Since the introduction of longwall mining into southwestern Pennsylvania (Gateway Mine) and northern West Virginia in 1970, significant research has been completed to measure and predict the effects of subsidence on surface features and structures. Because longwall mining is designed to remove large blocks of coal completely and leave no coal behind to support the surface, longwall mining results in larger areas of subsidence troughs than conventional room-and-pillar mining. A typical panel of 1,000 feet wide and 10,000 feet long with six feet of coal could affect a surface area of almost 230 acres. Mining of the panel would remove almost 2.5 million tons of coal. Maximum vertical subsidence would occur on the surface along the centerline of this panel and could be in excess of three feet depending on the depth to the coal seam, the rock over the coal seam, and the surface topographic features.

Surface subsidence resulting from longwall coal mining of the Pittsburgh coal seam in Greene and Washington counties, Pennsylvania is affected by various geologic and engineering factors including:

- Thickness of rock over the coal seam (overburden)
- Thickness of the coal seam removed (excavated height)
- Type of rock (lithology) comprising the overburden
- Topography of the surface (surface relief, or variation in elevation and characteristics of land above the coal seam)
- Width of the longwall panel
- Location of the subsided surface in relation to the center and edges of the longwall panel

While all types of subsidence can cause damage to surface features and structures (houses, roads, etc.), the type and severity of damage depends on the forces (stress) that propagate to the surface as the mine roof collapses. These forces may include stretching (tension), squeezing together (compression), and sinking of the ground (vertical displacement). The effects of the forces are measured and studied by developing a subsidence profile, which shows how subsidence would look on a cross-section usually drawn at a right angle to the longwall machine as it moves lengthwise into the panel. The position of a surface structure in relationship to the underlying panel is critical to the severity of damage experienced at the surface.

According to Walker and LaScola (1989):

> "It is widely recognized that the vertical displacement associated with subsidence causes little appreciable damage to structures, so long as the magnitude of the movement is uniform across the length of the structure. The most commonly observed damage is caused by the horizontal tensile and compressive strains associated with the bending of the ground. In subsidence engineering, bending of the ground surface is discussed in terms of inclination or tilt, and curvature. When analyzing the stresses on a

structure caused by mining, it is necessary to address the stress caused by both the advancing subsidence wave and the development of the subsidence profile."

Generally, the greatest amount of vertical displacement will occur along the lengthwise centerline of a longwall panel. The U.S. Bureau of Mines observed this phenomenon in a detailed study of longwall mining in the Pittsburgh coal seam in Greene County, Pennsylvania. The seam was 5.5 to 6.0 feet thick and 350 to 900 feet below the surface. It was mined in a 600-foot wide panel. Average subsidence varied from 3.25 feet (3 feet 3 inches) at the center of the panel to 0.41 feet (less than 5 inches) at the edge of the panel. At a distance of 150 feet away from the panel, vertical displacement was 0.05 feet (about one-half inch). Of the 16 monitoring sites used in the Bureau of Mines study, the most pronounced subsidence (4.04 feet) occurred at the center of the widest and shallowest panel (Adamek, V., Jeran, P. W., and Trevits, M. A., 1987).

According to the authors, "structural damage is determined by the extent of the surface deformations...," which can be measured and predicted using calculations of the following:

1. Differential subsidence (inclination or tilt). This is the vertical distance between two points divided by their horizontal distance apart.

2. Curvature (differential inclination or slope). This is a measure of how the slope or inclination changes by curving or bending of the surface as one moves from the center of a subsidence trough to its edge.

3. Horizontal strains – tension and compression (differential horizontal displacements). Tension causes a lengthening and compression a shortening displacement measured in a horizontal plane. Tension tends to create cracks and compression tends to create bulges in the earth's surface.

The mechanics of subsidence prediction and analysis are very technical and require engineering and advanced mathematical skills. The reader is referred to the *Subsidence Engineers Handbook* (National Coal Board, 1975) for additional information.

Exhibit 2.3-1 shows an example from the Bureau of Mines study of subsidence and inclination over a 600-foot-wide longwall panel with overburden varying from 700 feet at the center of the panel to 650 feet at the one edge of the panel. At the center of the panel, a maximum subsidence of 3.25 feet was measured with no measurable change in slope.

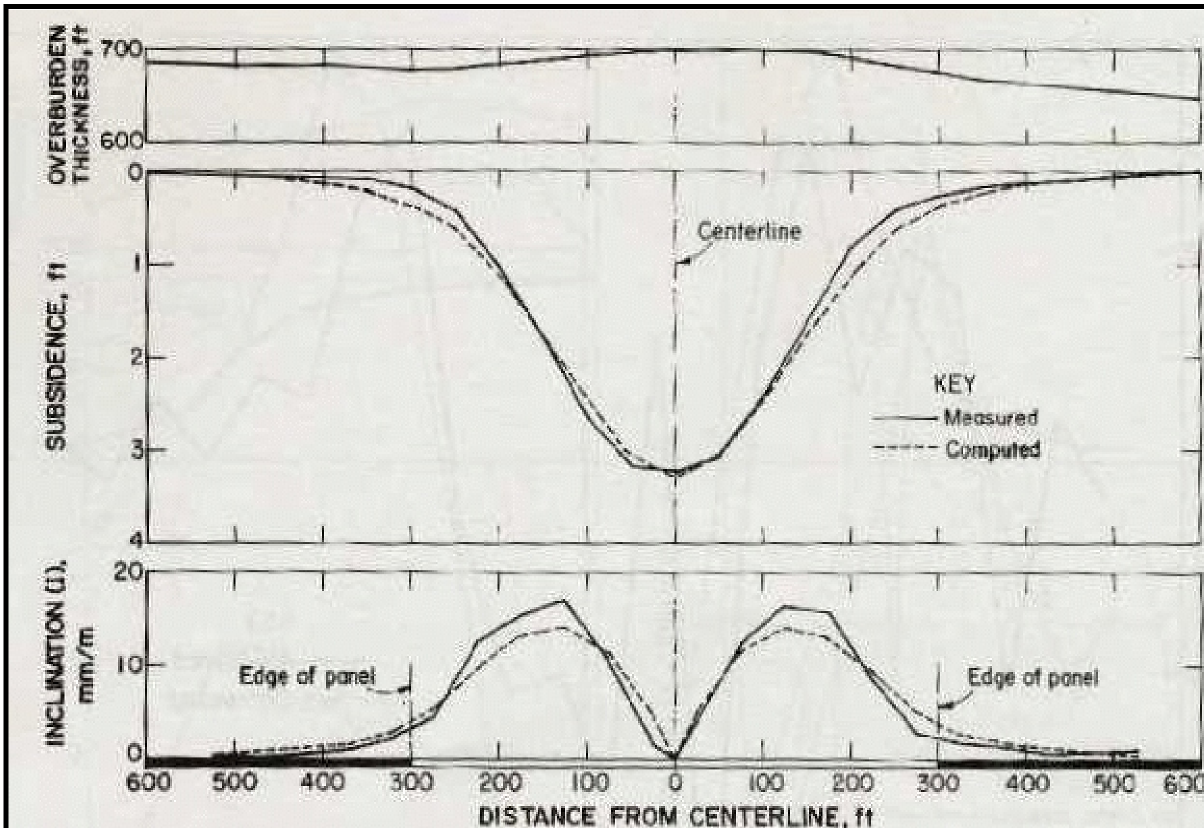

Exhibit 2.3-1 Subsidence Profiles over Longwall Panel **(Adamek et al., 1987)**

Subsidence (vertical displacement) decreased from the center of the panel to the edges. Inclination or curvature reached maximum levels at the approximate midpoints between the centerline and the panel edges. (Note that inclination was measured in millimeters per meter; one inch equals 25.4 millimeters, and one meter is 3.28 feet or about a yard. Using these conversions, the maximum inclination in this study was less than one inch per yard.)

The study also examined the horizontal displacement created by the subsidence event. Given that the ground sinks from less than an inch at the panel's edges to 3.25 feet at its centerline, the surface experienced measurable horizontal movement. **Exhibit 2.3-2** shows the horizontal displacements observed at the site. Maximum movement was less than 8 inches.

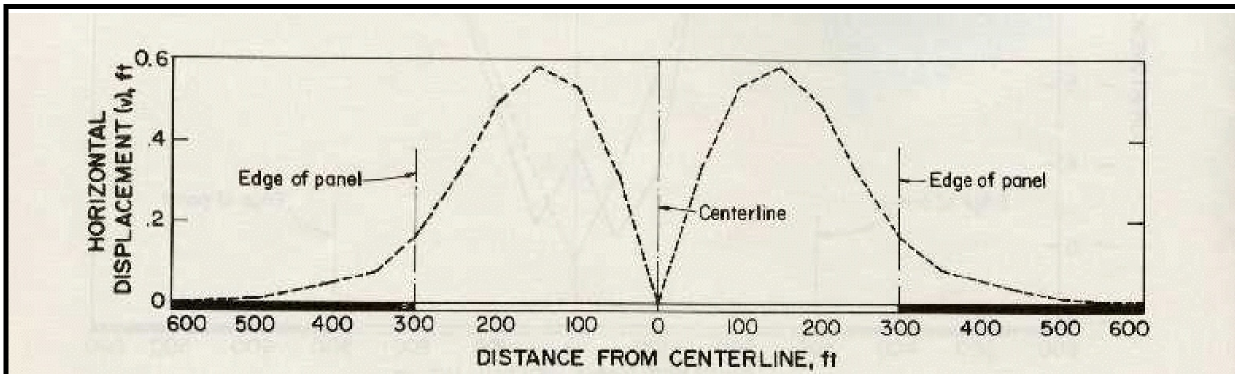

Figure 2.3-2 Horizontal Displacements over Longwall Panel (Adamek et al., 1987)

In summary, the Bureau of Mines study found subsidence along the lengthwise centerline of longwall panels to be a vertical phenomena (3.25 feet on one panel) with no measurable horizontal displacement. At approximate midpoints between the centerline and the panel edges, horizontal displacement was found at its maximum (less than 8 inches for one panel). Surface features and structures above a longwall panel will experience varying levels of stress and subsequent deformation depending on specific location above the panel. Subsidence and deformation depend on:

- Vertical displacement
- Horizontal tension (stretching of the surface)
- Horizontal compression (squeezing of the surface)

Another study by the Bureau of Mines (Fejes, 1986) found that subsidence over 450- to 500-foot wide panels at depths of 800 to 1,500 feet with extraction of 5.9 feet of coal resulted in subsidence at the center of the panel of 1.7 to 2.2 feet (width/depth ratios of 0.4-0.5). Surface deformation was found to continue beyond the panel edge and sometimes resulted in a raising of the surface. According to this study, some subsidence occurred more than a year after the initial subsidence when the panel was mined. The Bureau researchers believe that mining an adjacent panel stimulated the continued subsidence over the mined-out panel for more than 19 months after mining ended. Ground stress associated with the differential subsidence resulted in horizontal movement and damage to surface structures.

The Bureau of Mines also studied a Greene County longwall panel and its related subsidence to learn how subsidence affects well water quantity and quality (Moebs & Barton,1985). Overburden at this site was between 750 and 1,000 feet; the coal removed was approximately 5.5 feet thick. In addition to maximum vertical displacement along the centerline of the panel, the study found:

- An initial subsidence of one-half foot occurred as the longwall face moved beneath the measuring instruments at the surface.

- Subsidence continued at a rate of approximately one-half foot per month until vertical displacement reached a maximum of 3.25 feet at the centerline seven months after undermining.

- Water wells only within the boundaries of the longwall panel showed a precipitous decline as a result of undermining. Water levels were unaffected in wells 500 feet or more beyond the panel boundaries. No evidence was detected of adverse effects on the small streams or springs located within 1,200 feet of the panel.

Another Bureau of Mines analysis (Jeran and Barton, 1985) found that subsidence deformation increases significantly as longwall panel width increases in proportion to coal seam depth. The researchers set up three categories to describe the three conditions of relationship between width and depth, as follows:

- Sub-critical: the panel width is less than the depth of the panel from the surface (for example, a panel is 600 feet wide and 1,000 feet deep).

- Critical: the panel width equals depth from the surface (for example, width and depth are both 1,000 feet).

- Super-critical: the panel width is greater than panel depth (for example, panel width is 600 feet and depth is 500 feet below the surface).

The researchers found that longwall panels wider than their depth (Super-Critical Condition) displayed complex horizontal and vertical surface movements and significant strain on surface features. They concluded:

> "The super-critical geometry results in a subsidence curve [cross-section profile] with multiple points of maximum subsidence. The critical case has one point of maximum subsidence. The sub-critical case has a maximum point at its center, but this is less than the maximum possible subsidence."

In a fifth report from the U.S. Bureau of Mines research, Jeran and Adamek (1988) observed that in the rolling hilly terrain of Greene County, the hillsides were showing significantly more subsidence effects than the valleys. The magnitude and direction of horizontal deformation were increased on hill slopes by soil and rock slumping and moving downslope. These downslope slumps may represent a geologic phenomenon of mass movement where the surface is adjusting to changes in the slope induced by subsidence.

Another Bureau of Mines study completed by Ingram (1989) showed that both the horizontal and the vertical forces of tension and compression move in a wavelike motion along the surface slightly ahead of the advancing longwall face. **Exhibits 2.3-3 and 2.3-4**, provide a schematic of this process. **Exhibit 2.3-3** depicts how the surface is subjected to waves of stretching (tension) and squeezing (compression) as the longwall face passes. The advancing wave creates a tensional force and then changes to a compressional force.

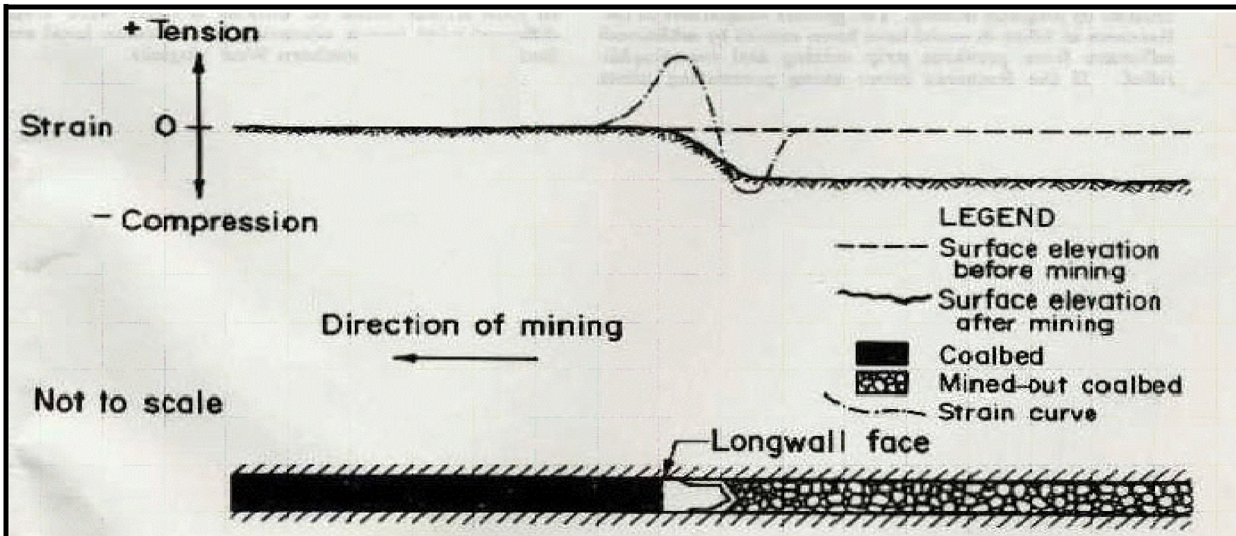

Exhibit 2.3-3 Compression and Tension from Movement of Panel Face (Ingram, 1989); **Profile Parallel To the Panel**

Exhibit 2.3-4 shows the tensional and compressive wave as the surface subsides over the panel. In a super-critical situation, this wave becomes a complex of overlapping stresses of tension and compression as well as multiple subsidence troughs. Thus, in addition to the vertical and horizontal displacement discussed in earlier Bureau of Mines

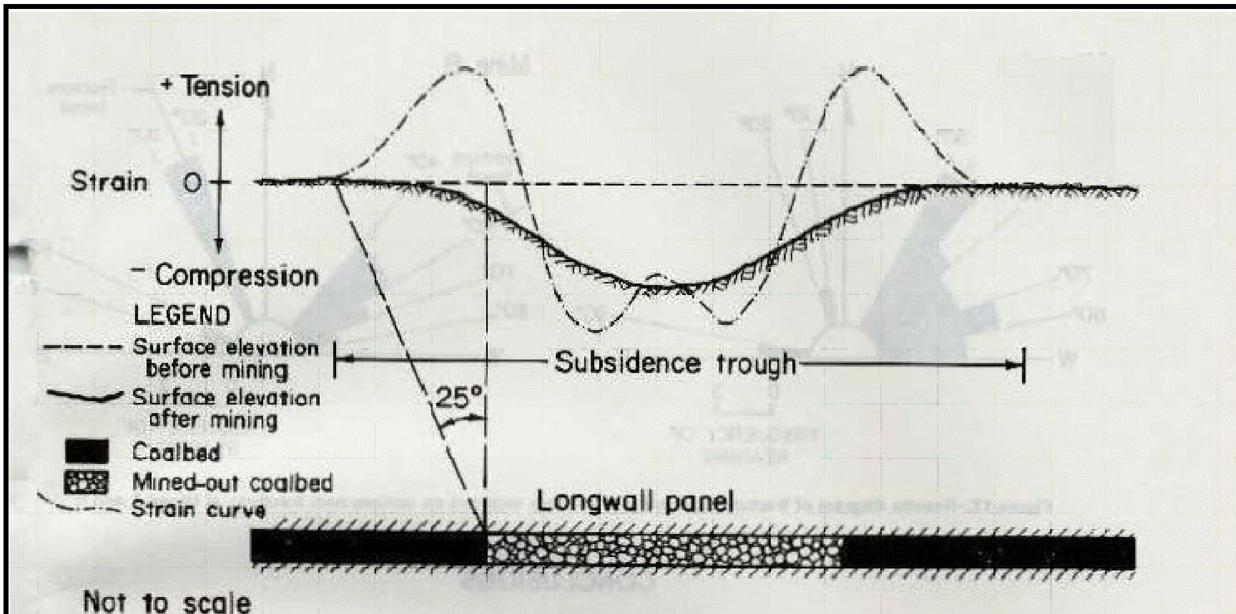

Exhibit 2.3-4 Compression and Tension over Subsidence Trough (Ingram, 1989); **Profile perpendicular to Panel**

studies, Ingram identified a different kind of upward movement of the earth's surface in relation to the wave.

The Bureau of Mines study reported by Walker and LaScola (1989) used four concrete walls to examine the effect on surface structures of vertical and horizontal movement caused by subsidence. The study examined the stress and damage created by a 1,000-foot-wide longwall panel, mining 6 feet of coal below 650 feet of overburden. Three "static" 36 feet long by 4.66 feet high walls (labeled ***B*** – midway between centerline and panel edge; ***C*** – between B and the panel edge; and ***D*** – near panel edge) were placed parallel to the longwall face over the panel at specified distances from the centerline of the panel. A fourth "dynamic" wall, ***A*** (86.33 feet long by 4.0 feet high), was placed perpendicular to the longwall face along the centerline of the panel.

After undermining, all four walls were deformed, but none of the three static walls were cracked. Of the static walls, wall ***B*** was located across the predicted maximum compression point, and wall ***D*** was located across the predicted maximum point of tension; these walls showed the most curvature. Because of location, these walls were subjected to the highest amount of tension and compression resulting from horizontal ground movement. Wall ***A***, which was longer and located parallel to the direction of mining, was cracked into three pieces as the longwall face passed underneath, primarily in response to tensional forces.

The researchers concluded that structures tend to respond to the stresses caused by undermining in a similar manner as the ground. However, the structures respond at varying rates and times. The variations as well as the rigidity of the structures resulted in deformation and damage.

Subsidence research had been performed by the former U.S. Bureau of Mines and various contractors (including Resource Technologies Corporation) for the Bureau of Mines prior to the opening of the Bailey Mine in Richhill Township, Greene County. Some of this published research involved the Pittsburgh coal seam in Greene County, PA, in southwestern Pennsylvania, in general, and in West Virginia.

As early as 1975 Stingelin et al. used the principles of subsidence prediction, as developed in Europe, to modify and apply to U.S. geological conditions. Developed for the anthracite region of northeastern Pennsylvania, the resulting prediction methodology was also tested successfully in the Bituminous coal fields of Pennsylvania and western Maryland. This simplified model gives a prediction of maximum subsidence expected along the centerline of a panel.

Since this and other earlier attempts at mine subsidence prediction, the Bureau of Mines, OSMRE, and university researchers, as shown by the cited selected research publications, have advanced the state-of-the-art in subsidence prediction over longwall panels and in understanding of the nature of the underlying forces. Recent research studies have concentrated on protecting surface structures during a subsidence event. Such principles as the plane-fitting technique have proven to be effective in mitigating the effects of the bending and twisting actions associated with ground subsidence (Peng and Yi Luo, 1994).

Continued research into longwall mining's effects on the surface features and structures is ongoing by government and university researchers. In a 10-county study area in western Pennsylvania (PADEP, 1999, 2001 – Act 54 reports), the effects of both longwall and room-and-pillar mining on surface structures and features and water resources were studied. Of 15 perennial streams undermined by longwall panels, 9 exhibited pooling conditions, 4 exhibited diminished flow, and 2 exhibited both pooling and diminution. Additional research has been completed and can be seen in the report on streams, wetlands, and riparian areas.

Longwall panel dimensions continue to increase. Since the original Gateway Mine panel configuration in 1970 (460 feet wide and 6,150 feet long), panels have increased dramatically in their dimensions. Currently, panels in the Bailey Mine are 1,100 feet x 10,500 feet. Planned panel dimensions at the New Century Mine in Fallowfield Township, Washington County, Pennsylvania are 850 x 12,500 feet. These increases in panel dimensions raise the fear for potentially increasing surface damage, particularly in more densely populated areas.

In summary, longwall panel width and depth are critical to what happens at the surface. With panel width increasing beyond overburden thickness (depth to the coal seam), super-critical conditions are established. Thus, more extensive surface areas are exposed to potential deformation, and maximum subsidence is more likely to occur at multiple points across a panel. Super-critical conditions with respect to panel width and depth have the potential to increase the extent and severity of surface damage. In contrast, making panel longer will have no effect on the severity of surface subsidence events. Longer panels will increase mine efficiency and economics.

2.4 Pittsburgh Coalbed – A Geologic Description

The Pittsburgh coalbed was deposited over a period of several million years during the geologic time period known as the late Pennsylvanian, which ended about 286 million years ago. The coalbed was formed in a large basin that included all of Greene County and much of Washington County. It is the most extensive and economically important coalbed in the region. The basin axis passed through Washington and Greene Counties and a calcareous, or limey, shale was generally deposited over the coal-forming swamp. Clastic deltaic deposits (sand, silt, and mud) were introduced from the southeast and northwest. The deposits created a roof above the Pittsburgh coal that is most commonly alternating thinly bedded, dark gray to black, fissile, carbonaceous shale, coal stringers, and sandstone lenses, often called "draw slate." The draw slate is generally less than 4 feet thick (McCulloch et al, 1975).

The rock layers above the coal and draw slate (overburden) are predominantly interbedded limestone, shale, and siltstone. Sandstone is generally present in eastern areas, manifesting itself as channel sandstone and as sandstone cutouts of the coal seam.

The rock type (lithology) of the overburden plays an important role in the severity of surface subsidence, particularly in Washington County where thickness of the overburden is less than that encountered southwestward as the Pittsburgh seam plunges deeper along a synclinal axis (USGS OFR 97-864).

The Pittsburgh coal, although variable in thickness, maintains a persistent four to eight foot minable thickness throughout the area and is most commonly five to six feet thick. The coal generally thickens southward where it reaches a maximum of 16 feet or more in southeastern Greene County. The coal generally occurs as a main seam and roof coal with a shale (draw slate) parting.

Quality is an important factor of the Pittsburgh seam. The Pittsburgh coal has shown the following ranges in chemical analyses (*Keystone Coal Industry Manual* -1982, p. 6l4, for Greene County (dry-ash free basis):

Sulfur	0.8-3.2%	Ash	4.2-10.8%
Btu/lb	13,040-14,140	Moisture	1.7-3.7%
Volatile Matter	33.0-36.4%	Fixed Carbon	52.2-57.3%
Ash Fusion Temp	2,110-2,620F		

The Pittsburgh coal has a market for steam generation used in powering electricity-producing turbines. Where the sulfur content is below 1.5 percent (washed), the coal meets metallurgical specifications for sulfur (1.3-1.4%), ash (5.0-6.0%), and free swelling index (7.5-8.0). Because of the decrease in demand for metallurgical coal, much of this metallurgical reserve will eventually be used as steam coal. Most of the metallurgical-grade reserves are in the eastern areas of Washington and Greene Counties where they were heavily exploited in the past by room-and-pillar deep mining.

2.5 Status of Longwall Mining in Southwestern Pennsylvania

Current Pittsburgh seam longwall mining status in Washington and Greene Counties, PA as reported in *Coal Age* (2002) is summarized in **Table 2.5-1.** This includes the Blacksville No. 2 Mine that has its entry in West Virginia but is mining predominantly in Greene County, Pennsylvania. Mon-View Mining's Mathies mine was shut in early 2002. Maple Creek Mine and Dilworth Mine are scheduled for closings in late 2002, and the High Quality Mine is scheduled to initiate operations in 2003

In addition to these active longwall mines, longwall activity occurred in three additional mines now included in the mined-out areas on the accompanying exhibits of current and past mining activity in Greene and Washington Counties, Pennsylvania. These mines are Blacksville No. 1, Humphrey No. 7, and Gateway. The location and permitted extent of these mines are shown in **Exhibit 2.5-1**, **Exhibit 2.5-2 and Exhibit 2.5-3.**

Table 2.5-1 Active Longwall Mines in Southwestern Pennsylvania (Pittsburgh Seam)					
Mine	**Seam (Inches)**	**Cut Height (Inches)**	**Panel Width (Feet)**	**Panel Length (Feet)**	**Overburden (Feet)**
Bailey 1	62-72	62-72	1,100	10,500	600 - 1,000
Bailey 2	62-72	62-72	1,000	9,000	600 -1,000
Blacksville No 2	78	74	1,000	10,000	850 - 1,150
Cumberland	78-84	78-84	930	10,500	750 - 1,050
Dilworth	76-80	76-80	1,020	5,000	500 - 800
Mine No. 84	90	68	1,100	9,000	500 - 750
Emerald No 1	72-84	72-84	984	9000 - 12000	380 - 950
Enlow Fork 1	68-72	68-72	1,000	9,000	600 - 1,000
Enlow Fork 2	68-72	68-72	1,000	9,000	600 - 1,000
Maple Creek	67	67	850	5,000	400 - 500
High Quality	62	62	850	12,500	400 - 600

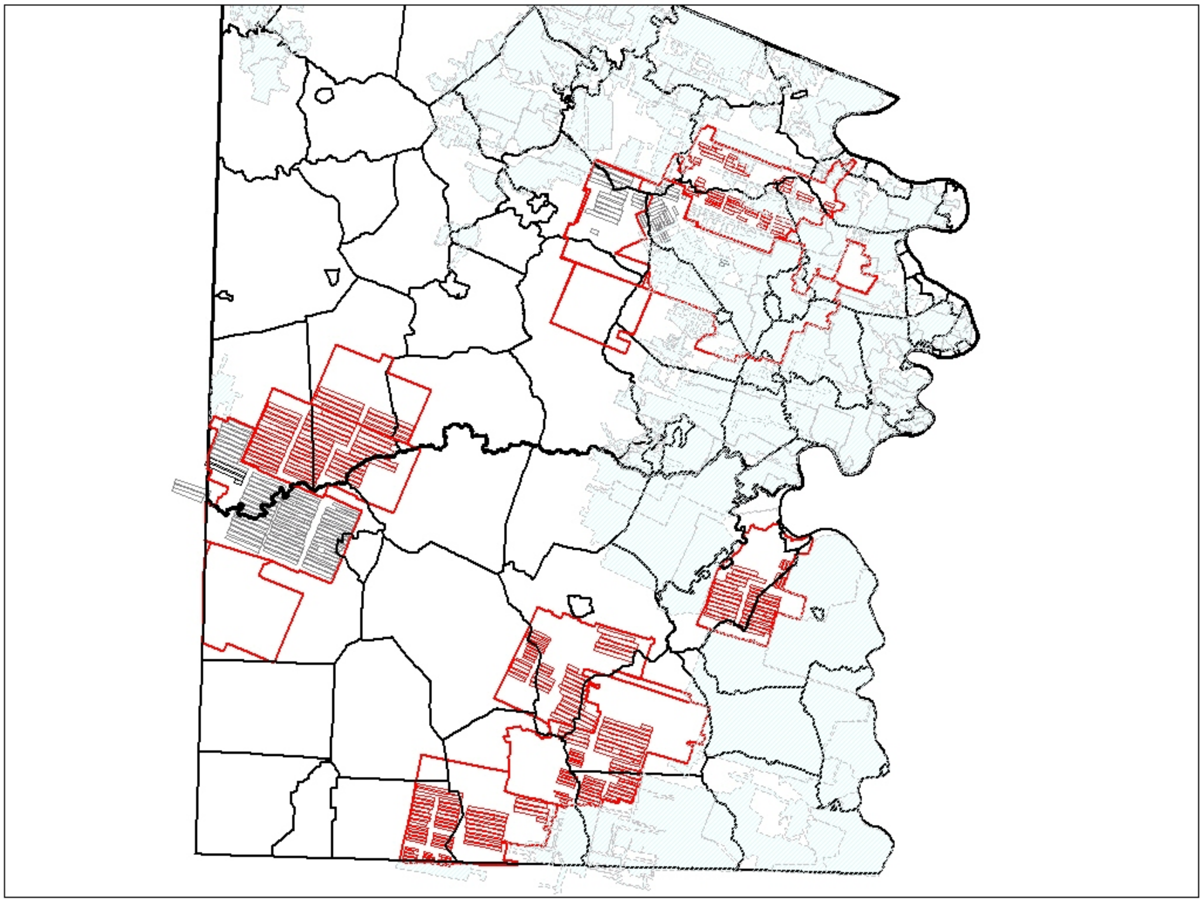

Exhibit 2.5-1 Current Longwall (red or gray panels) and Past Pittsburgh Seam Mining (Blue) in Greene and Washington Counties

A larger scale map of longwall and past room-and-pillar mines in Greene County is shown in **Exhibit 2.5-2.** This is followed by a similar map for Washington County (**Exhibit 2.5-3**).

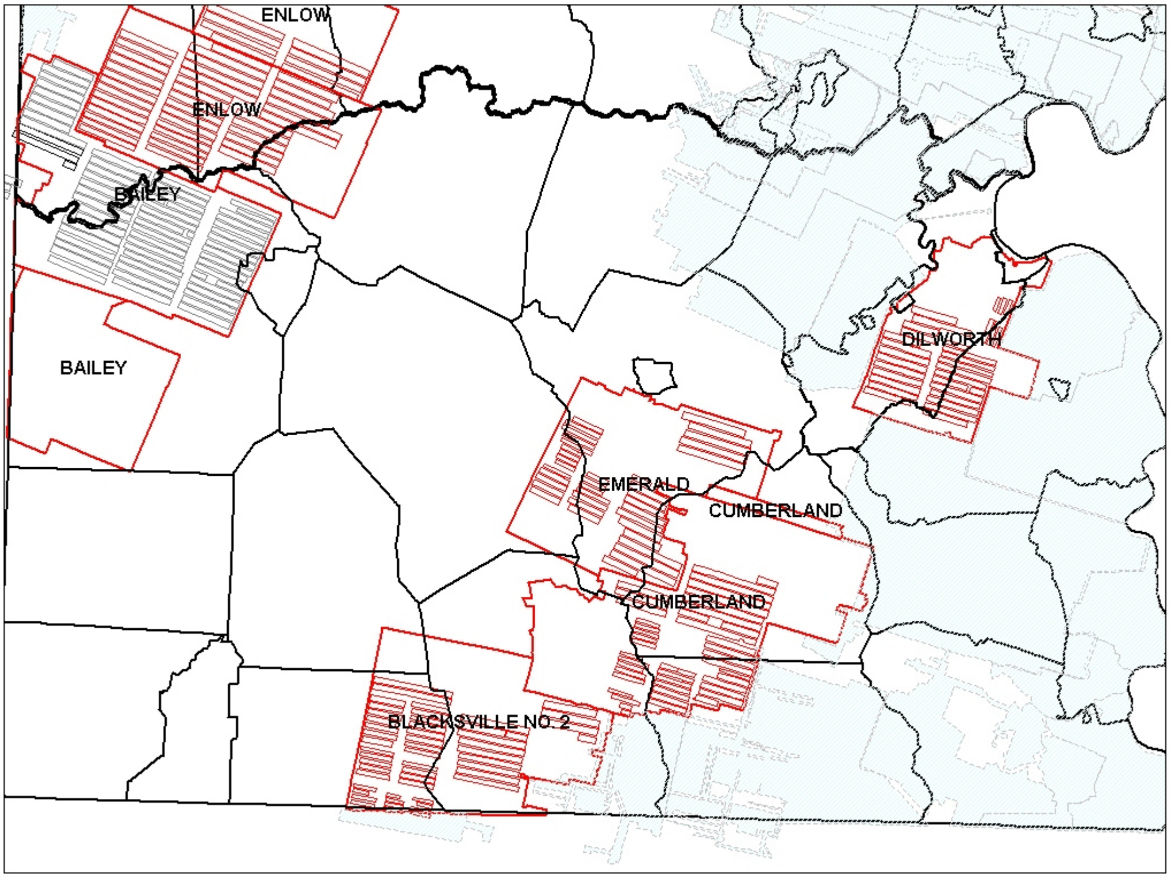

Exhibit 2.5-2 Current Longwall (red or gray panels) and Past Pittsburgh Seam Mining (blue) in Greene County, Pennsylvania

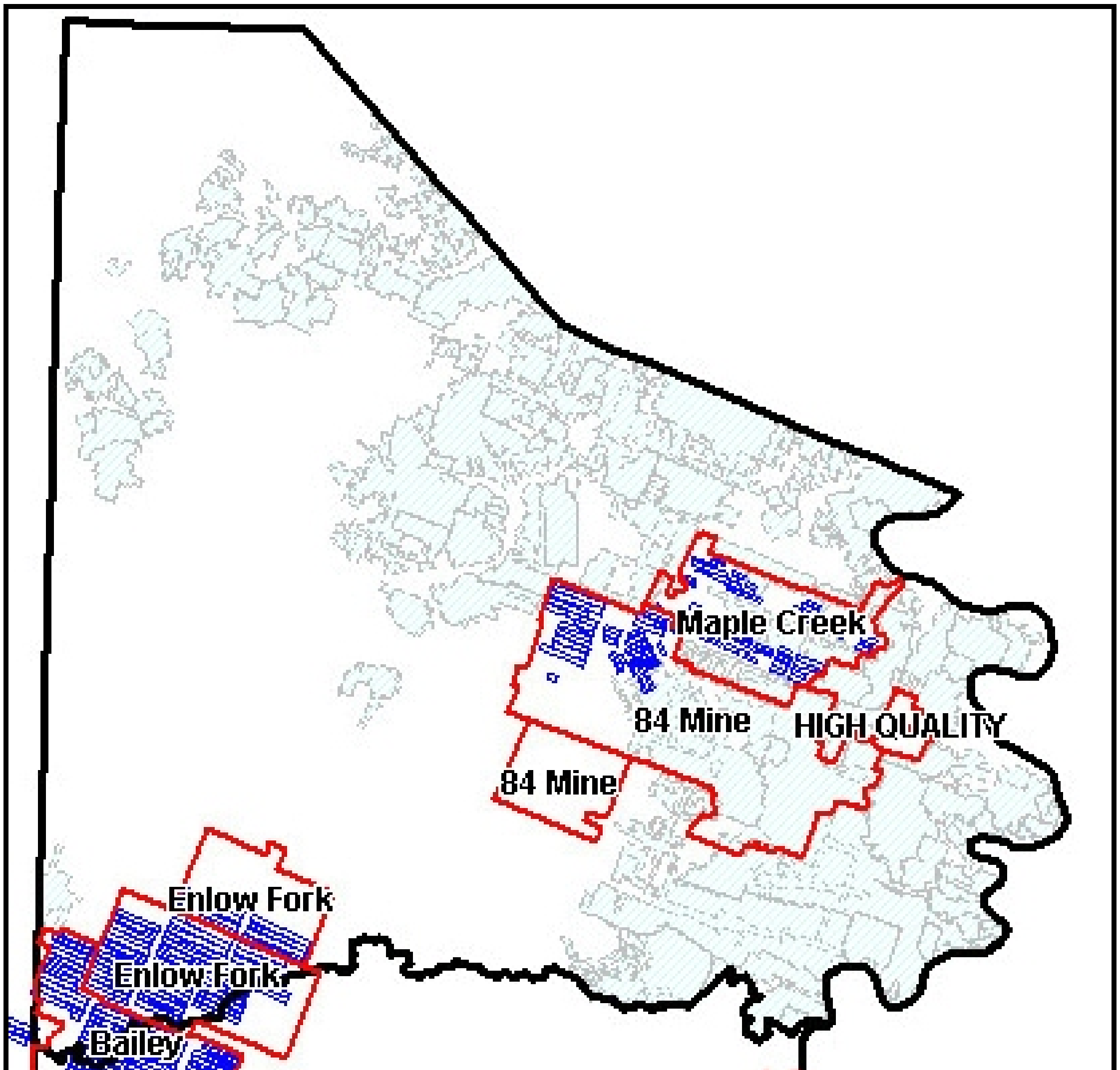

Exhibit 2.5-3: Current Mining Permits (red), Longwall Panels (blue), and past Pittsburgh Seam Mining (light blue) in Washington County, Pennsylvania.

3.0 DATA

The data used to complete this study came from a variety of sources:

- PADEP Act 54 database (8/94-8/98)
- PADEP claims database (McMurray)
- PADEP Mine Subsidence Insurance database (Harrisburg)
- PADEP six-month mine map repository & database
- OSMRE mine map repository (abandoned mine lands)
- OSMRE database on subsidence mitigation
- Consol Energy database on damage claims & payments/repairs
- RAG database on damage claims & payments/repairs
- PA Coal Association data & library resources
- Tri-State Citizens Mining Network (headquartered in Washington County)
- County tax assessment databases (re: changes in assessment values)
- County tax assessment databases (re: tax revenue from coal mining)
- County recorders of deeds databases (re: property sales information over study period)
- Historic records of national property value trends over time (inflation)
- Anecdotal records from media sources
- RTC GIS database on mining activity

The most important data considered for both Washington and Greene Counties is listed below:

- Current and historical mining maps for insertion into a GIS
- Coal company data pertaining to property settlements
- Parcel and tax index maps
- Tax roll information for the last 10 years
- Maps of infrastructure such as sewer and water
- PADEP subsidence claims database
- OSMRE emergency subsidence claims

Resource Technologies Corporation (RTC) has developed and maintains a geographic information system (GIS) identifying mining activity in Washington and Greene Counties. RTC has maps of mined-out longwall panels, mined-out room-and-pillar mines, previous surface and deep mining, and current active mining permits. Much of these data are derived for DEP and coal company maps. The database associated with the mines contains information such as date of mining, size of the mine, volume of coal, and production history.

To learn whether homeowners are being compensated for damages due to longwall mining, RTC sought and obtained coal company data on settlements. These data were aggregated to a tax index map scale to protect privacy and maintain confidentiality.

A GIS is a computer-based system that allows for simultaneous analysis of many layers of map data, such as the relationship of underground mining to overlying surface property. In addition, a GIS permits analysis of associated tabular data, such as county assessment information with map data. Using a GIS system to relate property information to mining information is relatively easy. Essential to the process is the conversion of all data to the same map base and relational database structure. RTC completed the conversion of all county assessment records, mine maps, and tax index maps as part of the contract with DEP to perform this study. With the exception of the coal company compensation records, the maps and record bases are now part of the public record.

The pertinent aspects of the coal company compensation records were made available to this project under a confidentiality agreement. The agreement stipulated that the data could be used only in an aggregated form (tax map location rather than specific address). This procedure was necessary to satisfy the confidentiality requirements contained in various agreements between the coal companies and various surface owners. In Washington County, the tax index maps were digitized from paper base maps. In Greene County, a digital version of tax index maps was created by aggregating individual parcels into tax map groupings. In both counties, historic tax assessment change records had to be reconstructed from the annual data stored digitally on computer tapes.

Although this project is based on the scale of tax index maps, it was desirable to use individual parcel maps during the analysis phase of the project. The greater detail of parcel location leads to greater accuracy using the GIS approach. For example, the parcel map was laid on the mining map to identify which properties could potentially be affected by longwall mining. **Exhibit 3-1** shows how surface maps were assigned to the longwall panels. Properties whose major portions did not overlie a panel were not identified as longwall properties

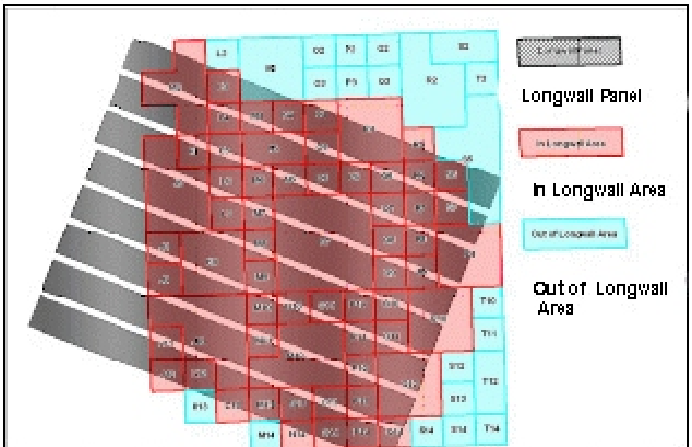

Exhibit 3-1 Example of Assignment of Map to Longwall

The parcel map for Greene County was acquired from the county. This permitted RTC to identify individual properties that could be affected by longwall mining. However, in Washington County, only the tax index maps were available. RTC had to consider that every property in an index map containing longwall mining could be affected by the mining, even though only a small portion of the index map may have a longwall panel in it. This is because the locations of the individual properties within the index map are not known.

Tax roll information was obtained from both counties over a period of about 10 years. This information was used to track whether property values changed from year to year, and if longwall mining influenced these changes. In Washington County, 12 years