CANYON FUEL COMPANY, LLC

2005 Midterm Permit Review

Task ID# 2348

DUGOUT CANYON MINE - C/007/039

May 19, 2006

CHAPTER 2

SOILS

At the Pace Canyon fan portal site, the topsoil and underlying unconsolidated materials will be removed and stockpiled together. The entire mixture will be treated as topsoil in compliance with R614-201-234.300. The recovery of topsoil/growth medium will be maximized at the site.

TABLE 2-2

TOPSOIL AND SUBSTITUTE TOPSOIL VOLUMES

AREA	MATERIAL TYPE	Volume Estimated at Salvage
NORTHWEST FACILITIES AREA (AREA 2)	TOPSOIL/OVERBURDEN	1,653 CY
COAL STORAGE AREA (AREA 3)	TOPSOIL/SUBSOIL	4,869 CY
SEDIMENT POND, SLOPE AREA, AREAS BETWEEN ROAD AND CREEK (AREAS 4, 6, 7)	TOPSOIL/SUBSOIL	20,118 CY
WATER TANK AREA (AREA 8)	TOPSOIL/SUBSOIL	247 CY
SLOPE EAST OF COAL STORAGE PILE (AREA 9)	TOPSOIL/SUBSOIL	333 CY
GILSON WATER WELL*	TOPSOIL/SUBSOIL	134 CY
SMALL SUBSTATION	TOPSOIL/SUBSOIL	140 CY
	TOTAL	27,494 CY

Topsoil/Subsoil Stockpile Survey	Cubic Yards
North Pile (1998), Includes Area 5 Soils	11,300
South Pile (1998)	13,939
Gilson Well Pile (2006)	134
Small Substation Pile (2006)	140
Subsoil Pile (2006)	734
TOTAL	26,247

At the time the Dugout Canyon area was first mined, no topsoil was segregated and saved. Topsoil and other fill material was apparently used in construction of the surface facilities pads and roads. Much of the topsoil appears to have been mixed with mining wastes (including the topsoil/growth medium in Pace Canyon). During the construction phase of the Dugout Canyon Mine facilities in Dugout Canyon, this material will be excavated and, where suitable, stockpiled for use as a topsoil substitute/growth media after treatment. The substitute topsoil/growth media will be placed after recontouring of the site has occurred during reclamation activities. The exact quantity of the substitute topsoil/growth media available for use is not known at this time but has been estimated to be at least 26,247 CY. Approximately 1,568 CY of soil will be removed during culvert construction. The majority of this soil will be returned to the channel area during final reclamation and will not be used in other areas unless excess material is available (Appendix 2-6). Soil will be placed in accordance with the methods described in Chapter 5 of this M&RP.

Fill that had been imported as part of the pad and culvert construction activities may be used as backfill against highwall and cutslopes and backfill during portal closure or in depressions to aid in the achievement of AOC. If the imported material is to be used as subsoil, it will be characterized in accordance with the Division's guidelines for topsoil and overburden. This characterization will occur at the time of reclamation.

The topsoil/growth medium salvaged at the Pace Canyon fan portal site will be characterized in accordance with the Division's guidelines for topsoil and overburden. This characterization will occur once topsoil salvage is completed. One sample will be taken from each permanent stockpile or for every 1200 cubic yards salvaged, whichever is greater.

233.300 Physical and Chemical Analyses

Physical and chemical analyses of the soil material will be conducted while generating substitute topsoil. Samples of the soils will be obtained after physical segregation has occurred. The rate of sampling will be one sample per every 500 CY (approximate) of material generated. Additional

APPENDIX 2-6

Topsoil, Substitute Topsoil, and Storage Pile Calculations

20,225 SF X 6.5 FT = 131,463 CF ÷ 27 CF/CY = 4,869 CY

Area 4. Material to be removed from the slope located between the Sediment Pond and Facilities Area

Surface Area = 68,000 SF

Assume 6 FT of A, B, and C horizons to be removed
68,000 SF X 6 FT = 408,000 CF ÷ 27 CF/CY = 15,111 CY

Area 5. Additional soils will be removed from the Dugout Creek area as part of the installation of a culvert that will carry the stream from the upstream end of the disturbed area to the downstream end. These soils will be removed and stored separately or isolated from soils removed from the remainder of the disturbed area. A volume of approximately 1,568 CY will be removed from the creek area (Appendix 2-5). These soils will be returned to the channel area during final reclamation for use as growth media. After placement of these soils in the channel area, any available excess "channel" soils will be distributed where needed within the disturbed area. The Area 5 soils are located in the North Pile as shown on Plate 2-3 of the M&RP.

Area 6. Material removed from between road and creek in the southeast portion of the permit area:

Surface Area = 5,100 SF

Assume an average depth of 8 FT of material removed.
5,100 SF X 8 FT = 40,800 CF ÷ 27 CF/CY = 1,511 CY

Area 7. Material removed from flat area east of sediment pond and road and west of creek.

Surface Area = 11,800 SF

Assume an average depth of 8 FT of material removed.
11,800 SF X 8 FT = 94,400 CF ÷ 27 CF/CY = 3,496 CY

Area 8. Material removed from the water tank area located north of the main facilities area.

Surface Area = 1,333 SF

Assume an average depth of 5 FT of material removed.
1,333 SF X 5 FT = 6,665 CF ÷ 27 CF/CY = 247 CY

Area 9. Material removed from the slope east of the coal storage pile.

Area 7 Topsoil	3,496 CY
Area 8 Topsoil	247 CY
Area 9 Topsoil	333 CY
Total Material Available	27,220 CY

Total thickness of topsoil/substitute topsoil to be spread during final reclamation:

26,247 CY X 27 CF/CY = 708,669 CF
708,669 CF ÷ 640,332 SF = 1.11 FT = 13.3 in

The total volume of topsoil/substitute topsoil to be spread at final reclamation may vary from ~~13.8~~ 13.3 inches. The total volume of substitute topsoil generated during the reclamation of the mine site that could be used and has not been included in these calculations could increase the total volume of useable growth media by 6504 CY (Area 1). If the material is deemed as useable, the total soil cover for the area could be increased. ~~to 17.1 inches~~.

CHAPTER 5

ENGINEERING

LIST OF APPENDICES (Continued)

seam outcrops in the vicinity of the proposed surface facilities, and Figure 6-1, Plate 6-3, 6-3A and 6-3B provide geologic cross sections based on data collected from drill holes in the area. Furthermore, information related to the physical conditions which may affect mining is presented in Sections 622 (a discussion of the cross sections), 624.100 (a discussion of stratigraphic and structural conditions), and 624.300 (a discussion of rock clay content), as well as Appendix 6-1 (drill-hole logs).

Subsidence Control Measures. Most of the land within the permit area will eventually be affected by subsidence. Anticipated areas of subsidence are shown on Plate 5-7. This subsidence boundary was projected to the surface based on an angle of draw of 30 degrees as measured from the vertical as required in R645-301-525.542. It is presumed that the actual angle of draw will be less, based upon results of mining and subsidence in the general area. Plate 5-7 illustrates the projected extent of subsidence based on a 30 degree angle of draw . The primary areas where future subsidence is not anticipated are the areas overlying the previous workings shown on Plate 5-1 (since these areas will not be re-mined). Plate 5-7 also illustrates a subsidence buffer zone that extends beyond the limits of Federal Lease U7064-027821 and State Lease ML-48435. This buffer zone does not suggest that CFC will mine outside of the lease boundaries, however, it does indicate the limit of projected subsidence. Appendix 5-11 contains a report "Prediction of Surface Deformation Resulting from Longwall Mining" which discusses subsidence. The specific sections within the report discuss, subsidence mechanism; mining, geologic conditions and subsidence characteristics; predicted ground movements and the monitoring program. This information is provided per deficiencies in the 2005 mid-term review of the M&RP.

Subsidence Monitoring. Numerous control points have been established within the permit and nearby areas to assist in subsidence surveys (see Plate 5-7). Coordinates and elevations of these control points, as established in January 1984, are provided in Table 5-2. Coordinates and elevations of control points are also provided in the Mine's Annual Reports. The control points consist of traverse monuments, benchmark monuments, and survey stations ~~(as indicated on Plate 5-7)~~ which have been constructed generally as follows:

- <u>Traverse and Benchmark Monuments</u> - These monuments are constructed with ~~a 3¼-inch diameter~~ tap-on convex cap with a center punch mark and a ~~5-footlong~~ center rod. The center rod has been emplaced in a ~~5.5- to 6-foot deep poured~~ concrete casing ~~of approximately 10 inches in diameter~~. Where rock was encountered before the required depth, the rock was broken with a stone rod and an anchor point was grouted into the rock using a concrete patching material. Alternatively, monuments in rock were emplaced as described below ("Rock Monuments and Stations"). ~~The diameter of the upper portion of the monument pour was enlarged to 1.0 to 1.5 feet. Concrete was emplaced in a continuous pour.~~

- <u>Survey Stations</u> - These stations consist of ~~No. 5~~ rebar rods with a length of approximately 5 feet. Each rebar has been fitted with a ~~2-inch diameter~~ aluminum cap ~~which has a plastic insert designed to secure the cap to the rod~~. The caps are plain with a center punch mark and a concave label across the top. Where survey stations are installed in boulders or rock which did not allow the use of ~~a 5-foot length of~~ rebar, they were installed as indicated below ("Rock Monuments and Stations").

- <u>Rock Monuments and Stations</u> - Where survey monuments and stations are established in boulders and rock which do~~es~~ not allow the installation of a ~~5-foot long~~ rod in a concrete casing, these monuments consist of an aluminum alloy convex marker with a center punch and concave label. They are secured by drilling a ~~¾-inch diameter~~ hole to a depth of approximately 3 inches and installing the cap in a concrete grout mixture. ~~This product can be obtained from any concrete products center.~~

Future monuments and stations that are required for proper control will be installed ~~as described above~~ to provide one *monitoring point* per panel. Since geologic and mining uncertainties often force a change in planned mining sequences, future control points may be installed only after the mine panels are in their development phase.

~~Subsidence monitoring will be carried out on an annual basis and will entail direct ground surveys and visual surveys of the permit area. The major concern of the subsidence monitoring will be the renewable resources, including perennial streams and springs. Visual checks for subsidence will be made during all surface activities, especially during water monitoring activities. The methods to be used for monitoring will be ground surveys of monuments and visual surveys of areas surrounding monitored seeps, springs, and streams~~

during water monitoring or any other surface activities. In addition, roads used to access hydrologic monitoring stations will be visually evaluated during monitoring activities. Following an initial survey prior to the beginning of mining operations, future Re-surveys will concentrate on areas which have been mined in the past or are anticipated to be mined within the upcoming year. Hence, the area of detailed survey may be expanded each progressive year. Annual re-surveys of the mine permit area will produce vertical control at the same sites as the previous year. Information on each site will be produced annually while the area underlying the site is being actively mined or is still potentially subsiding. The subsiding areas which show no change for two consecutive years will be considered stable and will be omitted from further annual surveys. If additional mining is anticipated within the stable areas, these areas will again be added to the annual surveys.

In addition to the ground surveys, aerial photogrammetric methods will be included in the surveys when the areas become too large to feasiblely handle with ground surveys. This method may be added to enhance the ground surveys and to cover larger areas as the mine expands. These visual surveys will be used to detect surface irregularities and surface cracks.

Visual ground checks for subsidence will be made of areas surrounding monitored seeps, springs and streams during hydrologic monitoring. In addition, roads used to access hydrologic monitoring stations will be visually checked for evidence of subsidence during monitoring activities. The observations made during hydrologic monitoring will be included in the Mine's Annual Report.

Anticipated Effects of Subsidence. Based on experience in the region and the results of investigations performed by Dunrud (1976), future subsidence in the permit area is anticipated to result in the formation of tension cracks, with these cracks healing to some degree following formation. It is further anticipated that no substantial damage will occur to rangeland conditions as a result of subsidence within the permit area. The only potential effects in that respect will be the exposure of plant roots where tension cracks form.

It is not anticipated that material damage will occur to streams as a result of subsidence. Gentry and Abel (1978) demonstrated that topographic lows (e.g., stream channels) tend to be protected by upwarping of adjacent slopes during subsidence. Therefore, mining-induced surface fracturing should be very limited (or nonexistent) within stream channel areas. Any fracturing that does occur in stream channels is likely to fill rapidly as a result of sedimentation.

It is also not anticipated that subsidence will significantly affect springs within the permit and adjacent areas. Von Schonfeldt et al. (1980) found that uniform subsidence "rarely causes problems to renewable resources such as aquifers, streams, and ranch lands." Since second mining will occur uniformly across the permit area, the resulting subsidence should also be uniform, minimizing the potential impacts to overlying springs.

525.200 Subsidence Control

Adopted Control Measures. SCM has adopted a mining technology which provides for planned subsidence in a predictable and controlled manner. As planned, this subsidence will be uniform, thus minimizing impacts to surface resources.

Compliance With Control Plan. SCM will comply with all provisions of the approved subsidence control plan.

Correction of Material Damage. No material damage of surface resources is anticipated as a result of subsidence in the permit area. However, should material damage occur, SCM will correct any material damage resulting from subsidence caused to surface lands to the extent technologically and economically feasible by restoring the land to a condition capable of maintaining the value and reasonably foreseeable uses which it was capable of supporting before the subsidence. In addition, SCM will notify the Division of any slide, rock fall, or other disturbance known to be caused by subsidence that will have an adverse effect on the environment.

Protection of Significant Surface Resources. None of the following exist within the area of potential subsidence associated with the Dugout Canyon Mine:

- Public buildings or facilities,
- Churches, schools, and hospitals,
- Impoundments with a storage capacity of 20 acre-feet or more or bodies of water with a volume of 20 acre-feet or more,
- Aquifers or bodies of water that serve as a significant water source for any public water supply system, or
- Urbanized areas, cities, towns, or communities.

Hence, no special control measures are required to preclude subsidence impacts to these resources. Refer to Appendix 5-11 for additional discussion of subsidence.

Raptor nests and other wildlife resources which may be influenced by subsidence are presented on Plate 3-2. A discussion of protective measures associated with wildlife resources in the permit area is presented in Section 333.300 of this M&RP.

525.300 Public Notice of Proposed Mining

Each owner of property or resident within the area above an underground mining block and adjacent area that may be affected by subsidence will be notified by mail at least 6 months prior to mining or within that period if approved by the Division. The notification will contain:

- Identification of specific areas in which mining will take place;
- Approximate dates the specific areas will be undermined; and
- The location or locations where the SCM subsidence control plan may be examined.

526 Mine Facilities

526.100 Mine Structures and Facilities

As stated in Section 521.100 of this M&RP, no buildings existed at the mine surface at the time construction was begun on the Dugout Canyon Mine. Nonetheless, Section 521.100 of this M&RP indicates that two "existing structures" are present within the permit area which were presumably "used in connection with or to facilitate coal mining and reclamation operations for which construction began prior to January 21, 1981" (see R645-100-200). These are the existing county road and a UP&L power distribution line.

A description of the location of the existing county road within the permit area is provided in Section 521.100 of this M&RP. It is unknown when this road was initially constructed. This road is currently a gravel road which will be modified by the County (see Section 527.200). As indicated in Section 521.100 of this M&RP, it is anticipated that the county road will not be relocated within the permit area.

The county road ends at the BLM/State property boundary, which is located approximately 300 feet northeast of the southwest edge of the proposed disturbed area boundary (i.e., near the upstream edge of the sedimentation pond). Those operations to be conducted within 100 feet of the county road include construction and operation of the sedimentation pond with its associated inflow and outflow structures, construction and operation of the downstream end of culvert UC-5 with its associated energy dissipator, construction and operation of sewer pipeline and storage of materials, snow, or equipment. The owner of the land in this area is the United States of America, as administered by the U.S. Bureau of Land Management. The interests of the public and the landowner will be protected by:

- Complying with the requirements of the BLM land lease.
- Conducting the mining and reclamation operations in compliance with the permit issued by the State of Utah.

- Maintaining a guardrail along the south edge of the road at the outlet of culvert UC-5 and the energy dissipator, whose height will be equal to at least the axle height of the vehicles which frequent the road.

- Maintaining a guardrail along the north edge of the road adjacent to the sedimentation pond, whose height will be equal to at least the axle height of the vehicles which frequent the road.

The road in Pace Canyon is a pre-existing road, the exact date of construction is unknown, however it is shown on the USGS Pine Canyon 7 ½ minute quad map date 1972.

Plates 4-1 and 5-2 depict the location of an existing UP&L distribution line that will be improved and activated to provide electrical service to the mine. It is unknown when the original distribution line was initially constructed. This line will be upgraded as necessary to provide power to the mine.

Generally, all support facilities will be located within or in close proximity to the associated operations areas. It is currently anticipated that mine support buildings will generally be steel-frame buildings with concrete floors, spread footings, or slab foundations, with metal exterior walls. Buildings of this design have been used extensively in the region and allow for ease of erection, long-term structural integrity, and minimal maintenance.

Building construction will generally involve grading and preparation of foundation areas, excavation and installation of foundations, building erection, interior and exterior finish work, and connection of utilities. Storage areas will generally be open graded, providing outside storage for large supplies. Both building sites and storage areas will be graded to ensure effective drainage to disturbed-area ditches and culverts as noted on Plate 7-5. Operation and maintenance of support structures and facilities at the Dugout Canyon Mine will involve regular grading of facility areas, together with inspection, cleaning, and repairs as required.

No coal processing waste banks, dams, or embankments will exist in the permit area. Sediment that is periodically removed from the sedimentation pond will be disposed of with underground development waste generated from the mine or pumped back into the sealed, abandoned "Gilson West-Old Workings"

APPENDIX 5-11

Subsidence Report

PREDICTION OF SURFACE DEFORMATION RESULTING FROM LONGWALL MINING OVER THE GILSON NORTH-EAST BLOCK

PREPARED FOR

CANYON FUEL COMPANY

DUGOUT CANYON MINE

MARCH 2006

PREPARED

BY

MALEKI TECHNOLOGIES, INC.
CONSULTING MINING & GEOTECHNICAL ENGINEERS
SOUTH 5608 MAGNOLIA
SPOKANE, WA 99223
(509)-448-7911
MALEKI.TECH@COMCAST.NET

1.0 INTRODUCTION

This report was prepared at the request of Canyon Fuel Company (CFC) for an evaluation of surface subsidence mechanics and determination of typical deformation expected at the Gilson northeast study area (figure 1, block 2) in the Dugout Canyon Mine, Wellington, Utah. The study was initiated in response to a deficiency list prepared by resource specialists of the Utah Division of Oil, Gas, and Mining.

Specific objectives were as follows:

- Description of subsidence mechanisms and angle of draw;
- Description of pillar designs developed by CFC for the Gilson longwall block 2 directly to the east of existing panels in the Rock Canyon and Gilson seams,
- Calculation of subsidence profiles over the longwall block 2 in the Gilson Seam using both site-specific and regional subsidence measurement results, and
- General recommendations for surface subsidence monitoring.

The study area is located adjacent to the permitted areas in the Dugout Canyon Mine located in the Book Cliffs Coal Fields of eastern Utah. Longwall mining has been extensively used in both the Book Cliffs and Wasatch Plateau coal fields since its introduction at the Sunnyside mines during 1960's; it is generally considered an environmentally attractive method to mine coal. It minimizes damage to the surface by permitting gradual subsidence of overburden strata over mined-out areas while at the same time satisfying BLM requirements of maximizing economic recovery of coal resources (Maleki and others 2001).

CFC is planning to mine coal reserves from the study area using the longwall method in the Gilson Seam at a depth of 800 to 3,000 ft. Existing mine plans call for extraction of the reserve using an extraction height of 9.5 to 10 ft within longwall panels. Subsidence calculations (consisting of vertical movements and horizontal strains) were completed for four longwall panels of interest to this study, as illustrated in figure 1. Important to these calculations are both local and regional measurements over the longwall panels in the Wasatch Plateau and Book Cliffs Coal Fields. Figure 2 presents the location of subsidence monuments presently monitored by CFC.

This report is prepared in five sections. After this introduction, the subsidence mechanism is presented in section 2.0, followed in section 3.0 by a description of mining and geologic conditions and subsidence characteristics, including rock mechanics data, subsidence parameters, and a discussion of mine layout evolutions. Predicted deformation patterns are presented in section 4 using subsidence models that account for variations in overburden thickness over the study area. The subsidence monitoring program is reviewed in section 5.

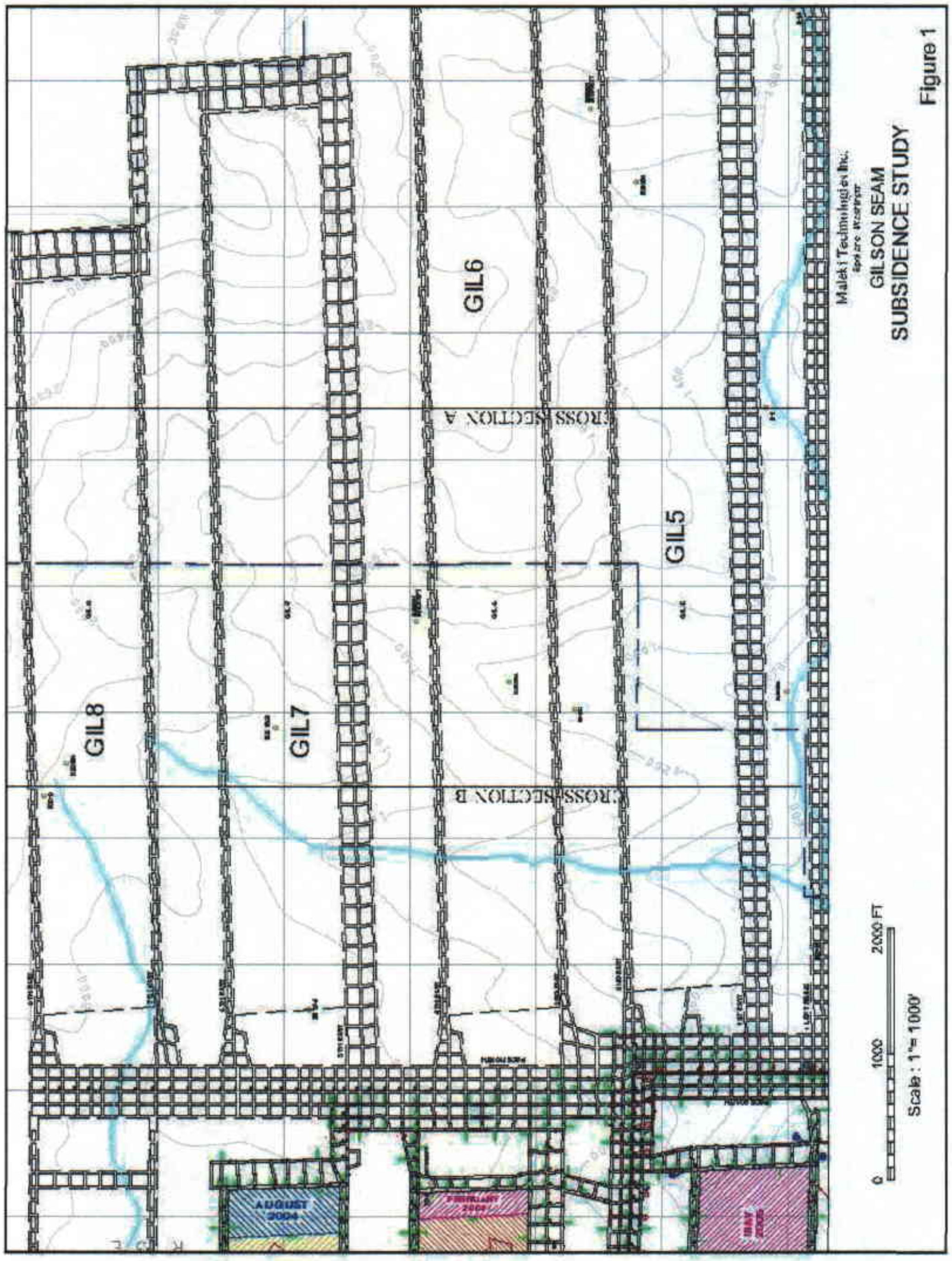

Figure 1. Longwall study area showing the location of Gilson Seam reserves and overburden contours, Gilson Block 2.

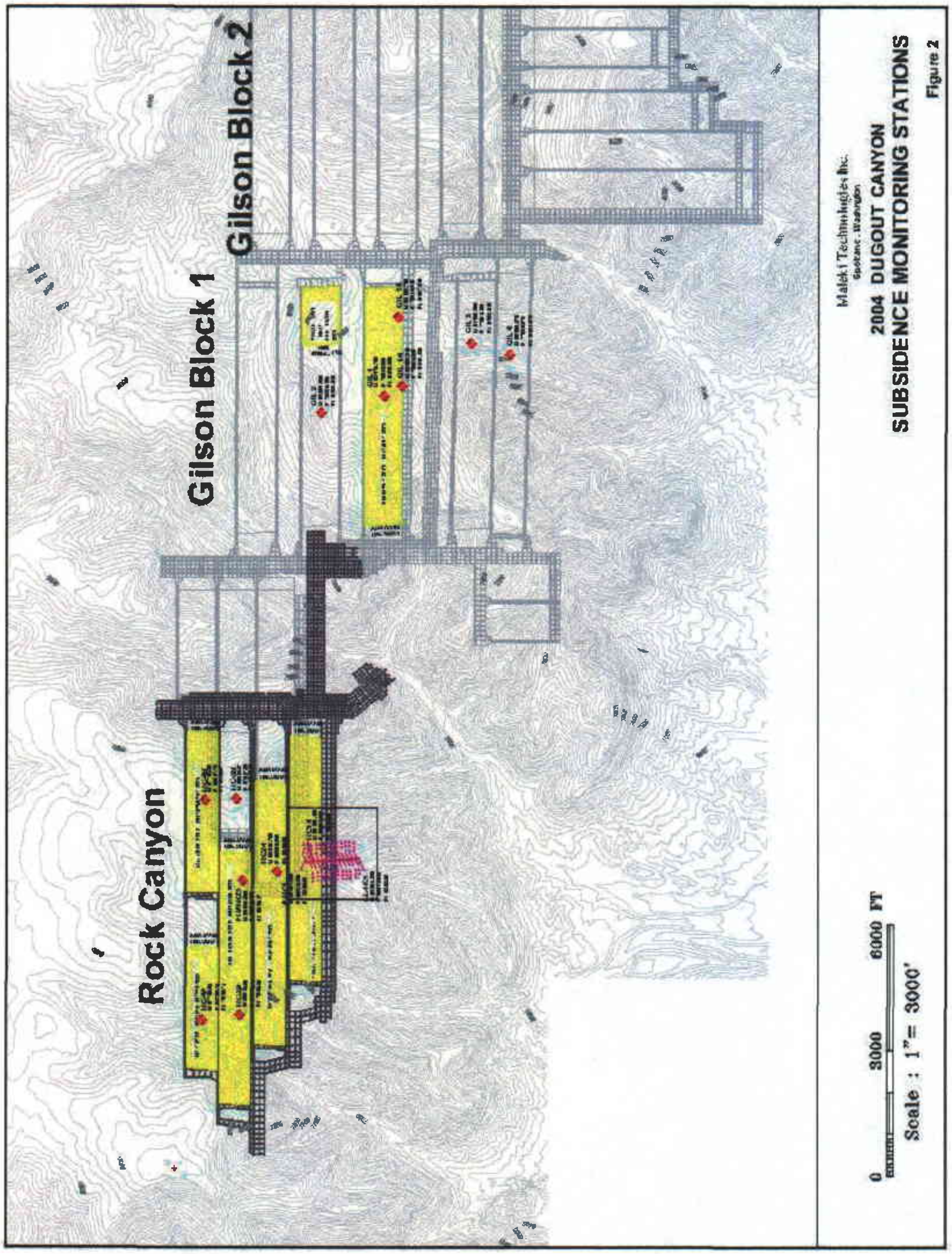

Figure 2. Mine layout and location of subsidence monitoring in the Rock Canyon and Gilson seams.

2.0 SUBSIDENCE MECHANISM

Surface subsidence occurs because of downward rock mass movement caused by the closure and collapse of mined-out excavations. Surface subsidence processes result in both vertical and horizontal displacement of rocks. Two major mechanisms of surface subsidence are associated with mining: formation of sinkholes and creation of troughs.

The type of subsidence mechanism predicted for the study area is the trough-type subsidence. It is characterized by the formation of a relatively smooth basin and is much less damaging than sinkhole subsidence. Sinkholes result from sudden or time-dependent collapse of overburden in localized areas, and these areas can be from several feet to tens of feet in diameter. Based on long-term measurements over the Hanna Basin, Wyoming (Karfakis 1987) and the Colorado Front Range (Matheson and Bliss 1986), researchers have established a relationship between the probabilities of sinkhole subsidence versus overburden depth. A great majority of sinkholes (98% probability) form where depths are less than 160 ft. At typical cover depths of 800 to 3,000 ft at the project site, the probability of sinkhole occurrence is very small.

As longwall operations are initiated in the first panel, roof span increases behind the longwall face until it caves. The roof span varies in mines, but typically ranges from 30 to 200 ft, depending on the strength of the roof rocks. The remaining overburden rocks will remain stable, transferring their load to the face and gate pillars. At some critical face position, the arching and load transfer mechanism collapses, and ground movement expands toward the surface, causing subsidence.

The caving process is associated with fracturing of near-seam strata and settling of overlying rocks. Four zones of movement are associated with subsidence (Peng 1992).

1. *Cave zone—broken and fragmented rocks that fill mined space.* The immediate roof rocks fracture into blocks often controlled by preexisting structure, filling the mined space. Bulking and rotation of individual roof rocks eventually limits the upward growth of failure. The thickness of this zone is estimated to be two to eight times seam thickness, depending on the bulking characteristics of the immediate roof rocks.

2. *Fracture zone—fractured rocks that fail because of shear stresses near the ribs and delamination toward the center of the panel.* This zone is located directly above the cave zone. The strata within this zone move downward, usually in large blocks, but without major rotation, to rest on the caved zone below. The permeability of the rocks is increased within this zone, which is estimated to extend twenty to sixty times seam thickness (Peng 1992) above the mine roof depending on geologic conditions and the strength of the rocks.

3. *Continuous deformation zone—deformation zone from the top of the fractured zone to the surface soils.* The strata flex downward without significant fracturing, gradually settling over the fracture zone. In the absence of soils, this zone extends to the surface,

forming compression zones at the surface to the center of the panel and tension zones at the edge of excavations.

4. *Soil zone*—This zone is an extension of the continuous deformation zone, which, depending on site-specific conditions, generally consists of soils and weathered rocks. Because of the less-brittle nature of soils, tensile cracks associated with transient subsidence may not be detected easily in front of the face and any existing fractures tend to heal quickly. Tensile fractures forming at panel boundaries last longer, but eventually get closed due to caving of fracture walls.

Three subsidence phases are associated with trough subsidence. These are shown in Figure 3.

1. The *subcritical phase* occurs immediately at the beginning when movement is in a small area at the center of the basin.

2. The *critical phase* occurs as the basin area expands when the maximum value of the downward movement is reached at the center. The critical excavation width is generally larger than 1.4 to 1.6 times the overburden thickness and is influenced by position and strength of competent layers within the overburden.

3. The *supercritical phase* occurs as the basin develops a flat bottom. In this phase, the basin area continues to increase with the cave area, but subsidence will remain at the maximum value attained in the critical phase.

Thus, the surface response of longwall mining activity, shown in Figure 3, begins with the subcritical phase, then progresses to the critical phase, and finally, to the supercritical phase where side-by-side longwall panels are extracted. The subsidence process first shows effects on the surface as the upper strata bend, including tension (expansion), which causes near-surface fractures to open up and new ones to be created. Figure 3 shows how the middle portion of the excavation expands as subsidence continues, going through a cycle of, first, tension and then compression, which closes tension cracks. Final subsidence shows an excavation with the middle portions lower in elevation, but back to a near-original state. Areas on the edge of the excavation basin are subjected to tensile strains.

In the Gilson Block 2, CFC is utilizing panel-barrier designs to control overburden caving, seismicity and surface deformation (MTI 2005). Considering panel width to average overburden depth ratios for the project area (0.4 to 1.0), these longwall panels are considered to have subcritical widths, and thus the great majority of subsidence is expected during the mining of individual longwall panels. The subsidence process is expected to be mature within 2 years after mining.

Subsidence characteristics for any coal field depends on site-specific geologic conditions and mining practices, including strata competence, geologic structure, topography, extraction height, extraction speed, and mine designs. For instance, rapid changes in topographic conditions are known to influence both naturally occurring and mining-induced rock mass wasting, including sandstone escarpment failure (Maleki and others 2001). The site-specific subsidence parameters for the Gilson study area are addressed in the following sections using available monitoring results locally and regionally within Utah coal fields.

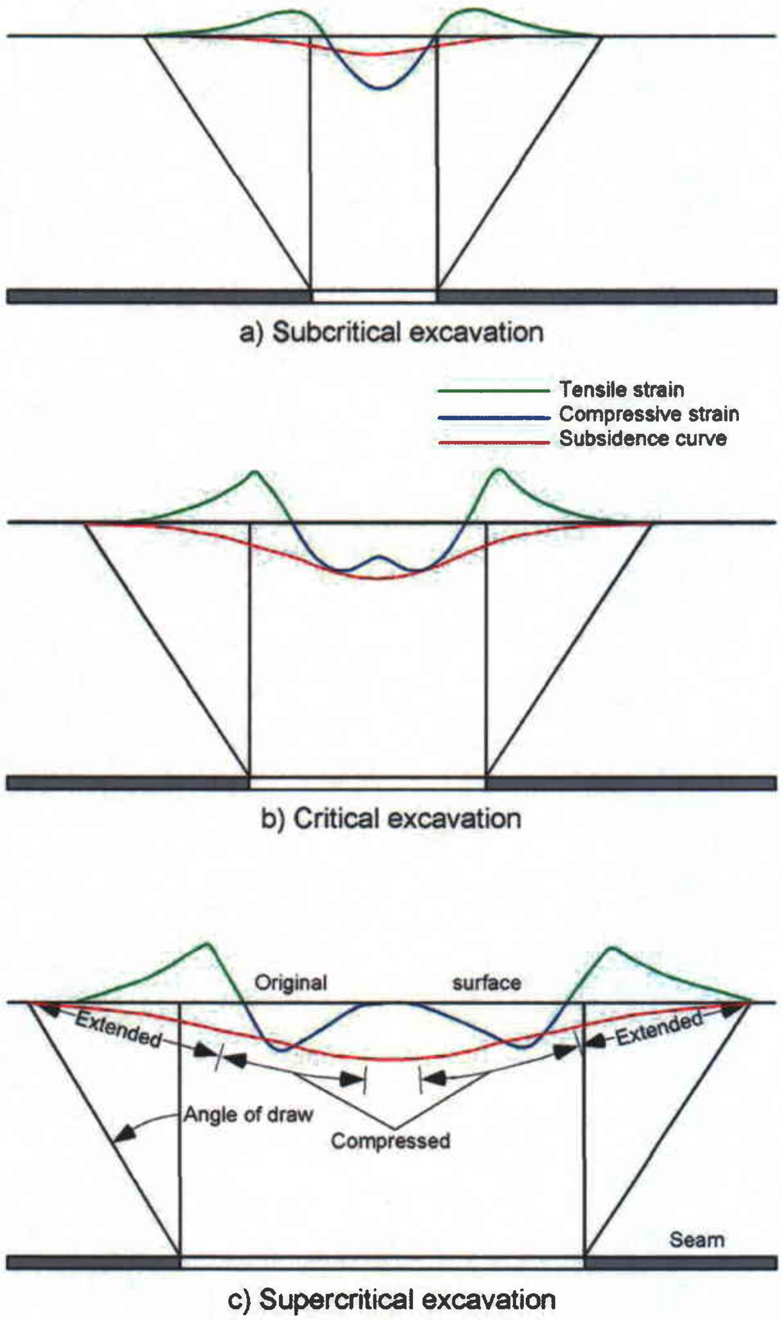

Figure 3. The three phases of subsidence development.

3.0 MINING, GEOLOGIC CONDITIONS AND SUBSIDENCE CHARACTERISTICS

3.1 Geotechnical Program and Mine Layout Evolutions

The Canyon Fuel Company, in cooperation with MTI engineering staff, implemented a comprehensive geotechnical program at the Rock Canyon Seam during the early stages of mine development. The program consisted of laboratory tests, underground and surface mapping, installation and monitoring of geotechnical instruments, and three-dimensional stress analyses. The intent of the program was to better understand strata behavior and to improve design of future workings in the Gilson seam.

Static rock mechanics measurements were analyzed on a routine basis and compared to model predictions at five instrument sites located strategically with respect to geology and stress conditions (figure 4). Results were important for verifying the performance of yielding gate pillars and for calibrating boundary-element models discussed elsewhere (Maleki and others 2003). To provide a basis for assessing mine seismicity, MTI created three-dimensional models while analyzing the results of mining-induced seismicity studies done by the University of Utah.

As illustrated in figure 4, the mine utilized two- and three-entry gateroad systems with 29-ft-wide yield pillars (47 ft center-to-center) and 750-ft-wide panels in the Rock Canyon seam. Yield pillars were selected to reduce strain energy accumulation in gate pillars and thus reduce the potential for gate pillar bumps. Pillar size was selected on the basis of a review of experience in the Book Cliffs Coal Field (Maleki 1992) and detailed stress analyses. The three-entry yield pillar system was replaced by a two-entry system in the Third West soon after receiving approval for the two-entry petition.

As illustrated in figure 4, the cover increases to the east, reaching a maximum of 1900 ft at the northeast corner of the Rock Canyon block. To control seismicity at higher depths, CFC decided not to retreat the face too close to the North Mains. This left substantial barrier pillars at strategic locations where high stress and seismicity were expected based on boundary-element stress analyses completed during the early stages of mine development in 2001. The barrier pillar left between the RC2 and RC4 panels became quite substantial, creating the possibility of mining the eastern portion of the RC4 panel (referred as RC4B) at moderate stress levels along the entire face. The RC4 panel was divided into two sections separated by a rock splay that thickened about mid-length of the panel. This inseam splay was identified by the operator during development of the Third and Fourth West and its thickness and strength were verified through extensive inseam horizontal drilling.

Based on the experience and geotechnical monitoring in the Rock Canyon seam, CFC decided to leave a barrier between the first two deep panels in the Gilson Seam, Block 1. The optimum size of the barrier was determined to be approximately 500 ft based on boundary-element stress analyses of barriers 200 to 500 ft wide. In addition detailed stress analyses were completed for evaluating the stability of Gilson East Mains and GIL1 tailgate, a three-entry abutment-abutment pillar design (MTI 2003). CFC adopted similar designs for Gilson Block 2 following successful extraction of GIL1 and GIL2 panels. Preliminary designs include use of 29-ft wide yielding gate pillars, abutment-abutment pillar designs for the tailgate of GIL5/GIL7 panels and panel-barrier designs for longwall extraction of GIL5 through GIL8 panels located at deep cover. Detailed stress analyses are planned for fine-tuning the mine layout for Gilson Block 2.

3.2 Geology and Stress Field

CFC is extracting the Rock Canyon and Gilson seams from the Cretaceous Blackhawk Formation. This formation is overlain by the cliff-forming Castlegate Sandstone of the Price River Formation. Several other sandstones that are laterally continuous over most of the reserve have been identified within the Blackhawk Formation in proximity to the seams. These are the Gilson, Rock Canyon, and Upper and Lower Sunnyside sandstones.

The cliff-forming Castlegate Sandstone overlies the entire property. It lies approximately 400 ft above the Rock Canyon Seam and is approximately 200 ft thick, but locally reaches 260 ft over the GIL2 panel. The Upper and Lower Sunnyside sandstones average 30 to 50 ft with a combined thickness of 80 ft. These sandstones are located approximately 30 to 90 ft above the Rock Canyon seam. Interburden between the Rock Canyon and Gilson seams varies from 30 to 60 ft.

The regional structural dip of the Blackhawk Formation is 7° to the northeast. There are three sets of joints in the sedimentary rocks: N110°E, N30°W to N40°W, and N40-70°E. Overall, joints are not well developed, and thus orientations vary locally. The face cleat is oriented approximately N110°E.

Field observations at the surface, underground, and along the coreholes indicate that joints are poorly developed, joint surfaces are undulating and rough, and persistence is low to medium both along strike and along dip. In addition, most joints are filled with calcite at depth and thus may resist shear movements. Measurements at different stratigraphic horizons indicate changes in joint orientations over the mine. No significant difference was observed in joint characteristics based on surface measurements (table 1). Observed trace length varies from 0.5 to over 20 ft.

Table 1. Joint statistics based on surface mapping.

Discontinuities	Set 1 (N70° to 110°E)	Set 2 (N30° to 40°W)
Mean spacing, ft	4.7	4.9
Horizontal trace length, ft	3-20	3-20
Persistence	Low-medium	Low-medium
Joint wall roughness	Undulating rough	Undulating rough
Wall strength	Slightly altered at depth	Stained locally at surface

There is excess horizontal stress in the Book Cliffs Coal Field with maximum stress oriented near-parallel to geologic structure (N110°E). The maximum far-field horizontal stress is 1,500 psi measured at the neighboring Soldier Creek Mine. This stress field is anisotropic with a minimum stress (secondary principal of 350 psi). In comparison to other neighboring coal mines, the horizontal stress field is moderate near Dugout Canyon.

Laboratory tests of coal-measure rocks indicate that most rocks are strong and stiff. The uniaxial compressive strength for near-seam sandstones, for instance, varies from approximately 9,000 to 23,000 psi, and Young's modulus varies from 1.8 to 4.0 million psi. These units are strong and can absorb high strain energy, which contributes to mine seismicity. Minimum strength is 5,300 psi for shales. The maximum value for the Young's modulus reaches 7.6 million psi at one location. The average uniaxial compressive strength for the Gilson Seam is 3100 psi.

3.3 Subsidence Parameters

Subsidence engineering parameters were estimated using the results of comprehensive measurements by the U.S. Bureau of Mines (USBM) and mining companies. During the 1980's, USBM completed subsidence monitoring over the historic Price River Coal and over the East Mountain, Utah. In addition CFC has measured subsidence over both the Rock Canyon and Gilson seams (figure 2).

Subsidence engineering parameters include subsidence factor, angle of draw, angle of critical deformation, and horizontal strain. The subsidence factor is the ratio of maximum measured subsidence to extraction height. Because this ratio depends on excavation width and overburden thickness, it should be measured in supercritical excavations where caving has reached the surface on collapse of the pressure arch.

The angle of draw defines the limit of surface movements beyond the edge of an excavation. It is measured from a vertical line drawn at the panel edge and a line connecting the panel edge to the point of "no" movement on the surface. In practice, the accuracy of surveying equipment defines the point of no movement. This accuracy is usually about 0.1 ft but varies depending on topographic conditions, measurement technique, etc. Angle of critical deformation is similar to the angle of draw, but is measured to a point of critical deformation with respect to existing structures; it is preferred by many practitioners because it avoids the shortfalls connected with the accuracy of surveying equipment. Based on subsidence data from 40 longwall panels, Peng (1992) found that it is 10° less than the angle of draw.

Horizontal strain is the change in horizontal length of the ground divided by the original length of the ground. Positive strain is used here to show tensile strain indicating an increase in the horizontal length of the ground. Compressive strain (negative notation) occurs when the ground is shortened or compressed. Maximum tensile strain is found in supercritical excavation and maximum compressive strain occurs in subcritical excavations. Horizontal strain increases with an increase in extraction height and decreases at greater depths. Surface topography also influences horizontal strain.

Table 2 summarizes estimates for the angle of draw and the subsidence factor for selected Utah operations. CFC measurement of the angle of draw using a series of monuments installed over a line to the south of RC1 panel (figure 2) has been inconclusive and influenced by ground uplift; a common subsidence feature in rugged topographies of the Book Cliffs Coal Field. USBM has reported measurements in the range of 23° to 30° over the Price River coal (Fejes 1986) and East Mountain (Dyni 1991). Considering all available data from Utah, an average angle of draw of 30° is prudent and conservative.

Figure 5 presents the measured subsidence factor for four Utah operations. Maximum measurements in the Book Cliffs vary from 0.37 to 0.40, lower than typical values measured in the Wasatch Plateau coal mines. The lower subsidence factor in the Book Cliffs is influenced by a higher percentage of competent overburden strata, practically limiting operators' ability to create supercritical excavations, a limitation imposed by safety concerns and rock burst events (MTI 2005).

The subsidence development curve (green line in figure 5) is used to estimate ground movement over the longwall panels at the Gilson block 2 where the panel width-to-depth ratio varies from 0.4 to 1.0. This is considered conservative because the Dugout measurements indicate very little movement below a panel width-to-depth ratio of 0.6.

Table 2. Subsidence parameters for selected Utah sites.

Site	Subsidence factor	Angle of draw, degrees	Comment
Dugout	.40	30	Critical
Price River Coal	.37	23 to 30	Critical
Wasatch Plateau, site 1(East Mountain)	.67-.70	25 to 30*	Supercritical
Wasatch Plateau, site 2	.70		Supercritical

* Two-seam mining

3.4 Gate Pillar Behavior

Because gate pillar designs may influence surface subsidence, some recent investigations have focused on evaluating subsidence above gate pillars. The Western U.S. measurements show different overburden deformation characteristics influenced by the choice of pillar designs. Based on a comprehensive case study by the USBM in 1991, Dyni showed that the narrow 30-ft-wide yield pillars commonly used in the two-entry Utah reserves crushed completely with no influence (or subsidence humps) above the gateroads. This is in general agreement with measurements over the longwall panels in the Price River coal and detailed underground measurements at the RC Seam confirming that gate pillars crushed behind the face (Maleki and others 2003).

CFC has successfully used abutment-abutment pillars in the GIL1 tailgate and is planning to use similar designs in the Gilson block 2. We expect these pillars to behave elastically based on underground observations in the GIL1 tailgate. Site-specific calculations are forthcoming.

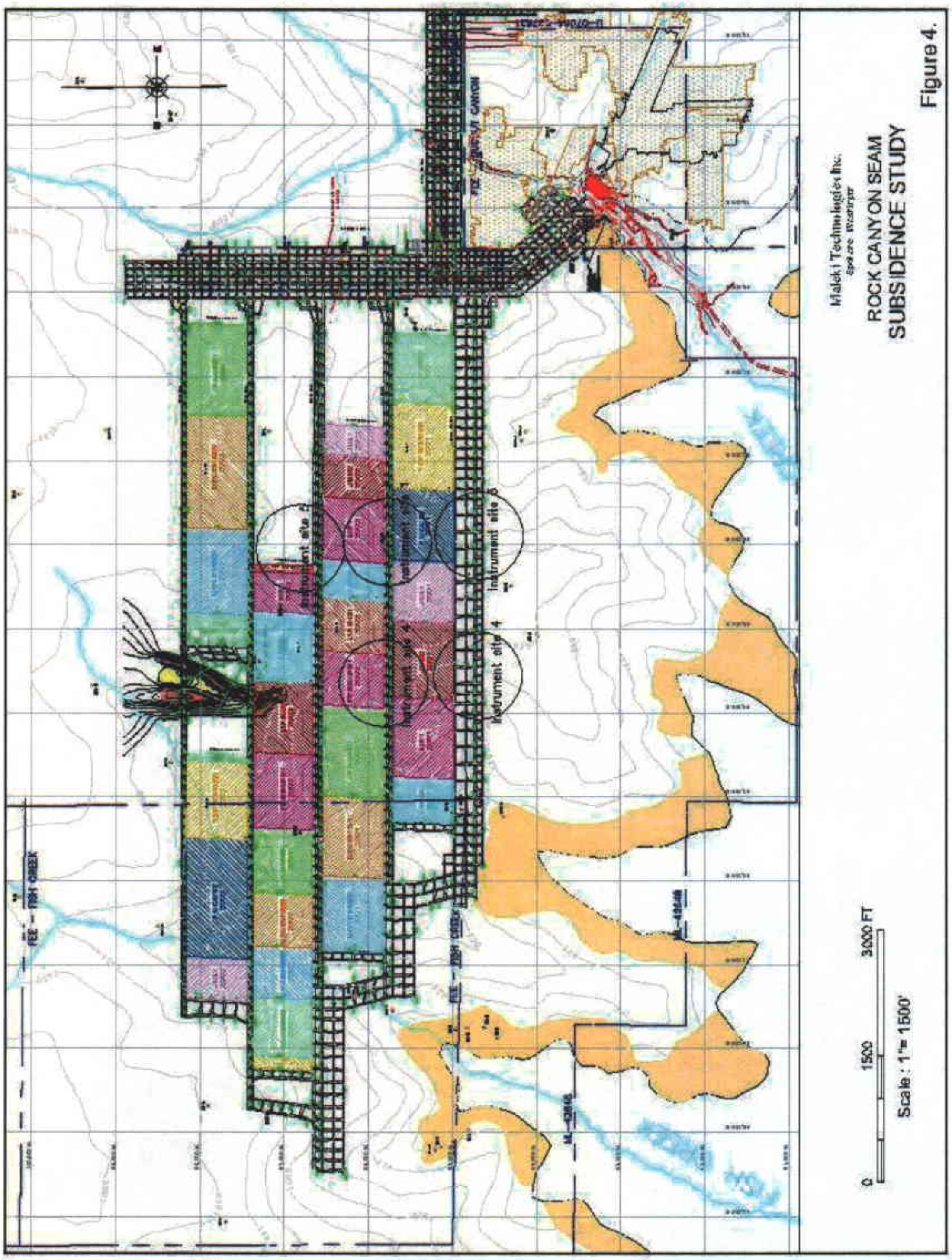

Figure 4. Mine layout and instrument location map in the Rock Canyon Seam.

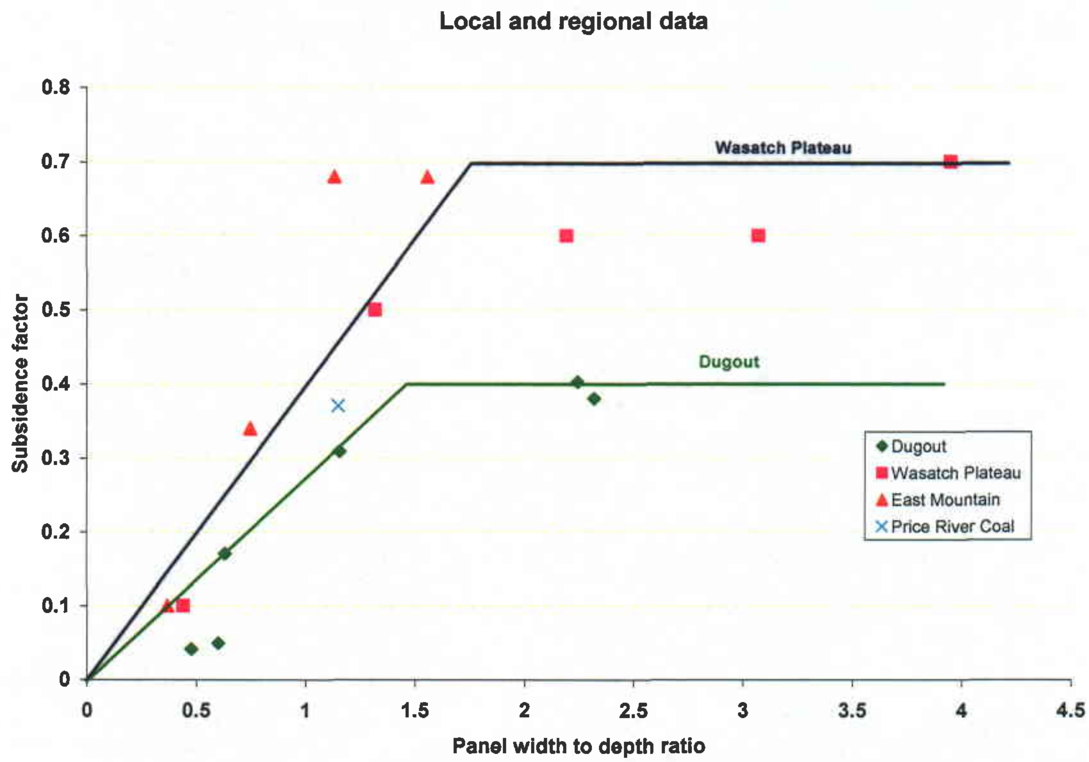

Figure 5. Measured subsidence factor vs. panel width to depth ratio for Utah operations.

4.0 PREDICTED GROUND MOVEMENTS

4.1 Methodology

Surface subsidence is the readily observable manifestation on the ground surface of the displacement field surrounding the underground portion of the mine. Predicting subsidence magnitude, therefore, constitutes a particular solution of the overall problem of finding the induced displacement field. To study subsidence phenomena and estimate the magnitude of subsidence, a number of empirical, physical, and numerical methods have been used.

Empirical methods, including profile functions, influence functions, and graphical methods were proposed by the British National Coal Board. These methods involve the analysis of existing subsidence from an area to predict future subsidence effects. These methods are based on the mathematical fit of a considerable number of measured subsidence profiles. They apply to geologic conditions in the area where they were developed and require adjustments if they are applied to different strata conditions.

To estimate surface deformation above the proposed longwall panels, we used a three-dimensional influence function method while accounting for site-specific conditions using the subsidence monitoring data from both the Rock Canyon and Gilson seams. These methods have become very popular for the prediction of subsidence and surface strains within the last two decades (USBM, 1983; Peng and others 1994; SDPS 2000). They are superior to graphical methods because they can be used to model an entire longwall block while allowing an examination of the sensitivity of results to variations in seam thickness, pillar designs, panel dimensions, and overburden thickness.

These methods rely on the influence of an extracted volume on the displacement components of a remote point on the surface. In the zone calculation method, for example, the circular zone of influence around a point on the ground surface is divided into a number of zones in such a manner that the influence factor of such an area is fixed at a certain value. If the full area of the influence were mined out, the point in question would undergo 100% of maximum possible subsidence. If some portion within the zone of influence were unmined, subsidence would be correspondingly reduced.

4.2 Results

Figure 6 presents surface subsidence profiles along two north-south cross sections (A and B in figure 1) over the analyzed area of Gilson block 2. Predicted maximum subsidence is 1.9 ft over B under shallow cover. The expected subsidence is lower at A under high cover.

Predicted tensile strains along two north-south cross sections are presented in figure 7. In this figure, we have presented horizontal strain patterns while accounting for variations in topographic and mining conditions. Figure 7 clearly shows final compression within the center of the panels and tension near barrier pillars. Surface strains are generally higher at lower elevations. This indicates a greater potential for localized fracturing over shallow cover area.

Using a criterion suggested by Singh and Bhattacharya (1984), calculated strains do not reach levels that can cause surface fractures (0.05). The panel and barrier designs adopted in this longwall block for ground control and safety limit surface deformation and potential fracturing.

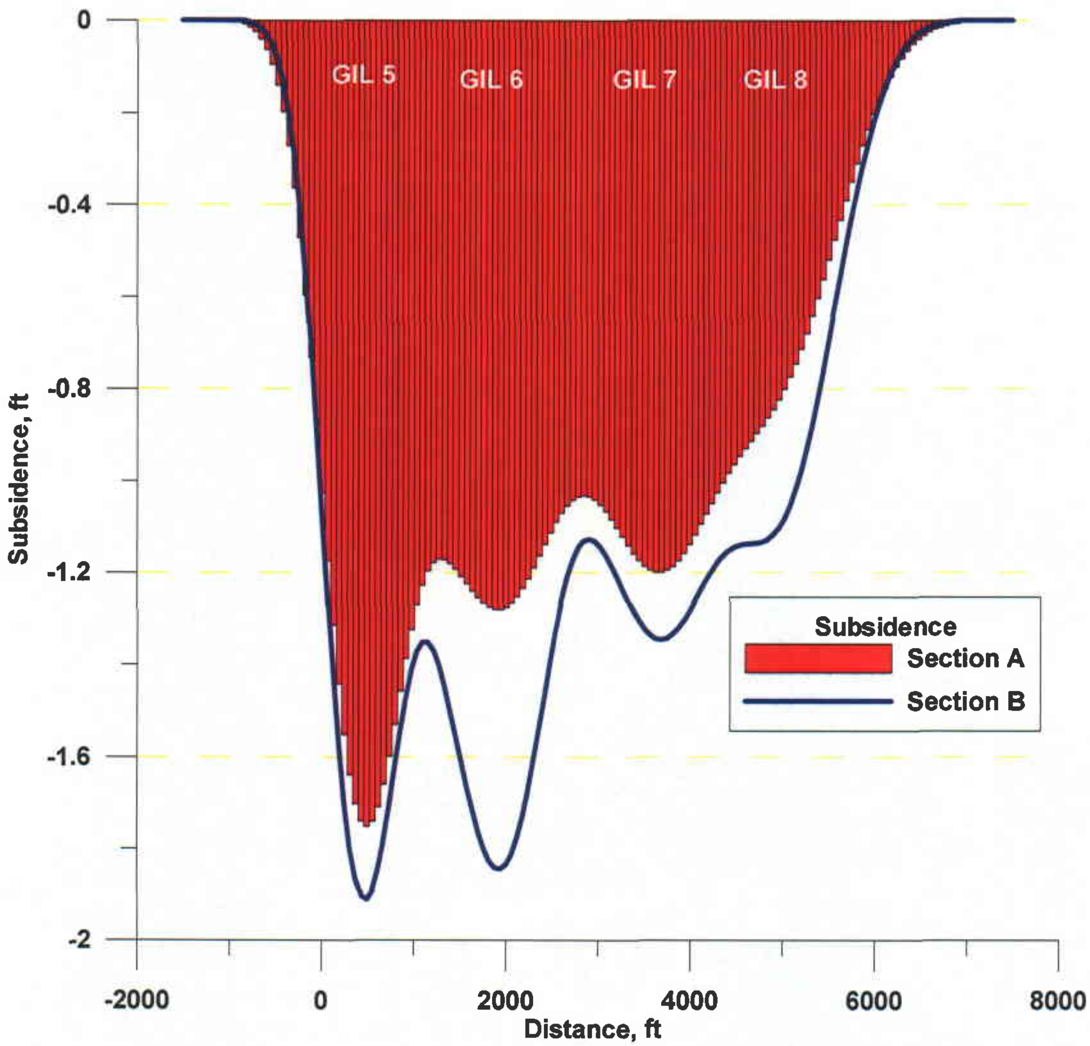

Figure 6. Typical subsidence profiles at locations A and B.

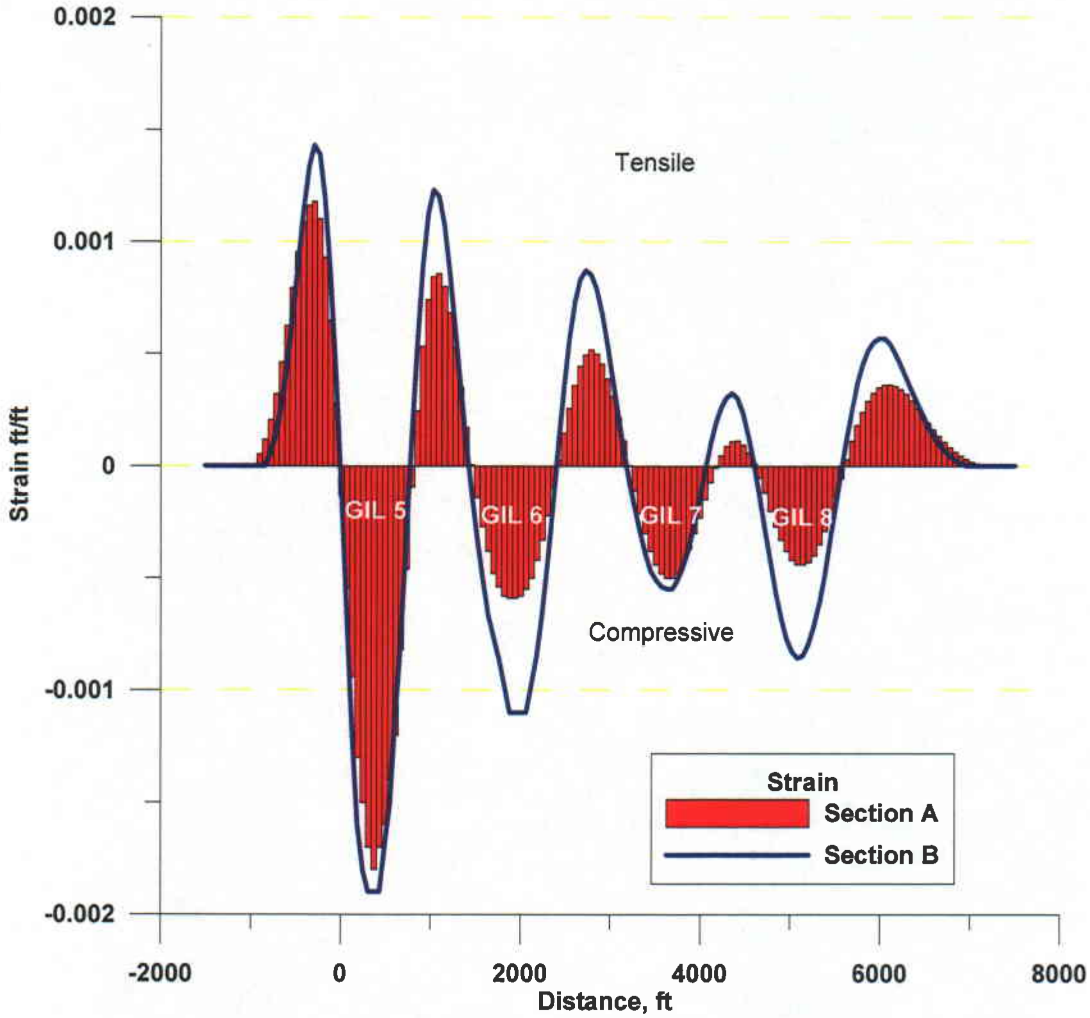

Figure 7. Typical strain profiles at locations A and B.

5.0 MONITORING PROGRAM

CFC is implementing a practical subsidence monitoring program over the longwall panels. After obtaining more-detailed subsidence data over the Rock Canyon Seam, the current approved monitoring plan allows for one subsidence monument per longwall panel. Existing monuments are surveyed once a year and the results reported in annual subsidence reports. Because ground movements have matured over the Rock Canyon block, we do not see any benefit for additional monitoring of the monuments installed over a line to the south of RC1 panel.

CFC has not observed surface cracking above the longwall panels and thus does not foresee the need for detailed monitoring. USBM researchers report very few mining-induced cracks over the East Mountain or the Price River coal (Dyni 1991; Fejes 1986). MTI has designed and analyzed surface monitoring programs over Colorado mines. In some shallow mines, geologic staff conducts an annual crack survey over active longwall panel areas. A visual inspection is deemed sufficient over the deeper mines. The survey data include crack location, orientation, horizontal length, and width. Based on these measurements, MTI recommends a limited monitoring program so that the presence of surface cracks (if any) can be verified.

References

Dyni, R. C., 1991. Subsidence Resulting from Multiple-Seam Longwall Mining in the Western United States – A Characterization Study. USBM IC 9297.

Fejes, A., 1986, Surface Subsidence Over Longwall Panels in the Western United States, USBM Report of Investigations. IC 9099.

Karfakis, M. 1987. Chimney Subsidence over Abandoned Coal Mines. International Journal of Mining and Geological Engineering, V. 5, pp. 131-134.

MTI 2003, Stress Analyses of Gilson East Mains and Barrier Pillars. Internal report prepared by Maleki Technologies, Inc., for CFC.

MTI 2005, Report prepared by Maleki Technologies, Inc. to SITLA entitled "Control of Mining-induced Seismicity Through Mine Design: Application of U.S. Experience and Numerical Modeling for the Cottonwood Tract". September 2005.

Maleki, H., R. Olson, D. Spillman, and M. Stevenson, 2003. Development of Geotechnical Procedures for the Analysis of Mine Seismicity and Pillar Designs, 22nd International Conference in Ground Control in Mining, Morgantown, WV, 2003.

Maleki, H., 1992. In-situ Pillar Strength and Failure Mechanism in U.S. Coal Seams, Proceeding of the Workshop on Coal Pillar Mechanics and Design. USBM IC9315.

Maleki, H., R. Heath, and G. Tetreault, 2001. Development of Guidelines for Determination of Maximum Economic Recovery, SME Transactions, Vol. 310, 161 pp.

Maleki and others, 2001. Development of a Statistical Technique for Assessing Sandstone Escarpment Stability. 19th International Conf. on Ground Control in Mining, WV University.

Peng, S. S., 1992. Surface Subsidence Engineering, SME, 161 pp.

Peng, S. S., and Yi Luo, 1994. Comprehensive and Integrated Subsidence Monitoring, WV University, 64 pp.

SDPS, 2000. Surface Deformation Prediction System, VPI.

Singh M. M., and S. Bhattacharya, 1984. Proposed Criteria for Assessing Subsidence Damage to Renewable Resource Lands, SME meeting, Preprint No. 84-391.

USBM 1983. SPASID, A Computer Program for Predicting Ground Movement Due to Underground Mining. USBM contract J02955031.