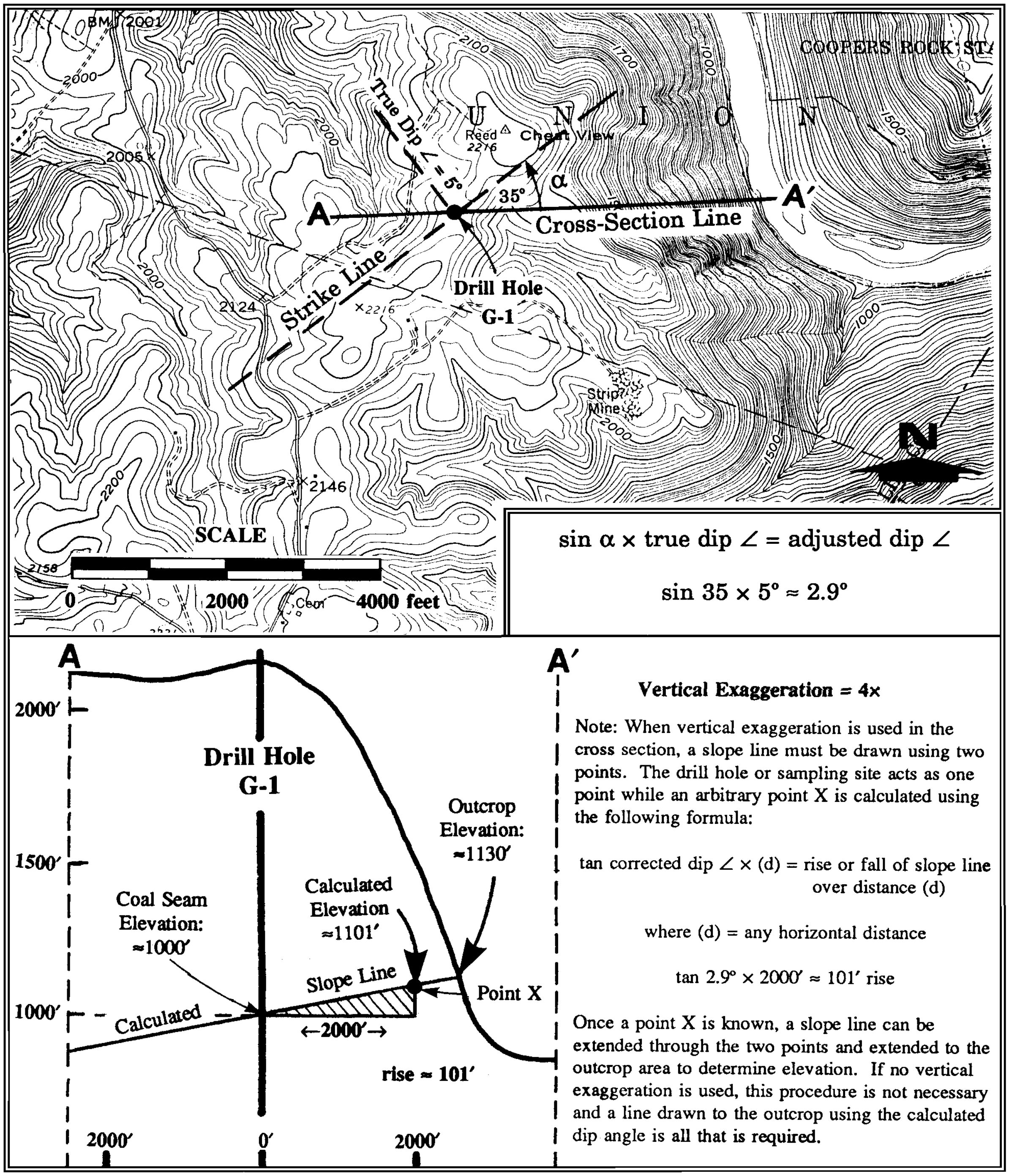


Figure V-2.-Example for Determination of Coal Outcrop Elevation *the section. This correction factor is the number of feet the drill hole or strata must be raised or lowered to compensate for the area strike and dip. The correction factor can be calculated by the following formula:*

$$\sin \alpha \times \tan \beta \times (d) = \text{vertical correction factor in feet}$$

Where: α = *the angle between the true strike line and the line on which the drill hole or observation point will be moved to intercept the cross-section line or plane*

β = *the true dip angle*

d = the lateral distance between the drill hole or observation point to the cross-section line or plane

Figure V-3 illustrates the use of this formula to calculate the amount of vertical rise which must be compensated for by the use of a drill hole located outside the cross-sectional plane. Note: The correction factor is an absolute number. *To determine if this distance is added or subtracted from the actual elevations, it must be determined if the movement from the drill hole to the cross-sectional plane is up-dip or down-dip. If the movement is in the down-dip hemisphere, it is subtracted from the actual elevation; if the movement is in the up-dip hemisphere, it is added to the actual elevation.*

B. DRAWING DETAILS

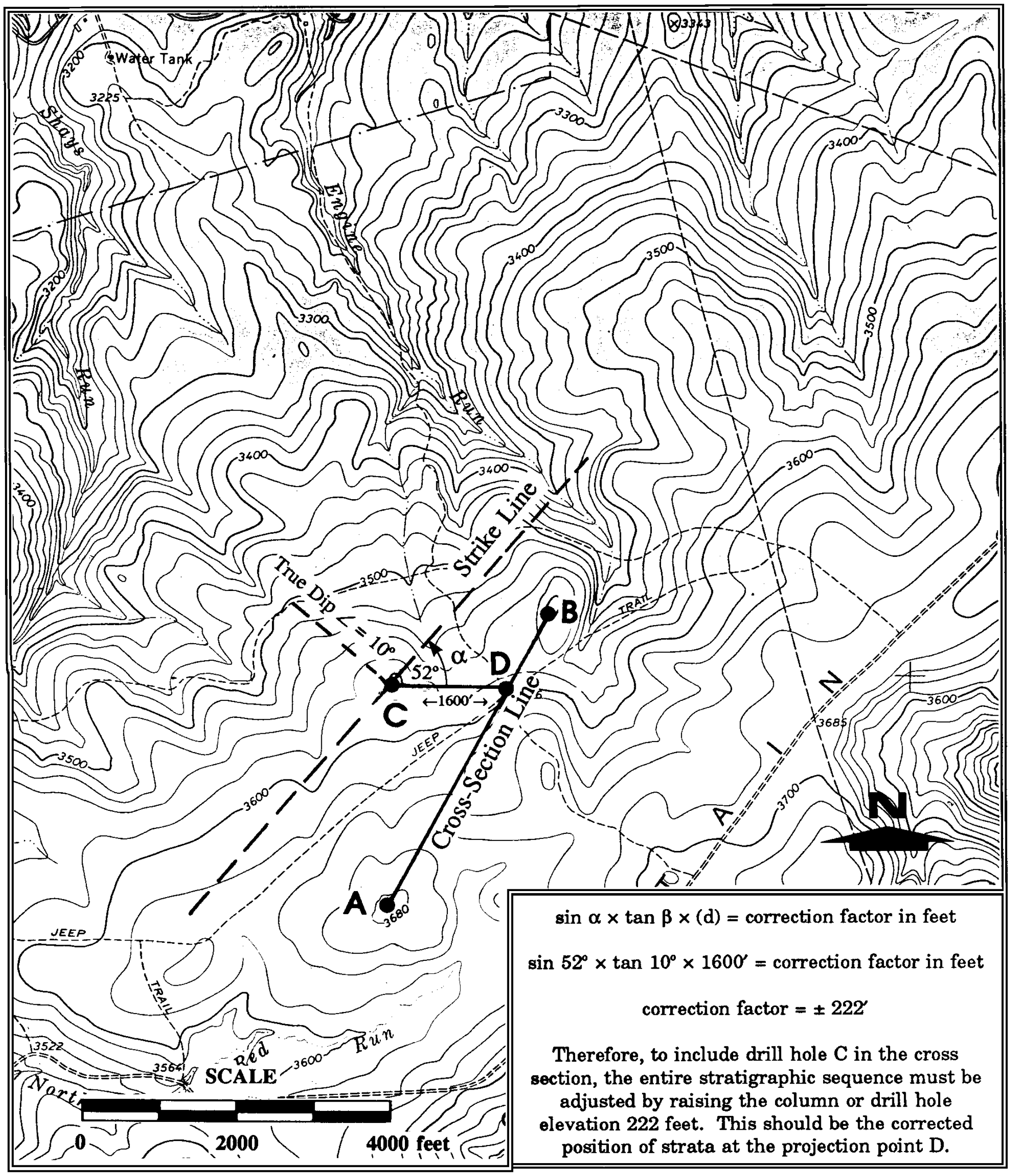
This section briefly describes the types of cross sections and maps that may be needed to adequately characterize the site geology. The actual types of drawings that might be required will be based on site-specific conditions and needs.

1. Geologic Cross Sections

A geologic cross section is a diagram or drawing, made from actual observations or inferred from other evidence, of underground geologic conditions along a given line or plane of the earth's crust (Thrush et al., 1968). Each geologic cross section should depict the overburden or other material from the upper limit of disturbance down to, and including, the deeper of either the stratum immediately below the lowest coal seam to be mined or any aquifer below the lowest coal seam to be mined that may be adversely impacted by mining. For underground mining operations, a cross section should extend through the entire area of proposed workings, including the maximum depth of cover. All geologic cross sections should label all coal seams and marine zones to be disturbed using presently recognized by the West Virginia Geologic and Economic Survey.

A cross section should be drawn from a minimum of two data points, such as drill hole sites and/or highwall/outcrop observation points. Usually, at least one cross section should be drawn as nearly parallel to the strata dip as possible, but primary consideration should always be given to an accurate portrayal of the permit area. The number of cross sections needed to depict an area may vary, depending upon the geology of the area and the size and type of mining operation.

At least one cross section should be drawn to represent the areas of disturbance associated with both surface or underground mining operations. For area type surface mines, cross sections



should depict both the length and width of the proposed site, and at least one cross section should

Figure V-3.-Example of Correcting for Elevation Differences in Inclined Strata intercept any pronounced structural feature such as a fault, fold, or significant fracture zone (lineament).

Each geologic cross-section should portray the nature, depth, and thickness of all strata, including coal seams and rider seams, using standard geologic terminology and symbols (See Appendix 1-3). The nature of each stratum refers to the type of material and its lithologic characteristics. A legend, and both horizontal and vertical scales (including elevations), should be indicated on the drawing, with any scale exaggerations noted. Cross sections should always include the surface topography in concert with the subsurface geology. The cross-section line should also be shown on the appropriate permit map(s).

> <u>*EXAMPLE 1*</u>
>
> *A site-specific geologic cross-section is provided in Figure V-4. This indicates that cross section, X-X', is based on drill holes A, B, and C through the projected workings of a hypothetical underground mine.*
>
> <u>*EXAMPLE 2*</u>
>
> *Locations of the cross section and drill holes in plan view can be shown as illustrated on the map in Figure V*-5.

Where sufficient ground-water information is known, a geologic cross-section should also show seasonal fluctuations in the hydraulic head. This type of information can then be used to determine the minimum elevation or relative position in the backfill, where acid- or toxic-forming materials can be disposed and remain above the postmining water table. However, such a cross-section will not necessarily provide any indication of the direction of ground-water movement. Information on ground-water movement is accomplished through the use of a potentiometric surface map. Such a map is more closely related to hydrology, and will not be discussed in this handbook.

2. Geologic Column

A geologic column is a composite diagram that shows, in a single column, the sequence of stratigraphic units in a given locality or region. A geologic column would include information collected from several drill holes, or sampling sites, to form a single generalized stratigraphic section. The geologic column typically places the oldest rocks at the bottom and the youngest at the top, with all inclined strata adjusted to the horizontal. The purpose of the geologic column is to identify the different geologic strata based on age and their relative position to one another.

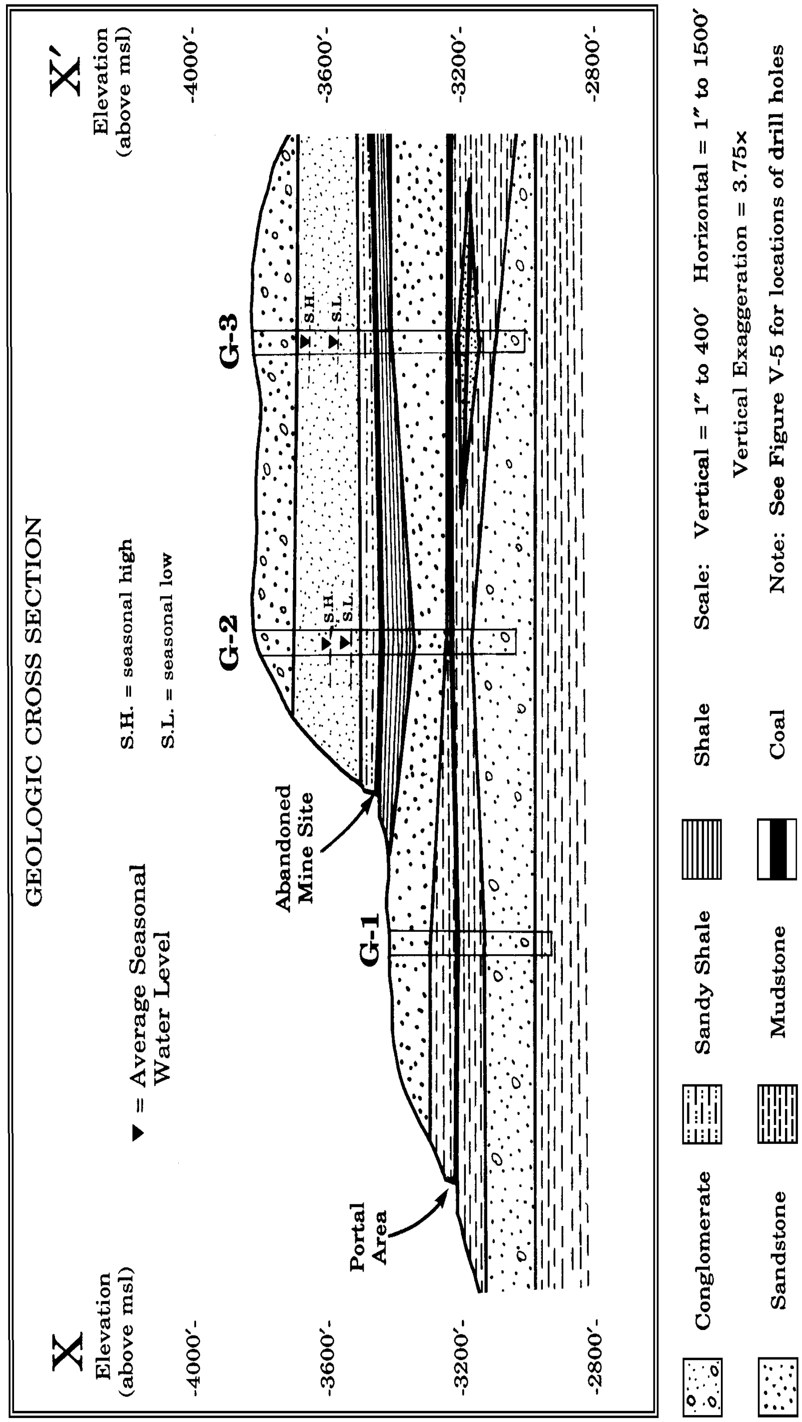
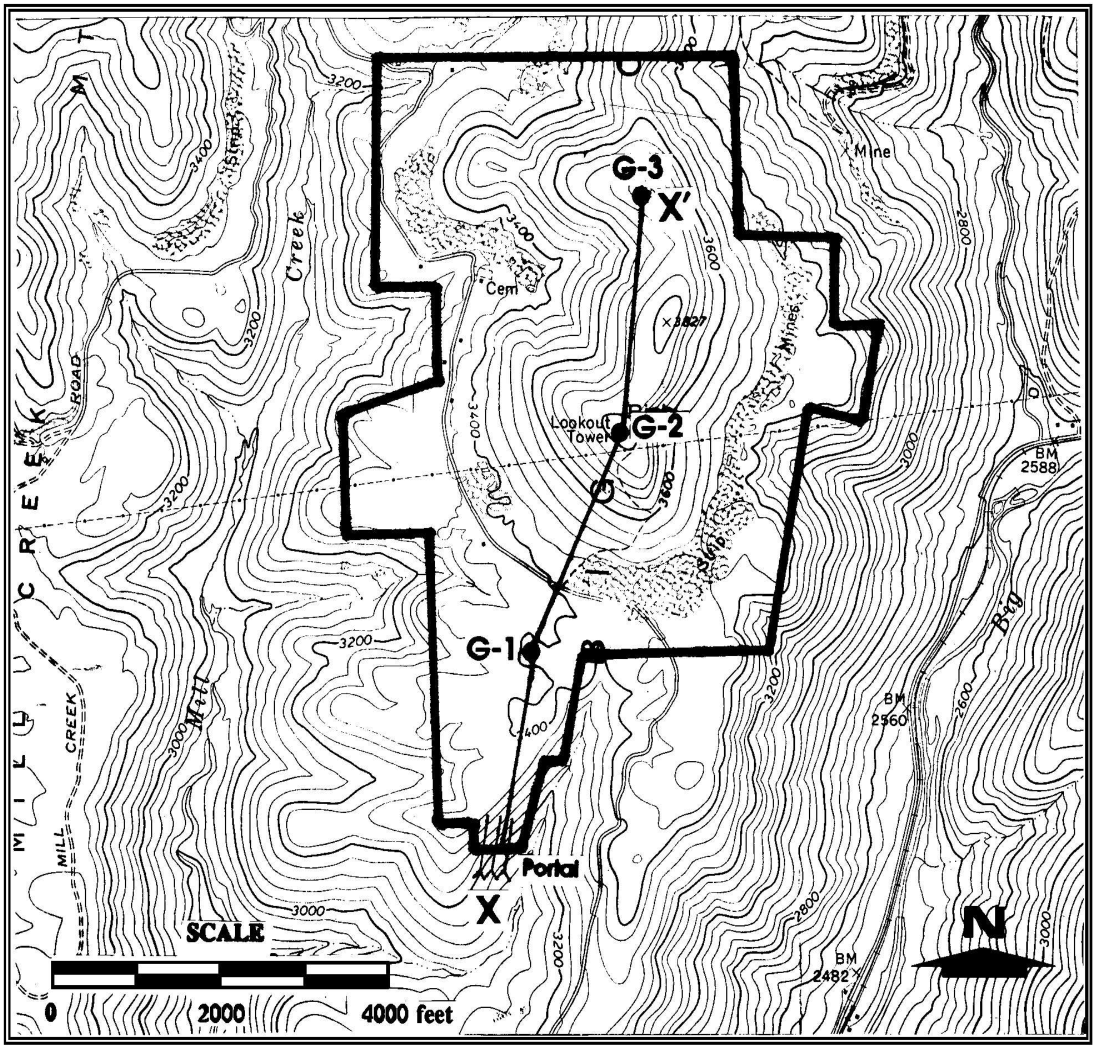


Figure V-4-Typical Geologic Cross-Section X - X'



OLD KING COAL MINE
CROSS-SECTION LINE X - X'

Location	Elevation
Portal Area	3210'
Drill Hole G-1	3405'
Drill Hole G-2	3815'
Drill Hole G-3	3770'

Quadrangle: Gobpile Creek

Latitude: N 38° 00'00"

Longitude W 80° 00'00"

Maximum Extent of Underground Workings

Mine Openings

Figure V-5.-Location of Cross-Section X - X'

<u>EXAMPLE</u>

Figure V-6 is an example of a geologic column, based on well log data from drill holes A, B, and C. (See Figure V-5.)

When constructing a geologic column, standard geologic symbols should be used in the drawing. (See Appendix 1-3). Readily distinguishable lithologic units, or marker beds, such as named coal seams or rock units, should be indicated along with all aquifer units. For surface mining applications, the relative position of all acid- or toxic-forming zones, and all zones proposed for use as topsoil substitutes, must be shown.

3. Fence Diagrams

A fence diagram is defined as a drawing in perspective of three or more geologic cross-sections, showing their relationship to one another (Bates, et al., 1987). The scales will normally diminish with distance from the foreground to give proper perspective. The use of a fence diagram is most useful in areas where there is significant stratigraphic variations, both vertically and horizontally. They are also useful for areas where drill holes or sampling stations are scattered geographically, making a straight line section impossible.

<u>EXAMPLE</u>

Figure V-7a is an example of a fence diagram, based on well log data from drill holes shown on Figure V-7b.

Whenever a fence diagram is used, the vertical and horizontal scale used in each plane (all three-dimensions) of the drawing should be clearly indicated. The types of information required on a fence diagram are the same as those described for geologic cross sections described in this chapter (section 2). Only standardized geologic symbols should be used (see Appendix 1-3).

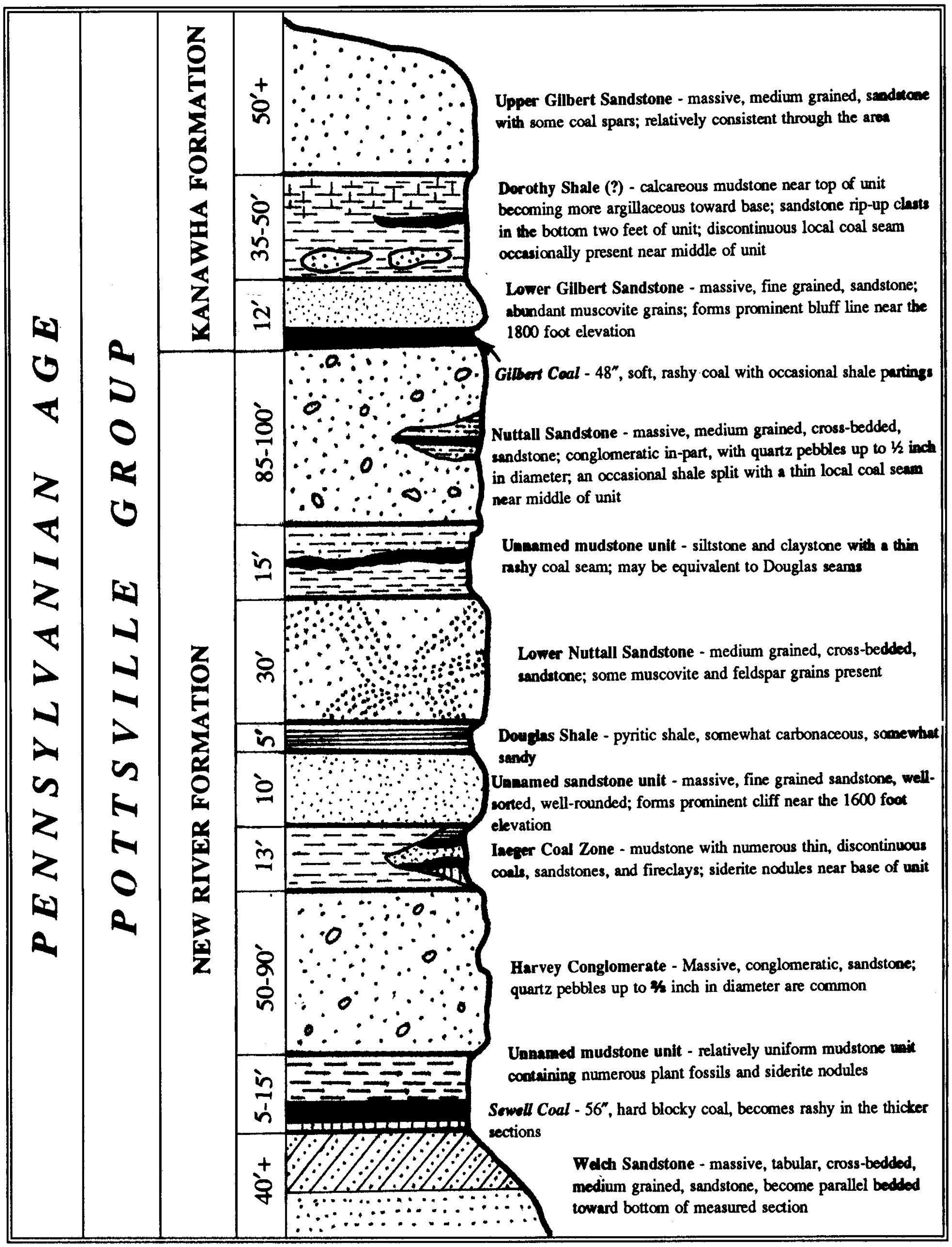


Figure V-6.-Composite Geologic or Stratigraphic Column

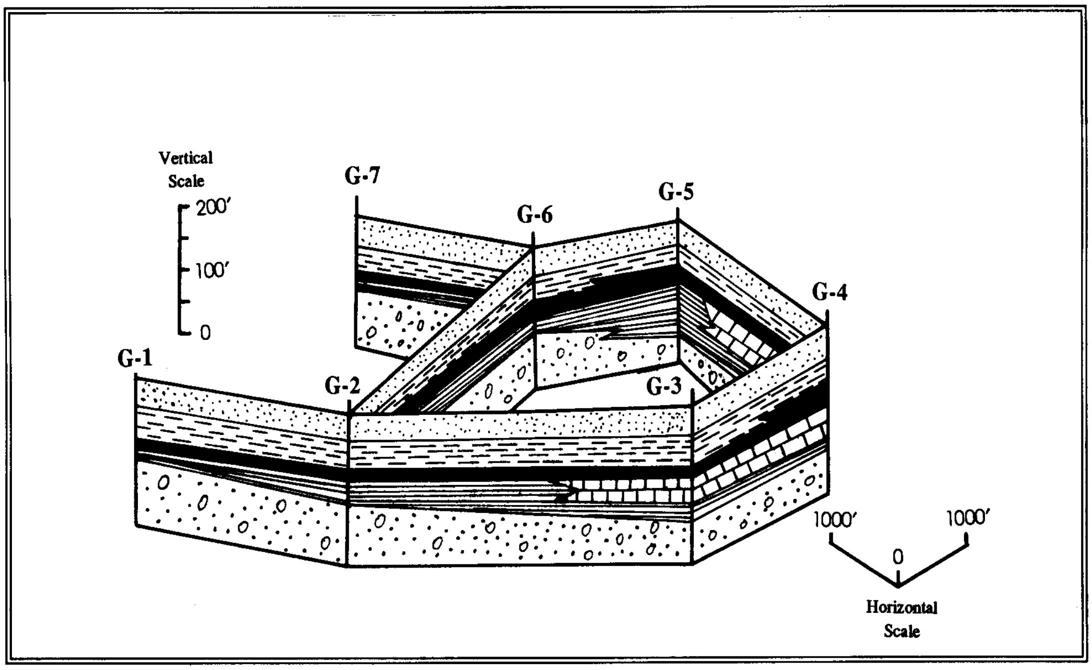


Figure V-7a.–Illustration of Fence Diagram

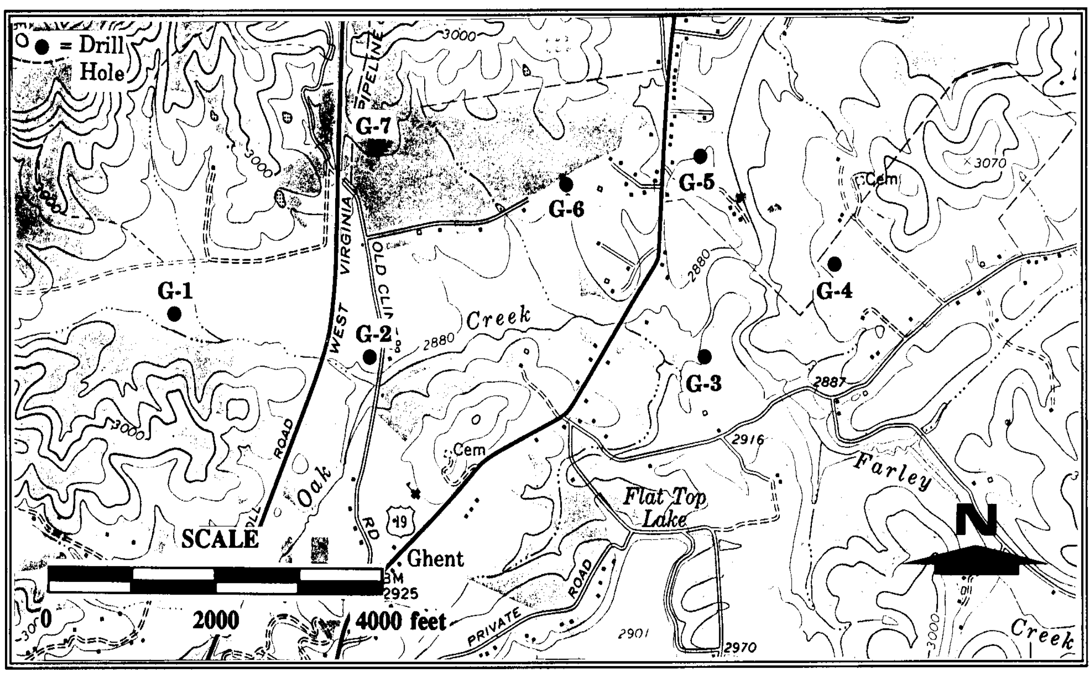


Figure V-7b - Locations and Relative Positions of Drill Holes Used to Construct Fence Diagram

4. Hydrogeologic Maps

The term “hydrogeologic map” is relatively self-explanatory. It is a map, on which geologic information is plotted, using symbols, patterns, or colors (See Appendix C). For surface mining operations, a geologic map will show the areal distribution of the various geologic features identified during the background data search and the geologic drilling and/or sampling program. It will also show the location, areal extent, and distribution of features, which may directly affect the geology of the area, such as past mining operations.

A hydrogeologic map should first show the locations and collar elevations of all oil wells, gas wells, and drill holes, as well as all highwall, outcrop, and topsoil sampling locations, which were used for the collection or correlation of geologic information. Secondly, the croplines of all coal seams, along with all major recognizable stratigraphic contacts (i.e. formational boundaries), should be plotted. However, these croplines should be drawn based on actual field observations or be extrapolated from drill hole data after being corrected for local strike and dip (see section A of this chapter).

All structural features, such as faults, folds, fractures, and lineament traces, should be shown, along with information on their axial traces and/or strike and dip directions. The strike and dip of the coal seams to be mined should also be included. These features influence the movement and storage of ground water, both in the premining and postmining stages of the operation.

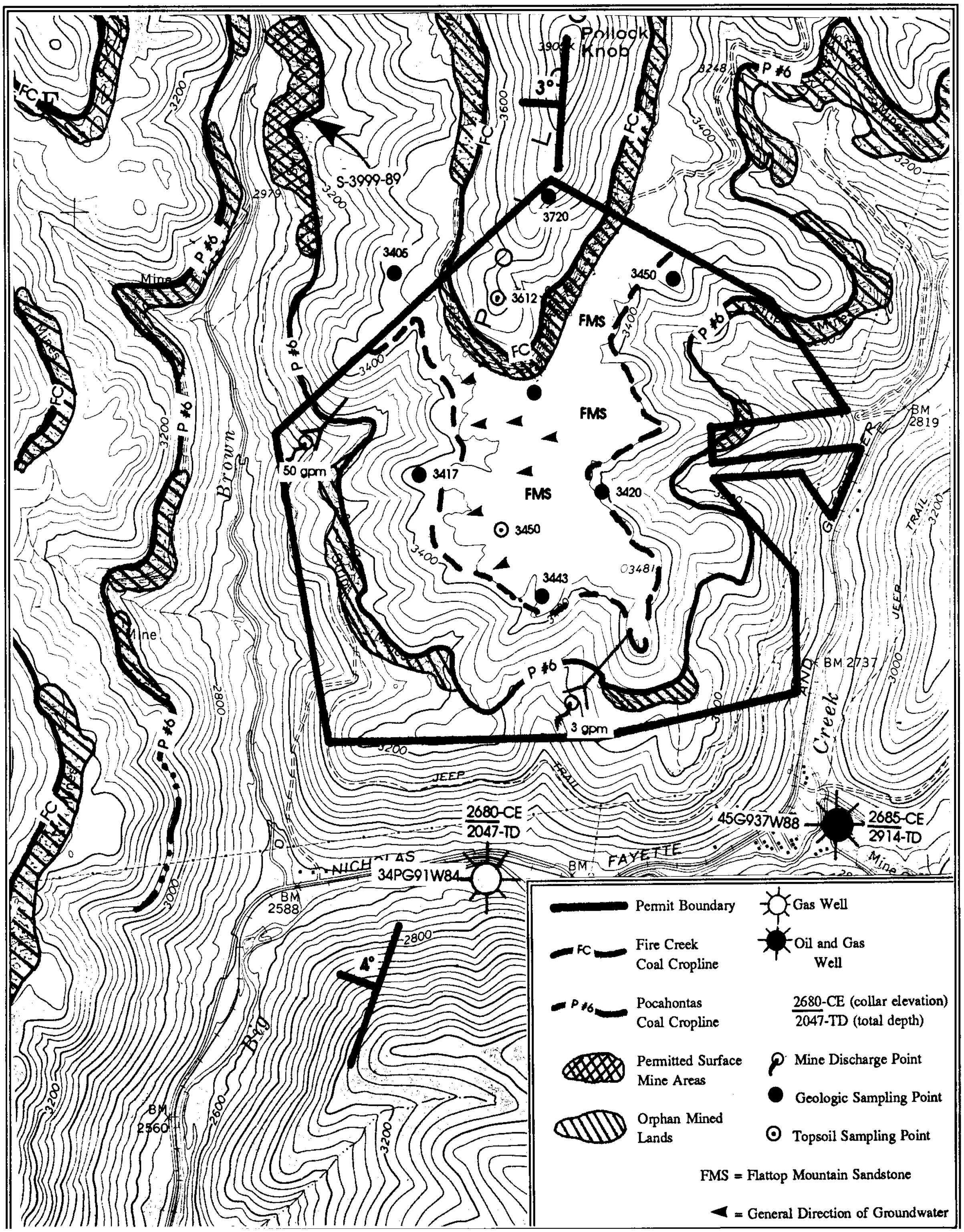
To determine the potential impacts to the area hydrology, additional information relating to ground-water discharge points should be included. This would include the location of all seeps, springs, and discharging mine adits. Care should be taken to match the position of these discharge points to the actual stratigraphic unit in which they are located. Where defined, the name and areal extent of all aquifers in the permit area should be shown along with the anticipated direction of ground-water movement. A separate "ground-water map" should be used where this type of information clutters or confuses the original geologic map.

Finally, the hydrogeologic map should also show the location of all mining related disturbances both within and immediately adjacent to the proposed permit area. Underground mines should be shown and include the location of openings and the extent of the underground workings (including auger workings). Where multiple-seam recovery has occurred, several maps may be required to show all underground workings. Depiction of surface mines should show all refuse and rock disposal areas along with the coal removal areas. If applicable, WVDEP permit numbers should be included.

EXAMPLE

Figure V-8 shows an example of a hydrogeologic map for an area-type mining operation in a relatively simple geologic setting.

Geologic maps should include a legend that identifies all symbols used, horizontal scale, contour interval, and the direction of true north.



V-8 *Typical Geologic Map*

5. Structural-Contour Maps

A structural-contour map can be considered as a subsurface topographic map drawn on some known surface, such as the base of the coal seam. These maps use structure contour lines to connect points of equal elevation along this known surface. These maps are most commonly used to determine the direction of ground-water movement in both proposed and existing underground workings. However, this type of map may also be required for surface mine operations where the elevation and configuration of the pit floor is critical.

Structural-contour maps should always show horizontal scale and the interval between contour lines. For most surface mining applications, the contours are always based on elevations above mean sea level (above msl). The contour interval should be determined based on the total vertical variation determined in the drilling and sampling program. For example, where the coal fluctuates between 1650 feet (above msl) and 1680 feet (above msl), a five-foot contour interval will probably suffice. However, in areas where there are greater vertical variations, a 10 to 20 foot contour interval may be needed to prevent cluttering of the map. However, the contour interval should always be small enough to provide adequate definition of the structure.

> *EXAMPLE*
>
> *Figure V-9a is an example of a structural-contour map drawn from drill hole elevations at the bottom of the coal. Figure V-9b is an example of a structural-contour map drawn from elevations extracted from an underground mine using survey points.*

6. Isopach Maps

An isopach map is very similar to the structural-contour map just described. However, an isopach map depicts geographical variations in the thickness of a given coal seam or stratigraphic unit. The line used to connect points of equal thickness is called an isopach or a thickness contour.

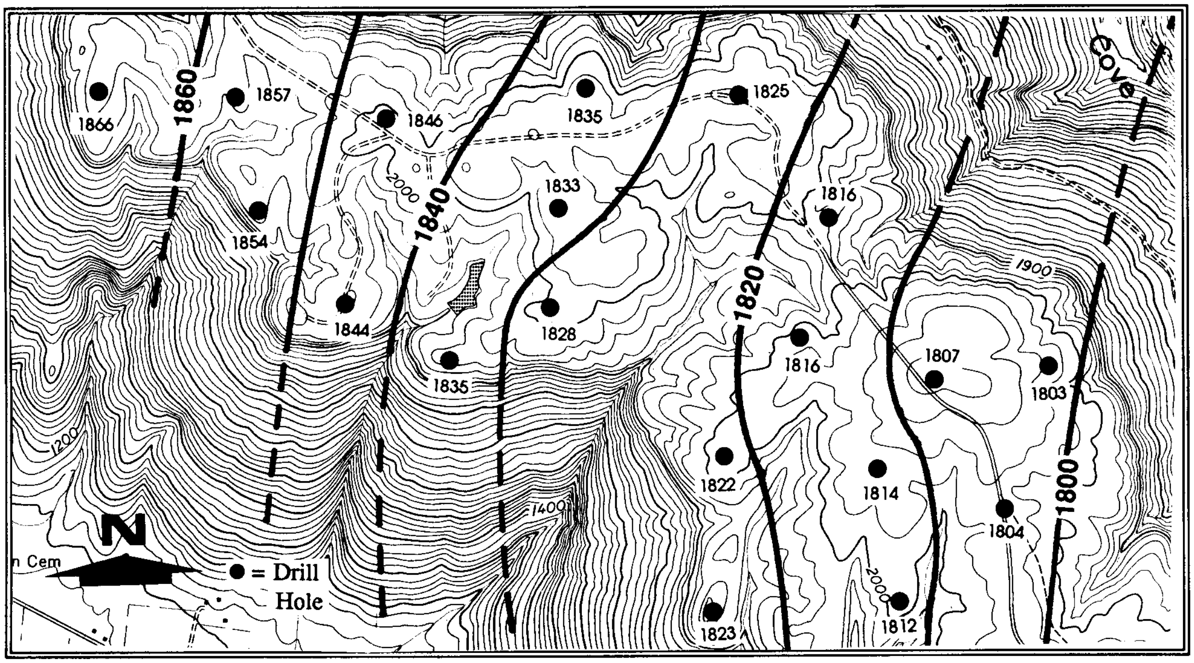


Figure V-9a.–Typical Structural-Contour Map Drawn on the Base of Coal Seam

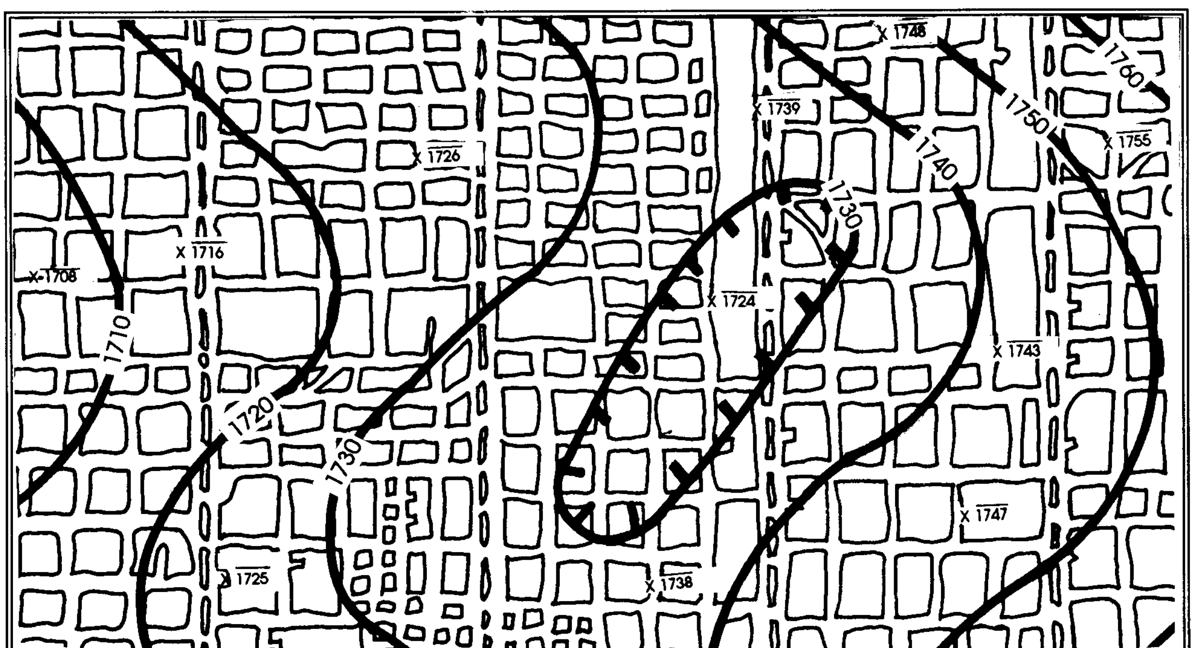


Figure V-9b.-Typical Structural-Contour Map Drawn Against And Underground Mine Workings Map

Isopach maps serve two different purposes. First, they are required for underground mining operations so that a determination of subsidence effects can be made. Secondly, they allow volumetric calculations to be made of a certain critical stratum, such as the volume of an acid-forming shale unit or durable sandstone. Such information is of extreme importance in developing a toxic materials handling plan and in determining the amount or percentage of durable rock available for use. For subsidence, the isopach map is drawn based on the variation in depth from the surface to the top of the coal. For volumetric purposes, the isopach map is drawn on the variation in thickness of the seam or stratum in question. This is simply done by either subtracting the elevations of the bottom of the stratum from the corresponding elevations of the top of the stratum, or by subtracting the depth at which the strata was first encountered from the corresponding depth at the bottom of that particular strata (See example 1).

EXAMPLE1

Top of black shale interval	*1765 feet above (msl)*
Bottom of black shale interval	*-1754 feet above (msl)*
Unit thickness at point	*11 feet*

or

Depth to bottom of black shale	*93 feet*
Depth to top of black shale	*-82 feet*
Unit thickness at point	*11 feet*

EXAMPLE 2

Figure V-10a is an example of an isopach map showing the depth or thickness of the overburden above a proposed underground mine. Figure V-10b is an example of an isopach map drawn on the thickness of a potentially acid-forming shale.

7. Lineament Maps (Fracture Trace Analysis)

A lineament is a linear geomorphic feature of regional extent that is believed to represent the subsurface environment. Lineaments maps are normally generated using standard aerial photography, infrared photography, and/or some form of remote sensing imagery, such as Landsat or side-looking airborne radar systems. Examples of lineaments may include linear topographic expressions, straight or trellis drainage patterns in streams, and linear vegetation patterns. These surface expressions may be directly related to faults, folds, or significant zones of fracturing. Such information can be used to help locate ground-water monitoring wells and determine structural controls of ground-water movement. For underground mining operations, lineament maps may also show areas of potential roof-control problems. However, it is strongly recommended that all lineament maps be field checked if such an application is proposed.

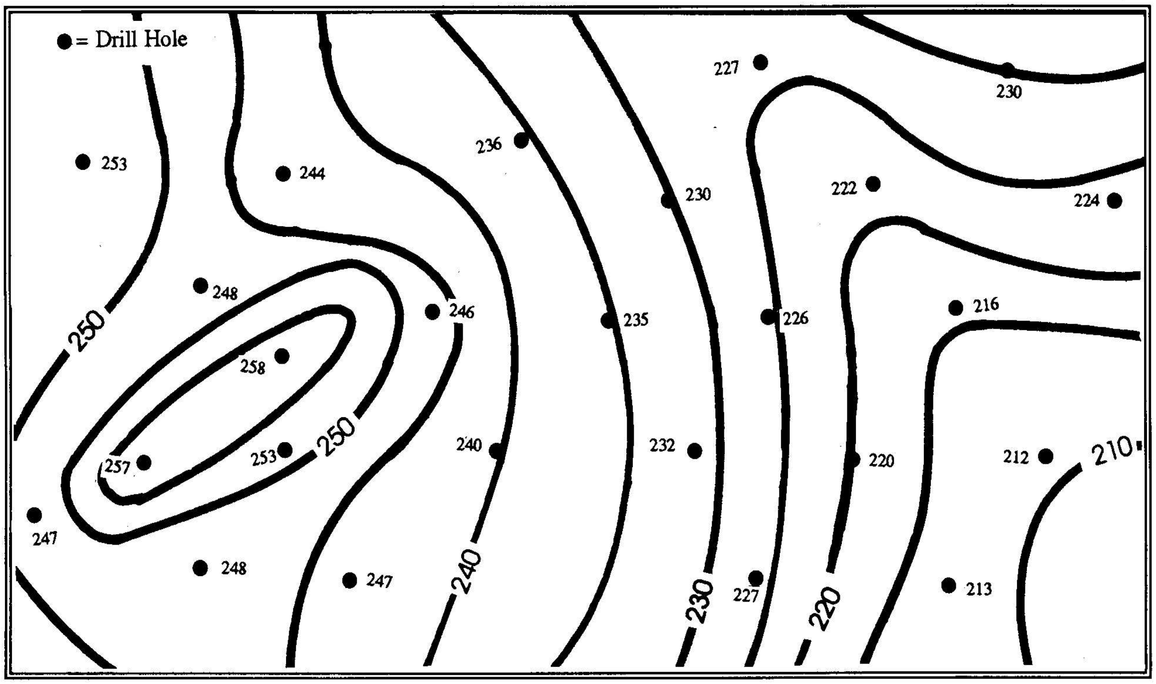


Figure V-10-a.–Isopach Map Showing Depth of Cover for an Underground Coal Mine

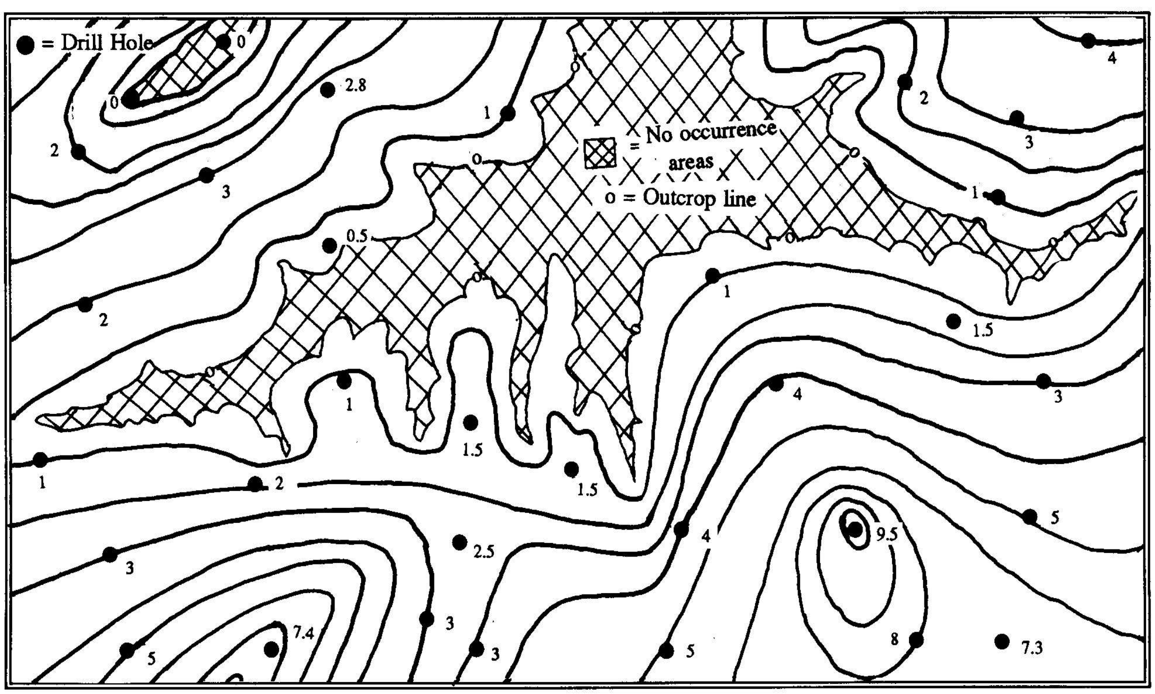


Figure V-10-b.– Isopach Map Showing the Relative Thickness of a Potentially Acid-Forming Shale Unit

Lineament maps range in detail and levels of sophistication. However, lineament maps should only be prepared by an individual, company, or agency experienced in lineament analysis. Lineament maps can be prepared by various consulting companies, government agencies, and universities. Prices vary depending upon the type of imagery used and the size of the area involved. It is therefore recommended that the WVDEP be consulted prior to any lineament mapping being undertaken.

EXAMPLE

Figure V-11 provides an example of a lineament map taken from standard and infrared aerial photography and overlain on a USGS topographic basemap.

8. Isosulfur and Other Isocon Maps

An isocon map shows the geochemical concentration of a specific element or compound. Its application for mining operations is usually restricted to sulfur content of a coal seam, although it can be used for any chemical constituent (e.g., neutralization potential). However, to provide accurate comparison, the map should be confined to a mappable unit and should represent the entire thickness of that unit. For instance, the sulfur content of the Upper Freeport seam can be easily mapped using geochemical information collected through the entire thickness of the seam. The use of such maps can help identify zones having a high potential for creating acid mine drainage. Figure V-10a provides an example of an isopach map created in much the same manner as an isocon map. However, with an isocon map, concentration units such as percentages or tons/1000 tons would be used instead of depth of cover.

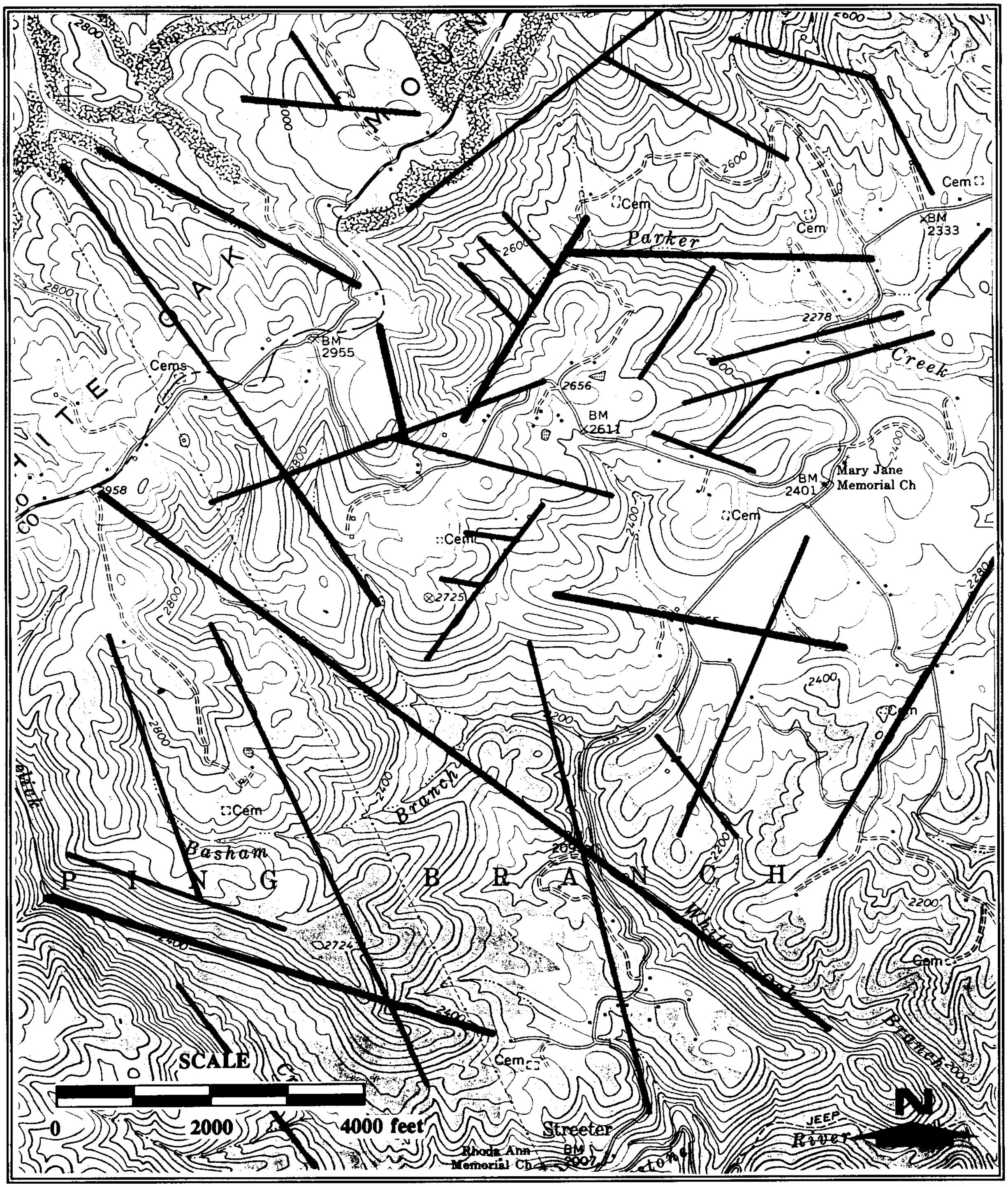


Figure V-11.-Example of a Lineament Map