Analysis and Regional Implication of Cleat and Joint Systems in Selected Coal Seams, Carbon, Emery, Sanpete, Sevier, and Summit Counties, Utah

by
Brigitte Hucka
Utah Geological Survey

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ABSTRACT

This study is intended to help Utah coal operators plan longwall and room and pillar mining operations. Cleat and joint orientations were performed in 22 active mines located in the Book Cliffs, Wasatch Plateau, Emery, and Coalville coalfields in Utah. Since joints in mine roofs very often outline slabs or blocks which may fall if not properly supported, this study should help to improve the safety of mine workings. Further, the productivity of continuous miner operations can be improved if working faces are oriented parallel to the main cleats.

The frequency of cleat distribution and orientation in the seams was investigated and the results of approximately 4000 field measurements are presented both as rose diagrams and contoured stereographic projections (Schmidt). This report also includes the macroscopic and microscopic (maceral inventory and rank determination) descriptions of coal seams, and addresses the extent of healing of cleat planes, sometimes responsible for changes in cohesion, by calcite or other accessory minerals.

Analytical data suggest that cleats in coal and joints in outcrop rocks are the result of tectonic forces. Cleats and joints are influenced by the presence of faults. Generally, in mines located close to faults, divergence of the two main cleat and joint systems occurs, with the face cleats or main joints oriented roughly parallel to the orientation of the faults. Further, cleats in coal and joints in surface rocks maintain the same pattern in the Book Cliffs, Emery, and Coalville coalfields; as a result, they may serve to predict the cleat orientation in coal seams. This phenomenon is important for mine layout purposes. However, in the tectonically more disturbed Wasatch Plateau coalfield, in some instances the cleat directions in the coal diverge with the joint directions, implying that prediction of the cleat orientations in coal is less reliable.

INTRODUCTION

In 1987 the Utah Geological and Mineral Survey (UGMS) initiated and funded a one-year study on selected geological factors affecting coal mining in Utah. The study area extended over 4 producing coalfields and included 17 important coal seams (figure 1). The coal-bearing strata included the Blackhawk Formation and the Ferron Sandstone Member of the Mancos Shale of Cretaceous age. The study was undertaken to gather information on cleat and joint systems in coal seams and surface rocks to aid coal operations in Utah.

Joints occur in a variety of rocks. However, sedimentary rocks (such as coal-bearing strata) are considered to be particularly susceptible. In coal such joints are called cleats. The presence of joints and cleats in coal seams has been known for centuries. Kendall and Briggs (1933) mention a work of Mammatt from 1834 entitled: "Geological Facts to Elucidate the Ashby de la Zouch Coalfield" (Leicestershire coalfield). More recent studies have focused on the origin of cleats. Some researchers emphasize a tectonic origin (Kaiser, 1908, p. 29), while others propose the non-tectonic origin of cleats (Hoefer, 1915). These two original ideas were combined by Ammosov and Eremin, (1963, p. 4), who champion two types of cleats: one type as "endogenetic" caused by contraction of coal, and the other as "exogenetic" formed by tectonic forces. A brief but thorough description of previous work on the origin of cleats is offered by McCulloch and others (1974, p. 3). The most prominent cleat is known as the main cleat (or master-joint cleat), according to Kendall and Briggs (1933, p. 164). In today's terminology, this cleat is called a face cleat, as opposed to the butt cleat, formerly called cross-cleat or board cleat. These two cleats form at approximately 90 degrees to one another.

Cleats in coal and joints in the roof rocks of coal mines are important features to be considered during mine planning and design. Their presence and orientation in coal seams affect permeability and the ability of methane gas to migrate from coal into mine workings. Similarly, water in coal-bearing aquifers tends to discharge into mine workings along fractures.

Cleats may also continue from a coal seam into the immediate mine roofs as joints. If such joint systems are oriented perpendicularly to the bedding planes, then together with interlayered planes of separation they may outline blocks of rocks slabs kept in the roof only by friction. Such blocks must be kept in place by roof bolting or other means of roof support, otherwise the blocks may slide into the working place, creating safety hazards. The direction of cleats in coal seams may affect the design of a mine since they constitute local zones of weakness which decrease the strength of the coal. Coal mines using the room and pillar mining method are usually designed with working faces oriented parallel to the main cleat direction in order to facilitate the cutting process (figure 2).

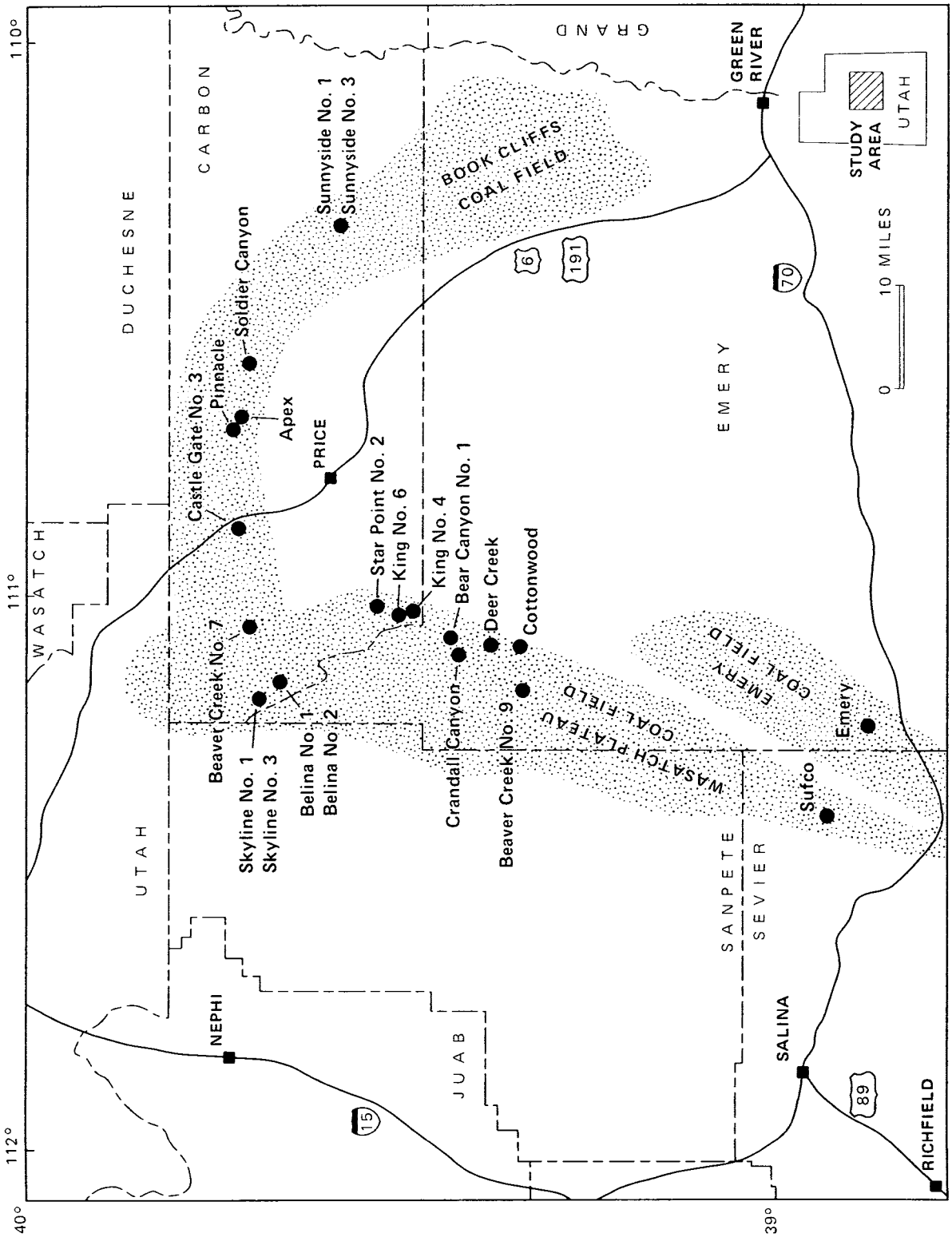

Figure 1. Locations of mines where cleat and joint orientations were taken. Strippled areas indicate major coal fields. (Boyer mine located in northern Utah is not shown)

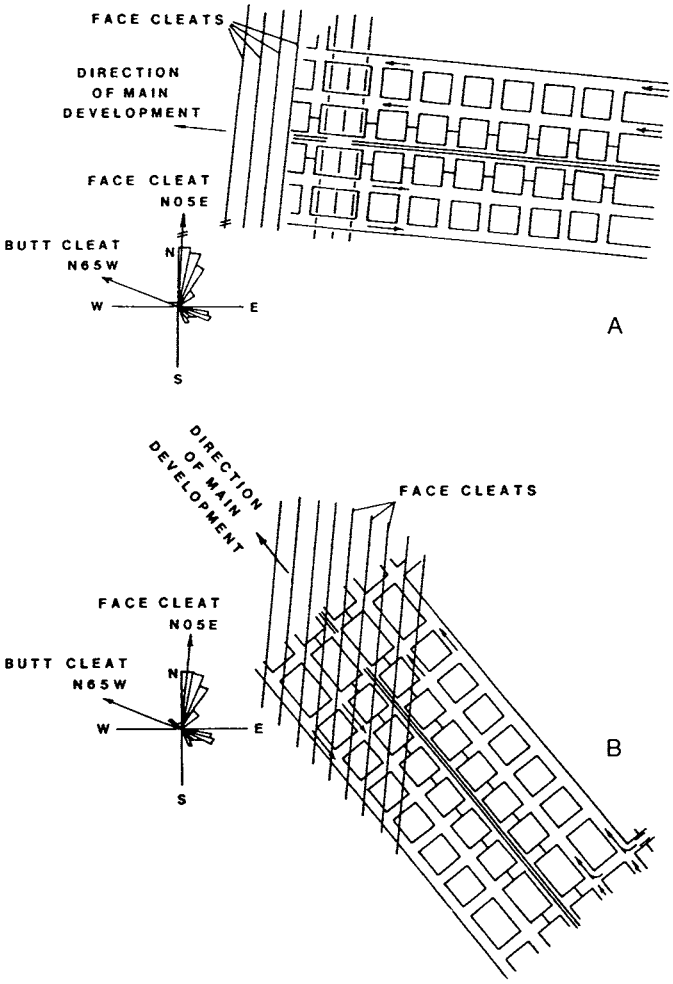

Figure 2. *Idealized mine development plan related to the direction of face cleats: a) efficient use of cleats for mining; b) inefficient use of cleats for mining.*

The mechanical strength of coal and associated rocks, as well as their gas-bearing capacity and permeability, depend on the density and development of cleat and joint systems present in the strata (Ammosov and Eremin, 1963, p. 1). The behavior of the coal-bearing strata is affected by the presence of these "discontinuities" (Turner and Weiss, 1963). Sudden gas and coal outbursts (ejections of immense volumes of coal accompanied by gas) are directly related to the presence of cleats and joint systems (Ammosov and Eremin, 1963, p. 101). The natural characteristics (geologic structure) of a coal seam are important to its efficient excavation. Therefore, as much as possible should be known of these conditions before mining the deposit.

Data on cleats and joints of coal and of the surrounding rocks should always be sought for mines. This knowledge should be supplemented as work progresses to achieve the method of mining best suited to the orebody. If coal seam characteristics are understood, it is then possible to assess the different types of suitable methods. Coal mining productivity may be improved by increasing the role of coal cutting and loading machinery. The success of any machinery depends on the structure, thickness, and strength of the coal in the seam and its adjacent rocks. Therefore, the purpose of this study is:

1) to document a select group of data from mines in four major Utah coalfields,
2) to use these specific examples to make conclusions about cleat and joints in general,
3) to provide mine operators of selected mines with detailed information on cleat and joint systems, geologic features important in planning and designing safe mine structures.

COLLECTION AND PRESENTATION OF DATA

The data for structural analysis of cleats and joints were drawn from observations in 22 active Utah mines and included 17 coal seams in four coalfields. The mines are listed by their geographical location, i.e., south to north and west to east, to facilitate the reader's orientation (plates A and B, and table 1). Data were also collected from joint systems in the areas surrounding the mines to examine possible relations between the cleats in the coal seams, joints in the roof strata, and joints in the surface strata. The cleats and joints were measured using a special geological stratum compass. This instrument is designed for measuring the azimuth of dip and the angle of dip in one operation. The measurements are taken so that the dip is always measured to the right ("right hand rule").

An average of 100 cleat readings were taken in underground seams at each mine to determine a reliable mean of the main cleat orientations. Readings were taken close to the advance of a continuous miner or a longwall face. The same number of readings were taken in the exposed strata within a mile of the mine. At some locations, less than 100 readings were obtained due to insufficient exposures.

Cleat and joint observations were complemented with coal characterization data consisting of megascopic description of the coal in-situ, microscopic description, and determination of the rank of coal through reflectance measurements on vitrinite.

The megascopic description was carried out to determine the respective proportions of the individual lithotypes (vitrain, clarain, durain, and fusain), rock partings, and mineral accessories. The description which serves as the first basis of assessement of the nature of coal was supplemented with the petrographic analysis to determine the percentage of coal macerals. Maceral composition of each seam was determined in white and ultraviolet light with the use of a Leitz Ortholux II microscope at 500x magnification and 50x oil immersion objective. The average maceral percentages were based on a 1000 points count of prepared coal pellets. Four coal pellets were examined from each coal seam (channel sample and samples from the top, middle, and bottom of seam).

Reflectance measurements were carried out on vitrinite to determine the rank. The mean value based on a 100 points count on each of the same samples (Ro) determined the rank (ASTM classification). Almost all coals examined belong to the high volatile bituminous range except the coal of the Boyer mine, which was subbituminous. The bituminous range includes three levels from high volatile bituminous A to high volatile bituminous C with high volatile bituminous A having the highest reflectance value with the lowest volatile matter content. The two other parameters

that determine the rank of coal are the volatile matter content in the case of the high-rank coals and calorific value for the lower rank coals.

Two methods of graphic presentation of cleats and joints were chosen. The first method of graphic presentation was done in the form of a "rose diagram." The petal width on the rose diagram being used is 10 degrees. However, the disadvantage of this representation is that the rose diagram represents direction and density of cleats but not their dip. The second method, less commonly used, is the graphic representation of cleats in the form of stereographic projection. This is achieved by the use of a Lambert projection or Schmidt projection (Schmidt, 1925). The stereographic projection uses the lower hemisphere as a reference sphere in which planes and lines pass through the center and intersect the sphere (figure 3). These intersections are then projected onto the equatorial or polar plane of the sphere. A face of the cleat represented by a plane may be plotted either in the form of a great circle or as a pole (the projection of the point at which the normal to the plane cuts the reference hemisphere). The resultant projection is called a stereogram (figure 4). A detailed description of stereographic projection is given in Phillips (1971).

Ninety rose diagrams and contoured Schmidt projections were evaluated using a computer program called MicroNET to help interpret the results of approximately 4000 measurements. The cleat and joint orientations were plotted on two regional maps (plates A and B—Boyer mine located in northern Utah not shown on regional maps) and summarized in table 1.

To delineate cleat and joint patterns, the equal-area diagrams were contoured (figure 4). Each contoured diagram, constructed with the help of MicroNET, represents a hemisphere on the surface of which the density of cleats and joints are contours in percentage concentraion. The contour intervals on the plots were chosen at 1, 6, and 10 percent. Well-defined patterns of cleats and joints can be seen from the plots.

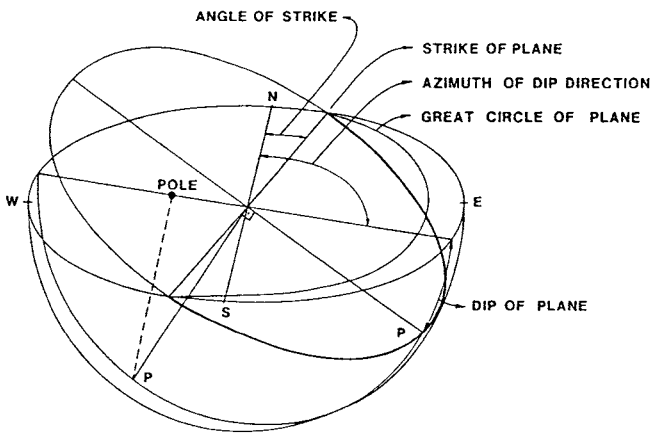

Figure 3. Stereographic projection.

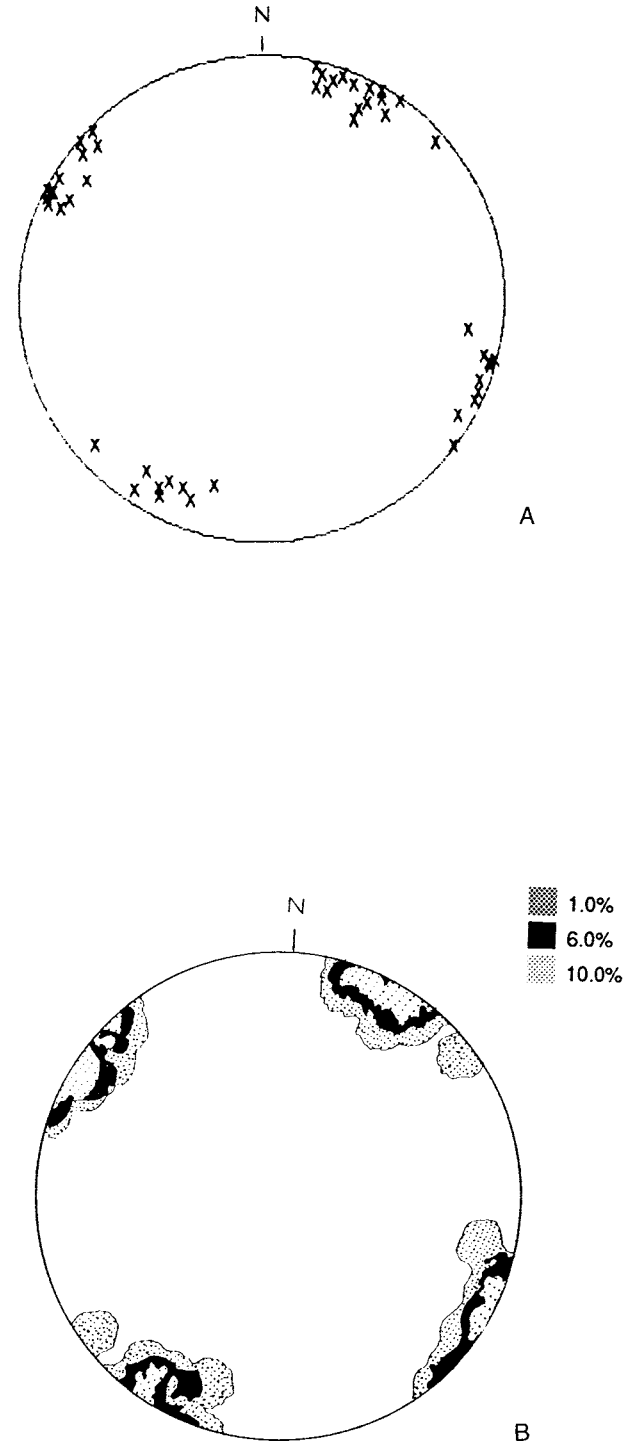

Figure 4. Schmidt net, n = 49, a) Stereogram of equal-area projection of cleat poles; b) Projection of figure 4a contoured and shaded.

Table 1
Cleat and Joint Orientations in Utah Coal Mines and Outcrop Rocks

Mine:	Cleat: 1. Face	Butt	Secondary
	Joint: 2. Main	Minor	Secondary
Emery Mine	1. N. 25 E.	N. 65 W.	N. 25 W.
	2. N. 25 E.	N. 65 W.	N. 25 W.
Southern Utah Fuel Co. No.1 Mine (SUFCO)	1. N. 15 E.	N. 55 W.	N. 15 W. N.85 W.
	2. N. 15 W.	N. 65 E.	
Beaver Creek No. 9 Mine	1. N. 15 W.	N. 75 E.	
	2. N. 25 E.	N. 45 W.	++
Cottonwood Mine	1. N. 85 W.	N. 15 E.	
	2. N. 85 W.	N. 05 E.	
Deer Creek Mine	1. N. 35 E.	N. 75 W.	N. 35 W.
	2. N. 15 E.	N. 75 W.	
Bear Canyon No. 1 Mine: Upper Hiawatha Seam	1. N. 65 E.	N. 25 W.	N. 65 W. N. 25 E.
Hiawatha Seam	1. N. 65 W.	N. 45 E.	
	2. N. 75 W.	N. 25 E.	
Crandall Canyon Mine	1. N. 65 W.	N. 35 E.	N. 25 W.
	2. N. 65 W.	N. 35 E.	
	2. N. 05 E.		++
King No. 6 Mine	1. N. 75 W.	N. 25 E.	
	2. N. 15 E.	N. 85 W.	
King No. 4 Mine	1. N. 75 W.	N. 35 E.	N. 15 W.
	2. N. 15 E.	N. 85 W.	
Star Point No. 2 Mine	1. N. 25 E.	N. 75 W	
	2. N. 05 E.	N. 75 W.	N. 25 W.
	2. N. 05 W.	N. 75 E.	
Belina No. 1 and Belina No. 2 Mines	1. N. 05 E.	N. 85 W.	
	1. N. 05 E.	N. 85 W.	
	2. N. 05 E.	N. 85 W.	
Skyline No. 1 and Skyline No. 3 Mines	1. N. 15 E.	N. 85 W.	N. 25 W.
	1. N. 05 E.	N. 75 W.	
	2. N. 05 E.	N. 65 W.	
Beaver Creek No. 7	1. N. 65 W.	N. 35 E.	
	2. N. 15 E.	N. 45 W.	
Castle Gate No. 3 Mine	1. N. 55 W.	N. 30 E.	
	2. N. 65 W.	N. 35 E.	
Pinnacle Mine and Apex Mine	1. N. 65 W.	N. 35 E.	
	1. N. 55 W.	N. 45 E.	
	2. N. 85 W.	N. 35 E.	N. 45 W.
Soldier Canyon Mine	1. N. 65 W.	N. 25 E.	
	2. N. 35 W.	N. 85 W.	N. 25 E.
Sunnyside No. 3 and Sunnyside No. 1. Mines	1. N. 65 W.	N. 35 E.	N. 65 E. N.45 W.
	1. N. 75 W.	N. 05 W.	
	2. N. 75 W.	N. 15 W.	N. 05 E.
Boyer Mine	1. N. 75 E.	N. 25 W.	
	2. N. 65 E.	N. 15 W.	

strikes of cleat and joint measurement values with the greatest frequency = mode (± 5 degrees)
++ unreliable; insufficient number of measurements

ORIENTATION OF CLEATS AND JOINTS IN UTAH MINES

This section summarizes the results of measurements made for this study and focuses on:

1) the prevailing cleat systems in coal seams,
2) the extent of cleat development in coal seams,
3) cleat distribution,
4) patterns of rock fracturing,
5) the average spacing of cleats,
6) mineralization of cleat apertures,
7) lithotype distribution, and
8) joint systems measured in the vicinity of the individual mines.

Information on geologic setting, the rank and nature of the coal, and petrographic analyses for each mine is presented in the appendix.

Prevailing Cleat Systems

Coal examined in this study is characterized by two sets of cleats: face and butt. These two sets form a system. In surface rocks these two sets are called main and minor joints. Face and butt cleats in coal, and main and minor joints in outcrop rocks are ordinarily nearly perpendicular to each other. Further, the systems are perpendicular to the bedding planes. The main systems in coal and surface rocks generally maintain their orientation in successsive beds.

As shown in figure 5, the two prevailing cleat systems are:

a) A system with the face cleat oriented in a northwest-southeast direction and the butt cleat oriented in a northeast-southwest direction. This system of cleats was observed in the following mines: Sunnyside Nos. 1 and 3, Soldier Canyon, Apex, Pinnacle, Beaver Creek No. 7, Castle Gate No. 3, King Nos. 4 and 6, Crandall Canyon, Beaver Creek No. 9, Bear Canyon No. 1, and Cottonwood.

b) A system with the face cleat oriented in a northeast-southwest direction and the butt cleat in a northwest-southeast direction. Divergence in the face and butt cleat orientations (plates A and B - shaded rose diagrams) seems to be, in most cases, related to faults near the following mines or encountered within the mines: Boyer, Belina Nos. 1 and 2, Skyline Nos. 1 and 3, Star Point No. 2, Deer Creek, Bear Canyon No. 1, Southern Utah Fuel Company No. 1, and Emery.

These two prevailing patterns characterize the main and minor joint systems of surface rocks. However, the order of dominance differs.

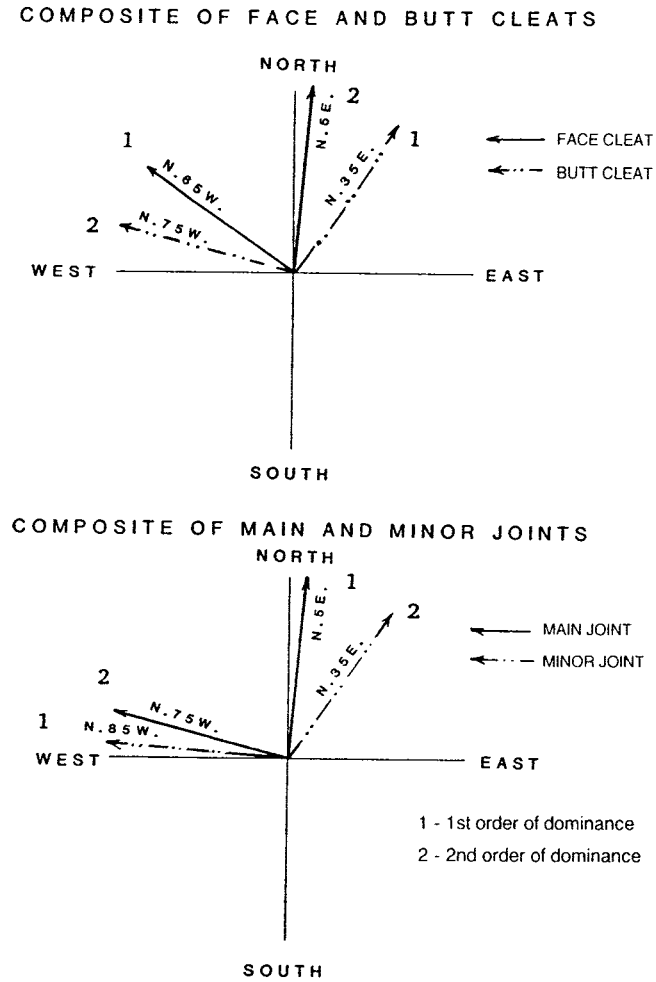

Figure 5. Composite cleat systems in coal and joint systems in surface rocks in the Book Cliffs, Wasatch Plateau, Emery, and Coalville coalfields (← cleat and joint orientations mostly encountered in coal and surface exposures).

Extent of Cleat Development in Coal Seams

Cleats in some instances cut the whole seam, and in other instances are limited to individual petrographic components of the coal. Face cleats, as a rule, are better developed in all investigated seams. Further, they are better developed in the bright components of the coal (clarain, vitrain) and are poorly discernible or even absent in the dull components of the coal (durain). Variations also exist within the former components: cleats are highly developed in the vitrain, which causes the coal to disintegrate in certain places into small pieces. In some cases the cleats can be traced into the roof rocks where they continue as joints. Usually, these joints are oriented in the same direction as the adjacent cleats in the coal.

Cleat and Joint Distributions and Patterns of Rock Fracturing

Data from several mines and surface exposures also indicate a pattern of polymodal cleat distribution and polymodal major and minor joint distribution. To understand the significance of this, consider Friedman's (1964, p. 471) description of the fracturing process in rocks: it involves the separation of rocks into two or more parts after the substance totally loses its cohesion and resistance to load, and it releases stored elastic strain energy. In figure 6 the extension and fracturing are represented in the form normal to the least principal stress (σ_3) and parallel to the maximum stress (σ_1). Macroscopically, (σ_3) may either be tensile (negative) or compressive (positive).

The data results show that some of these fractures may correspond to conjugate shear fractures with dihedral angles ranging from 30 to 50 degrees. Examples include the I-seam (N. 25 E. and N. 25 W.), Emery Mine; Upper Hiawatha seam (N. 15 E. and N. 15 W.), Southern Utah Fuel Company No. 1 Mine; Blind Canyon seam (N. 35 E. and N. 35 W.), Deer Creek Mine; Upper Hiawatha seam (N. 25 E. and N. 25 W.), Bear Canyon No. 1 Mine, as well as a joint pattern in the vicinity of the Emery Mine (N. 25 E. and N. 25 W.) and Star Point No. 2 Mine (N. 05 E. and N. 05 W.). The dihedral angle between the conjugate shear fracture systems could range from 45 to 90 degrees (Jaëger and Cook, 1979). Tensional fractures would parallel the acute bisector of conjugate shear fractures, and release fractures would be perpendicular to the acute bisector. Cleats observed in coal or joints in surface rocks may represent a combination of shear fractures, tension fractures and release fractures.

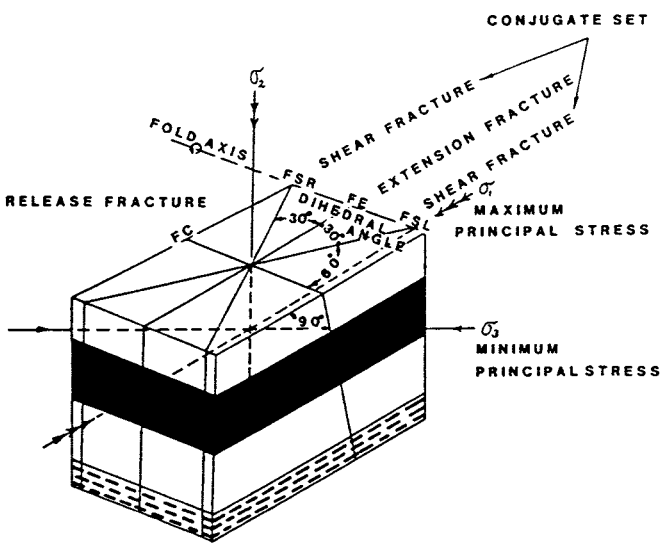

Figure 6. Fractures in rocks.

Average Spacing of Cleats

The average spacing of cleats within a coal seam is 12 to 20 cleats per foot. Local departure from the average spacing includes:

a) random pattern of spacing of large cleats cutting the entire thickness of the coal seam with spacing ranging from a few inches to several feet,

b) average spacing of 0.10 inch (120 cleats per foot) in the case of individual coal components (for example, vitrain) having a network of densely spaced cleats.

Quantitative data show that such spacing is related to the lithology. The difference between cleat spacing in coal and that of the adjacent rocks such as shale, siltstone, and sandstone is order of magnitude. In coal, spacing averages less than an inch, while the spacing in sandstone attains several feet.

Mineralization of Cleat Apertures

Extent of mineralization of cleat apertures is important since the minerals are also an indicator of the permeability of the fractures and may sometimes be responsible for a change in cohesion. Mineral accessories associated with cleats found in the study include calcite and pyrite constituting in-fillings or found as disseminated grains on cleat plane surfaces.

The aperture of cleats proved to be dependent on the thickness of the overburden strata. In some mines, where overburden strata exceeded 1500 feet, the aperture of the cleats was very small. On some occasions, fractures lacked mineralization. The same phenomenon was observed in gassy coal seams where the apertures were also small. Based on the cleat morphology, the surfaces of the cleats are in most cases smooth or striated. Some traces of shearing, bending, and slickensides were observed upon the cleat planes. In two cases, microfaulting within the coal seam with small dislocations was also observed. These dislocations were filled with pulverized coal, and the presence of associated accessory hematite was also noticed.

Lithotype Distribution

In addition to the cleat system investigation in coal, megascopic and microscopic descriptions of coal seams were carried out to provide information on the coal quality. The megascopic whole-seam summaries of lithotype distributions indicate that the coal under investigation is predominantly clarain. The resulting microscopic data revealed high volatile bituminous A to C coals, with the exception of the coal from the Wasatch coal seam which was subbituminous. The sections discussing individual mines include the rank of coal determined by reflectance measurements on vitrinite.

Joint Systems in Surface Exposures in the Vicinity of Individual Mines

Joint systems in surface exposures in the vicinity of individual mines were measured to establish correlations between cleats in

coal and joints in surface rocks. The joints, classified on the basis of their pattern, can be systematic and non-systematic. Joints were mostly of non-systematic origin (they display random patterns in plan and section). As in coal, two prevailing joint sets (main and minor), or bimodal cleat distribution, were observed. However, in some locations a third joint set could be seen. Differences in spacing of the cleats and that of the joint spacing can be several feet. Carbonate minerals, constituting the filling in the cleat fractures, were generally lacking in joint fractures. In some localities, plumose structures were observed upon joint planes.

CONCLUSIONS

A number of conclusions can be drawn from the data collected in this study, the most significant being that cleats in the coal and joints in the strata of the Blackhawk Formation and Ferron Sandstone Member of the Mancos Shale are the result of tectonic forces. This conclusion is based on the morphology of the cleat and joint characteristics, such as: smooth, planar, or slickensided surfaces; regular spacing and continuity of their orientaion over a large areal extent; open-space mineralization; and the presence of both pulverized coal along the cleat planes (gouge zone) and plumose structures. All of these are the result of shear and extensional fracturing. The data also indicate an existing relationship of cleats in coal and joints in surface rocks with regional structure. This is especially reflected in the Book Cliffs coalfield where the orientations of the butt cleats and the minor joints are roughly parallel to the axial trend of the monoclinal fold structure, while face cleats and main joints are roughly perpendicular to it. In the Wasatch Plateau coalfield the relationship is not so obvious. In this coalfield, where numerous fault zones (Pleasant Valley, Joes Valley, and the easternmost Gordon) extend from north to south and parallel the north-south axis of the field (Doelling, 1972, p. 75), the regional cleat and joint patterns show two main trends. The orientations of the main joints in surface exposures and face cleats in coal range from a northwest orientation in the Gordon Creek area to a northeast orientaion in most of the middle part of the Wasatch Plateau with a return to a northwest orientation in the Cottonwood area. In the Emery coalfield, the northeast orientations for the face cleats and main joints persist.

The data indicate that cleats and joints are influenced by the presence of faults. In eleven mines (mostly in the Wasatch Plateau coalfield) that are located close to faults, a rotation in the orientation of the two systems (face and butt cleats and main and minor joints in the surface exposures) occurred with the orientations of the face cleats and minor joints more or less paralleling the orientations of the faults. It is thought that the cleats and joints were formed by the same stresses that produced the faults. It cannot be said conclusively that the stresses that produced the faults — which result from extensional fracturing — were solely responsible for the change in the direction of the cleats and joints. Further, these characteristics suggest that the new cleat and joint patterns postdate the predominant cleat and joint patterns in the Book Cliffs and part of the Wasatch Plateau coalfields.

Orientation and spacing of joint systems in mine roofs are of great importance for mine operators because of safety reasons. Efficiency of continuous miner operation is increased when the faces of the main entries are designed to parallel the face cleats. However, if these cleats are continuous with mine roof joints, they may, in combination with prominent bedding planes, outline unstable block slabs that are not even partly supported by coal pillars and may slide into the working face. Figure 7a shows a typical longwall face installation equipped with shield supports.

When a face is oriented along the main roof joints and face cleats, coal production is more efficient (figure 7b). However, the stability of the mine roof is weaker. If working faces are oriented at an angle of about 15 degrees with the main roof joints, the cutting productivity may decrease but safety is enhanced (figure 7c).

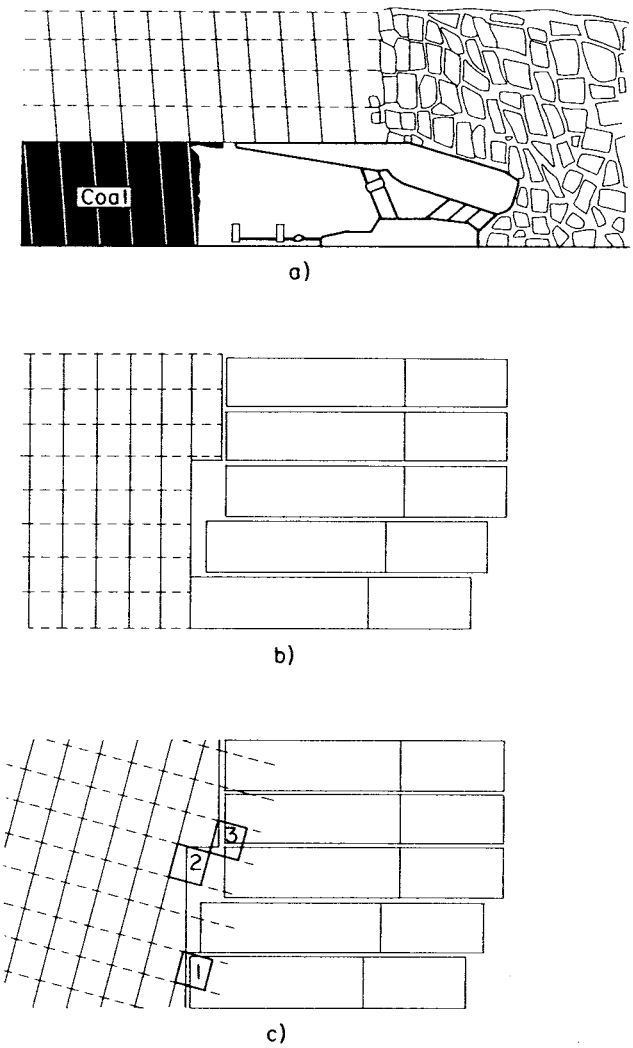

Figure 7. An example of longwall face orientation towards main joint system in the roof: a) section through a longwall face installation, b) with a joint system parallel to the longwall face (more efficient, but more hazardous), c) longwall face oriented at an angle of approximately 15 degrees towards the direction of main joint system with detached blocks 1, 2, and 3, partly supported either by the shields or by the coal face (less efficient but safer).

Cleats may also influence sudden outbursts of mine gas and coal in coalbeds. Dangerous accidents due to gas outbursts in Czechoslovak and Hungarian mines were reported by Riman and Vavro (1964, p. 45-48). A typical factor contributing to this phenomenon is the presence of joints and cleats. These also serve as a secondary reservoir of methane released from coal. This coal may be disintegrated and crushed by rock pressure and mining activities. The outbursts of gas and coal can be particularly numerous in deep gassy coal mines. As an example, the mine Waldenburg in Poland was extremely prone to outbursts: about 450 outbursts occurred in this mine during its lifetime. A particularly dangerous outburst involved the ejection of 7000 tonnes of coal (Riman, 1964, p. 219-220).

Another field in which a sound knowledge of cleats is required is that of methane drainage using long boreholes. The relevance of cleat orientations to the direction of drainage boreholes was demonstrated by methane drainage tests. It has been found that the flow of methane could be up to 10 times greater when the boreholes were drilled perpendicular to the direction of the face cleats (Rightmire, 1984, p. 9). This was confirmed by the results of methane drainage tests conducted in the Rock Canyon seam, Soldier Canyon mine, Carbon County, Utah. The horizontal boreholes were drilled approximately at right angles to the direction of the face cleats (N. 65 W.). These drainage boreholes yielded more methane than the boreholes drilled perpendicularly to the butt cleat direction (Hucka and Bodily, 1989).

As shown in this study, knowledge of joint patterns in surface rocks also could serve as an estimate of cleat patterns in coal at depth when planning new mine developments. For example, the results of the joint patterns in the Book Cliffs coalfield generally coincide with the cleat patterns in coal. Therefore, the orientations of the joints in the surface rocks could serve to predict the cleat orientations at depth. However, the knowledge of joint orientations becomes less reliable for the complexly faulted Wasatch Plateau coalfield, where the joint patterns deviate in many instances from that of the cleat patterns at depth (plates A and B).

In summary, this study has shown the feasibility of applying cleat and joint data to:

1) aid in planning successful mining layouts,
2) mine roof control, and
3) designing the orientation of methane drainage holes.

Further, the study fulfills another aim in providing mine operators with information about cleat and joint patterns underground and in surface exposures near producing mines.

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Many thanks also go to my colleagues, S. Sommer and T. Thompson for their assistance during underground cleat and surface joint measurements and to A. Keith for his continued encouragement.

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APPENDIX

COALFIELD
Emery 12
Emery
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Beaver Creek No. 9 16
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Crandall Canyon 24
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Star Point No. 2 (Plateau Mine) 30
Belina Nos. 1 and 2 32
Skyline Nos. 1 and 3 34
Beaver Creek No. 7 36
Book Cliffs
Castle Gate No. 3 38
Pinnacle and Apex 40
Soldier Canyon 42
Sunnyside Nos. 1 and 3 44
Coalville
Boyer 46

Mine Name: **EMERY**

Owner-Operator: Consolidation Coal Company

Location: Approximately 4 miles from the town of Emery, Emery County. (Portal: Section 34, Township 22 S., Range 06 E.)

Host unit: Ferron Sandstone Member of Mancos Shale mining I-seam (i.e., upper coal zone) (Doelling, 1972, p. 424).

Overlying unit: Blue Gate Shale Member of the Mancos Shale (Cretaceous) (Doelling, 1972).

Underlying unit: Tununk Shale Member of the Mancos Shale (Cretaceous) (Doelling, 1972, p. 424).

Coal field: Emery

Structure:

Attitude: Strata dip west-northwest less than 4 degrees.

Faulting: Faults of the Joes Valley-Paradise fault zone.

Seam description:

Seam name: I-seam

Thickness: 14.4 feet *Thickness mined:* 6.7 feet

Roof: Immediate roof consists of roof coal overlain by shale.

Floor: Immediate floor consists of floor coal underlain by siltstone. The overburden thickness ranges from 60-800 feet. Several feet of coal remain as immediate roof and floor coal. Throughout the seam, alternations of semi-regularly distributed rock partings were noticeable, indicating that several changes took place during the deposition of this seam.

Megascopic description: The coal is classified as banded semi-dull to dull clarain, interbedded at more or less regular intervals with durain bands and rock partings (particularly in the middle part of the seam). The rock partings may contribute to the higher ash content of the coal. The sparse, bright vitrain bands that are present range between 0.01 and 0.13 inches, while the durain bands attain a thickness of 0.5 feet. Several fusain lenses are also present.

Microscopic description: The I-seam avarages 66% vitrinite, 6.6% exinite and 27.4% inertinite. The inertinite content is relatively high in the middle part where more durain bands are present. The composition of these durain bands consists almost entirely of macerals of the inertinite group (semifusinite, fusinite). Disseminated accessory minerals (pyrite and quartz) are present within these bands as well. Rank determination by vitrinite reflectance shows an average reflectance of Ro = 0.6, classifying the coal as high volatile B bituminous.

Cleat measurements:

Seam: I-seam -107 measurements

Major cleat direction: Face: N. 25 E. *Butt:* N. 65 W.

Secondary cleat direction: Face: N. 25 W. *Butt:* not expressed in the measurement

Cleat description: Face cleat is well developed. Parting between the individual cleat fractures is very small; as a result, they are mostly devoid of mineral inclusions. The cleats are restricted to individual pertrographic components of the coal. They are better developed in the brighter part of the coal. Their surfaces are mostly smooth and, when observed along the end plane of the fractures, they are uneven. They are sometimes rugged or absent in the durain component of the coal.

Cleat filling: Secondary calcite, pyrite as disseminated grains on the cleat surface planes.

Cleat spacing: Between 0.75-1.25 inches with more closely spaced cleats in the brighter components of the coal.

Joint measurements in surface rocks surrounding the mine: 71 measurements.

Major joint direction: Main: N. 25 E. *Minor:* N. 65 W.

Secondary joint direction: Main: N. 25 W. *Minor:* not expressed in the measurement

Comments: The results show evident parallelism between the face cleat and main joint and butt cleat and minor joint cleat of the outcrop rocks, respectively.

Figures 8a and 8b are graphic representations of the cleat and joint investigation.

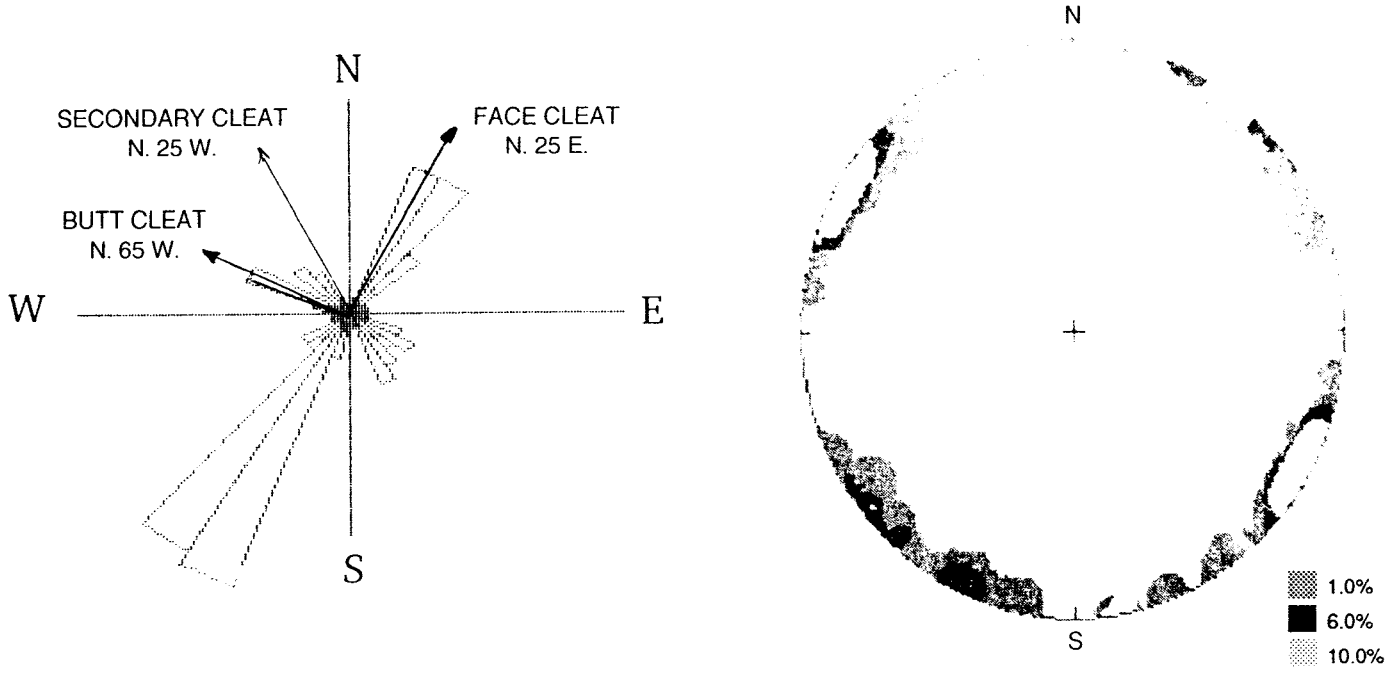


Figure 8a. *Emery mine - I seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 107. (Radii of individual sectors is proportional to the number of data points in that sector).*

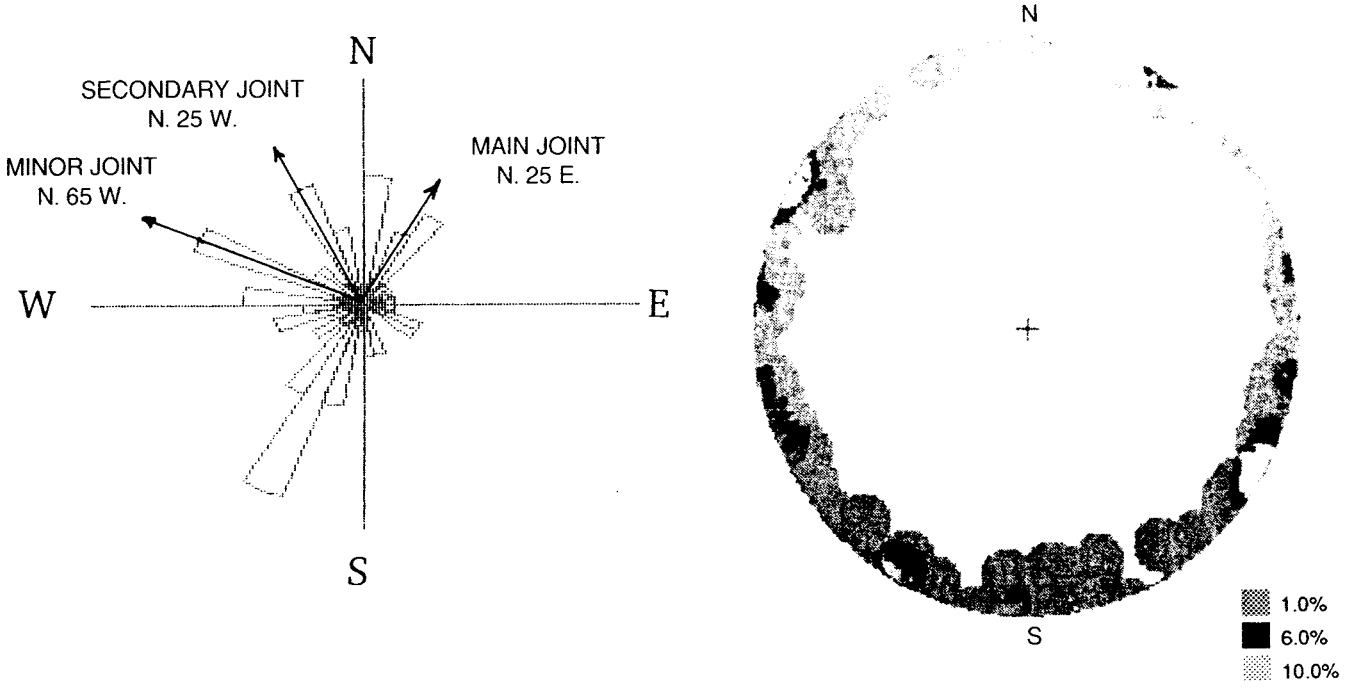


Figure 8b. *Emery mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 71.*

Mine Name: **SOUTHERN UTAH FUEL COMPANY NO.1 (SUFCO)**

Owner-Operator: Southern Utah Fuel Company, a subsidiary of the Coastal States Energy Corp.

Location: East Spring Canyon in the SE corner of the Acord Lakes quadrangle, approximately 27 miles east of Salina, Sevier County. (Portal: Section 12, Township 22 S., Range 04 E.).

Seam mined: Upper Hiawatha (Upper Ivie)

Host unit: Lower part of the Blackhawk Formation (Upper Cretaceous).

Overlying unit: Castlegate Sandstone (Upper Cretaceous).

Underlying unit: Star Point Sandstone (Upper Cretaceous).

Coal field: Wasatch Plateau

Structure:

Attitude: Strata dip 2 degrees to the west and northwest.

Faulting: The only significant deformation in this area is the Acord Lakes fault (Doelling, 1972, p. 141).

Seam description:

Seam name: Upper Hiawatha

Thickness: 12.5 feet

Thickness mined: 8.9 feet

Roof: The immediate roof consists of 1-3 feet of top coal overlain by mudstone, shale, or sandstone.

Floor: Varies between sandstone, siltstone, and shale.

The range of the overburden thickness is 300-1800 feet. Faults in the mine have a mean strike of N. 25.8 W. and are mostly graben or half graben bounding faults (Kravits, written communication, 1988). Occasionally, spalling occurs when the thickness of the coal exceeds 10 feet (in the area surrounding the longwall operation). Scouring of the roof strata into the coal seam or rolls were also encountered as mining progressed.

Megascopic description: The Upper Hiawatha coal is composed of indistinctly banded semi-bright, semi-dull and dull coal. The top of the seam is a semi-bright clarain with an abundance of clarain. Durain and thin vitrain bands are present in subordinate amounts. The middle part of the seam consists of semi-dull coal where dull clarain, occasionally bright clarain, and durain are the predominant components. In the lower part of the seam, durain is most abundant. Fusain lenses can be detected in varying parts of the seam, though mostly in the lower 2/3 of the seam.

Microscopic description: Maceral composition of the Upper Hiawatha coal averages 67.2% vitrinite, 5% exinite and 27.8% inertinite. The amount of inertinite is considerably higher in the middle and lower parts of the seam, and vitrinite decreases from top to bottom. The results of reflectance analyses show average reflectance Ro = 0.48, classifying the coal as high volatile bituminous C in rank.

Cleat measurements:

Seam: Upper Hiawatha - 50 measurements.

Major cleat direction: Face: N. 15 E. *Butt:* N. 55 W.

Secondary cleat direction: Face: N. 15 W. *Butt:* N. 85 W. (weak)
Average dip is 86.0 degrees.

Cleat description: Overall, the Upper Hiawatha coal has well-developed cleats. The cleats display a bimodal distribution with the first set of cleats showing a considerably stronger development. However, butt cleats of both sets are not well represented in the measurements. The plane surfaces of the face cleats are mostly smooth or planar and those of the butt cleats uneven. The results of an intensive cleat study conducted by the mine personnel (Kravits, written communication, 1988) at 36 locations within the mine confirm bimodal face-butt cleat distribution with mean face cleat striking N. 21 E. and N. 14 W. and butt cleat N. 75 W. and N. 75 E., respectively. A graphic representation of the results from one location is shown in figure 9a. Kravits' investigation points also to a possible third face cleat striking N. 05 E. His study, however, indicates no real trend for the cleat orientation of the two major sets of cleats.

Cleat filling: Calcite

Cleat spacing: Average 0.25 inches

Joint measurements in surface rocks surrounding the mine: 32 measurements

Major joint direction: Main: N. 15 W. *Minor: N. 65 E.*

Joint spacing: Several feet apart

Joint description: Joint surface planes at times show plumose structure in the sandstone where measurements were taken. The main joint direction corresponds with the face cleat of the second (minor) cleat set.

Comments: Graphic representation of the analytical data is shown in figures 9a and 9b.

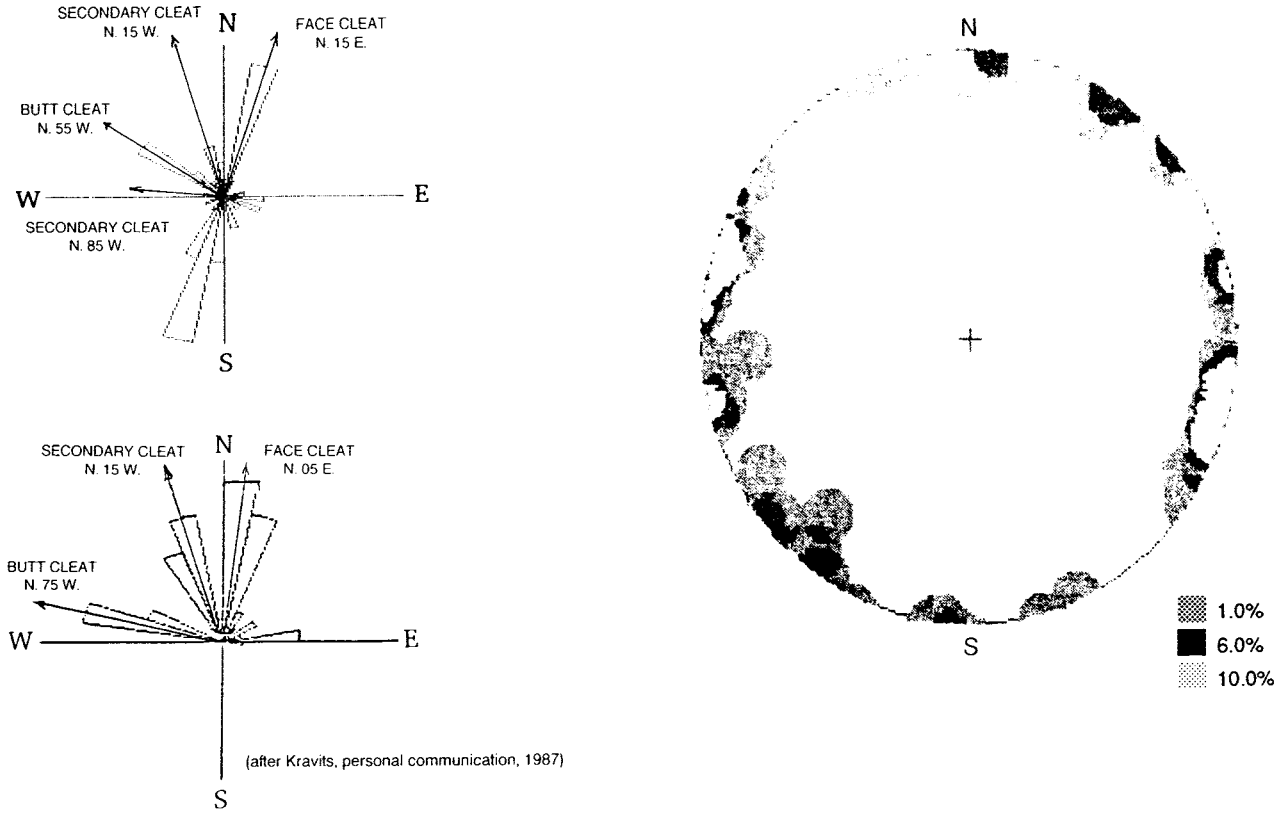


Figure 9a. *SUFCO No. 1 mine - Upper Hiawatha seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 50.*

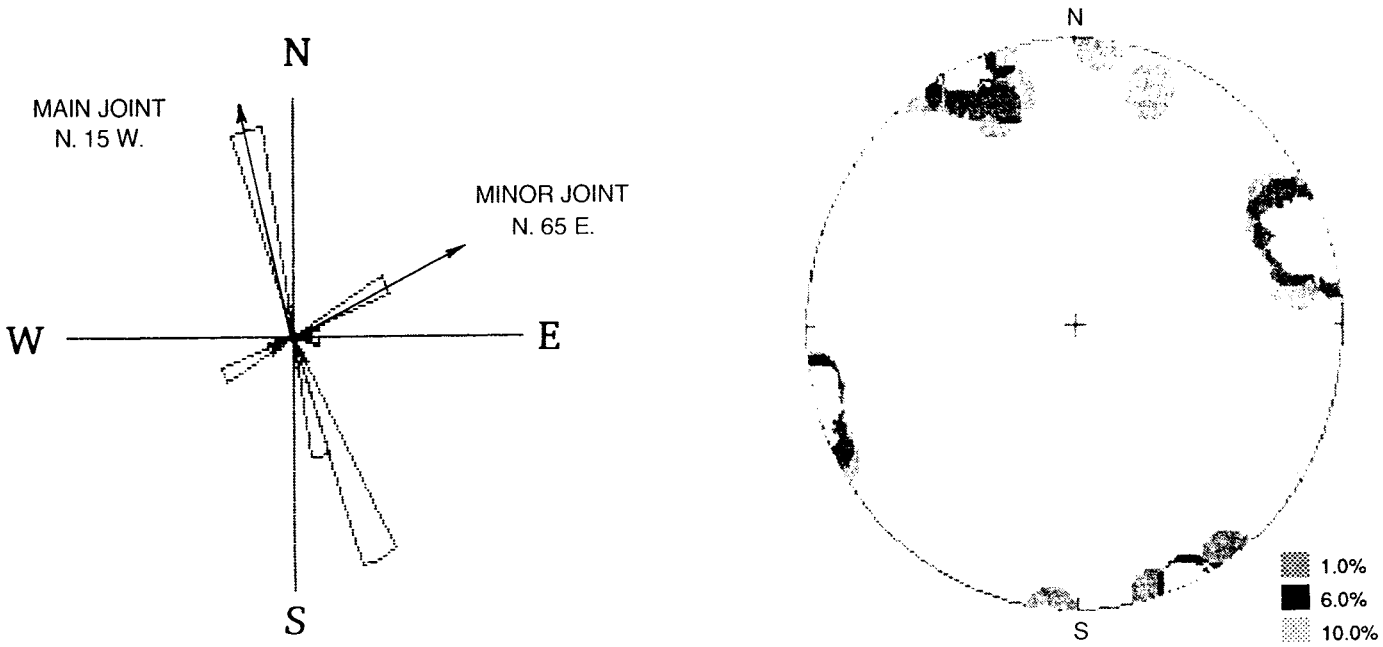


Figure 9b. *SUFCO No. 1 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 32.*

Mine Name: **BEAVER CREEK NO. 9** (former Trail Mountain)

Owner-Operator: Beaver Creek Coal Company, a subsidiary of ARCO Mountain Fuel Company

Location: Cottonwood Creek Canyon, 12 miles NW from the town of Huntington, Emery County. (Portal: Section 25, Township 17 S., Range 06 E.)

Seam mined: Hiawatha

Host unit: Lower part of the Blackhawk Formation (Upper Cretaceous).

Overlying unit: Castlegate Sandstone (Upper Cretaceous).

Underlying unit: Star Point Sandstone (Upper Cretaceous).

Coal field: Wasatch Plateau

Structure:

Attitude: Strata dip westward at an average of 7 degrees.

Faulting: Structurally, the area shows little deformation except for one fault at the south end of the Pleasant Valley fault zone which cuts through the Meetinghouse Canyon (Doelling, 1972, p. 203).

Seam description:

Seam name: Hiawatha

Thickness mined: 7.5 feet

Roof: Immediate roof consists of 1.5 feet of roof coal overlain by shale.

Floor: Immediate floor consists of 1-2 feet floor coal underlain by mudstone.

The maximum overburden thickness attains 2000 feet within the Trail Mountain area. Approximately 1.5 feet of coal and 1-2 feet as floor coal. The seam strikes N. 20 W. and dips 3-4 degrees west-southwest. Rock partings within the Hiawatha seam range from 2 inches to 2 feet. Clastic dikes ("spars") and laterally extending rolls (undulation of the coal seam) are geological features occasionally affecting the mine conditions.

Megascopic description: The Hiawatha seam can be divided into three intervals. The upper 1 foot interval is a bright, hard coal, mostly composed of moderate to thick vitrain bands. The middle interval is a banded clarain with a succession of bright and dull components (vitrain, clarain, and durian). The bottom interval is a bright, somewhat friable, resinous, indistinctly banded clarain.

Microscopic description: Petrographic analyses show an average of 81% vitrinite, 6% exinite and 13% of inertinite. The average reflectance for the seam is Ro = 0.55 classifying the coal as high volatile bituminous C in rank.

Cleat measurements:

Seam: Hiawatha - 99 measurements

Major cleat direction: *Face:* N. 15 W.
Butt: N. 75 E.
Average dip 86 degrees.

Cleat description: Cleats are generally well developed in both directions. Those cleats which are almost perpendicular to the bedding planes show regular distribution. The cleat plane surfaces in the bright components of coal are even or striated but have somewhat rough surfaces in the durain components. Resin encrustation on the cleat surfaces, filling in a tabular form or as small branching bodies, is quite common. Limonite staining occurs as well.

Cleat filling: Epigenetic calcite (occasionally 0.12 inch thick), pyrite disseminated in cleat fractures, or on the plane surfaces of the cleats.

Cleat spacing: 0.8-1 inch

Joint measurements in surface rocks surrounding the mine: 35 measurements

Major joint direction: *Main:* N. 25 E. *Minor:* N. 45 W.

Joint description: Due to the lack of good exposures of outcrop rocks, the limited number of joint measurements may not adequately reflect the major joint orientations.

Comments: Several feet from the mine portal a thick, clastic dike "spar" could be seen and traced for several feet in the mine. The dike, cutting across several crosscuts, consists of hard, fine-grained sandstone, and varies in thickness from several inches to approximately 1.5 feet. A few smaller spars were also observed within the seam (figure 10a). A spar sample analyzed by the U.S. Bureau of Mines laboratory determined the mineral composition to be dolomite.

Figures 10b and 10c illustrate graphically the results.

Figure 10a. *Beaver Creek No. 9 mine - Hiawatha seam - clay vein - wedge of indurated clay penetrating the coal*

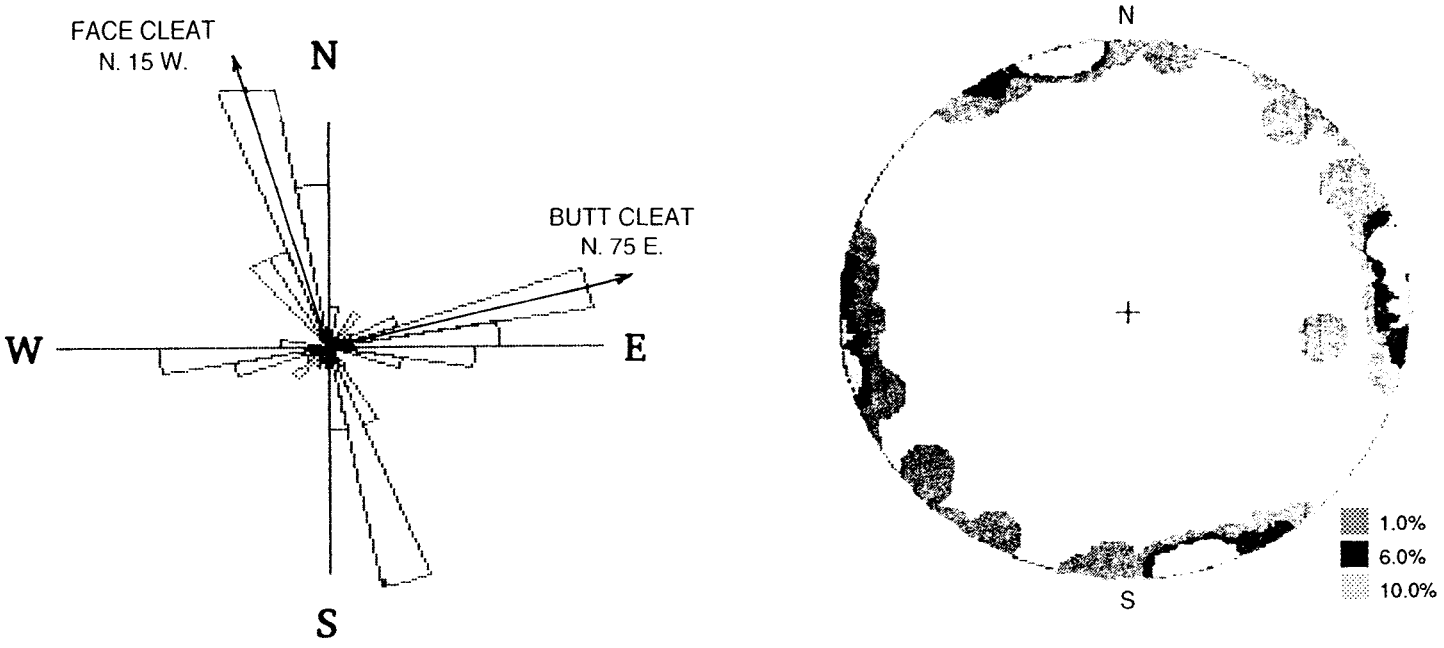


Figure 10b. *Beaver Creek No. 9 mine - Hiawatha seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 99.*

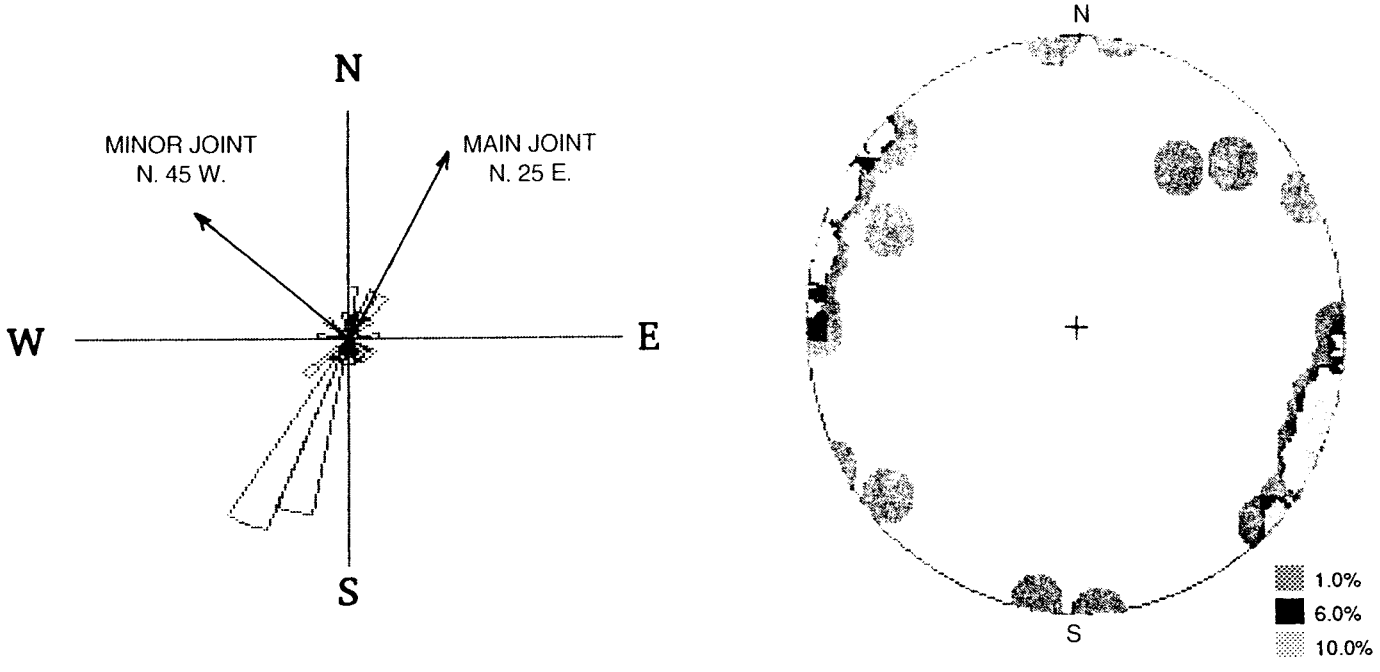


Figure 10c. *Beaver Creek No. 9 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 35.*

Mine Name: **COTTONWOOD AND DEER CREEK**

Owner-Operator: Utah Power and Light Company.

Location: The Cottonwood mine, located in Grimes Wash Canyon, and the Deer Creek mine, located in Deer Creek Canyon, are both west of the town of Huntington, Emery County. (Portals: Section 27, Township 17 S., Range 07 E., and Section 10, Township 17 S., Range 07 E.).

Host unit: Situated in the lower part of the Blackhawk Formation (Upper Cretaceous), the Deer Creek mine works the Blind Canyon seam and the Cottonwood works the Hiawatha seam.

Overlying unit: Castlegate Sandstone and Price River Formation (Upper Cretaceous).

Underlying unit: Star Point Sandstone (Upper Cretaceous).

Coal field: Wasatch Plateau

Structure:

Attitude: Strata dip less than 5 degrees except when adjacent to the faults.

Faulting: Faults of the Pleasant Valley zone, particularly the Pleasant Valley, Deer Creek and Bear Canyon faults. The overburden thicknesses attain 1650 feet (Blind Canyon) and 2000 feet (Hiawatha), respectively, at locations where measurements were obtained. The interburden between the Hiawatha and Blind Canyon seams averages 100 feet. Localized mine problems such as variation in the thickness of the seam (Hiawatha) and rolls or scours associated with paleochannel sandstone occasionally disrupt mining operations.

Seam description:

Seam name: Blind Canyon seam and Hiawatha seam

Thickness: 7.5 feet *Thickness mined:* 5.5 feet-Blind Canyon seam

Thickness: 8.3 feet *Thickness mined:* 8.3 feet-Hiawatha seam

Roof: Blind Canyon seam-sandstone

Hiawatha seam - carbonaceous siltstone

Floor: Blind Canyon seam - 2 feet of coal remains as an immediate floor underlain by interbedded carbonaceous siltstone and shale.

Hiawatha seam - Star Point Sandstone

Megascopic description: Hiawatha coal consists of semi-bright clarain. Medium bands of bright and dull clarain alternate with the thin bands of vitrain whose thicknesses are not sufficient to classify them as individual lithotype bands. More detailed examination reveals the presence of thin durain bands (average 0.3 in.) particularly in the upper part of the seam and a thin rock parting in the lower part of the seam. Blind Canyon coal is similar, with the exception that the clarain is moderately to highly resinous. The durain bands present in the Hiawatha seam were not observed during the meagascopic description of the Blind Canyon seam. A thin rock parting in the lower part of the seam is present as well. Accessory minerals consist of calcite and pyrite in both seams.

Microscopic description: Maceral composition of the Blind Canyon seam averages 76.3% vitrinite, 7% exinite and 16.7% inertinite; the Hiawatha seam averages 80.4% vitrinite, 5% exinite and 14.6% inertinite. Both seams have moderate inertinite content. The rank determined by the reflectance measurements on vitrinite shows both seams with the same reflectance values of Ro = 0.56, classifying the coal as high volatile C bituminous.

Cleat measurements:

Seam: Blind Canyon seam - 100 measurements
Hiawatha seam - 99 measurements

Major cleat direction: *Face: N. 35 E.* - Blind Canyon seam
Butt: N. 75 W.
Face: N. 85 W. - Hiawatha seam
Butt: N. 15 E.

Secondary cleat direction: *Face:* N. 35 W. - Blind Canyon
Butt: not expressed in the measurement

Cleat description: Overall, the coal from both seams is well cleated. The parting along cleat planes is small and occasionally the surface planes are partially covered with pyrite (Blind Canyon). The cleats in the Blind Canyon seam display a bimodal face cleat distribution. Their surfaces are striated or uneven.

Cleat filling: Calcite, pyrite

Cleat spacing: Average 1-1.5 inches in the Blind Canyon seam with the frequency of the cleats somewhat higher in the Hiawatha seam - 1.5-2 inches.

Joint measurements in surface rocks surrounding the mine:

90 measurements - approximately 0.8 mile from the Deer Creek mine portal,

98 measurements - in the vicinity of the Cottonwood mine portal.

Major joint direction: *Main:* N. 15 E. - Deer Creek Mine
Minor: N. 75 W.
Main: N. 85 W. - Cottonwood Mine
Minor: N. 05 E.

Comments: The results are shown in figures 11a, 11b, 12a and 12b.

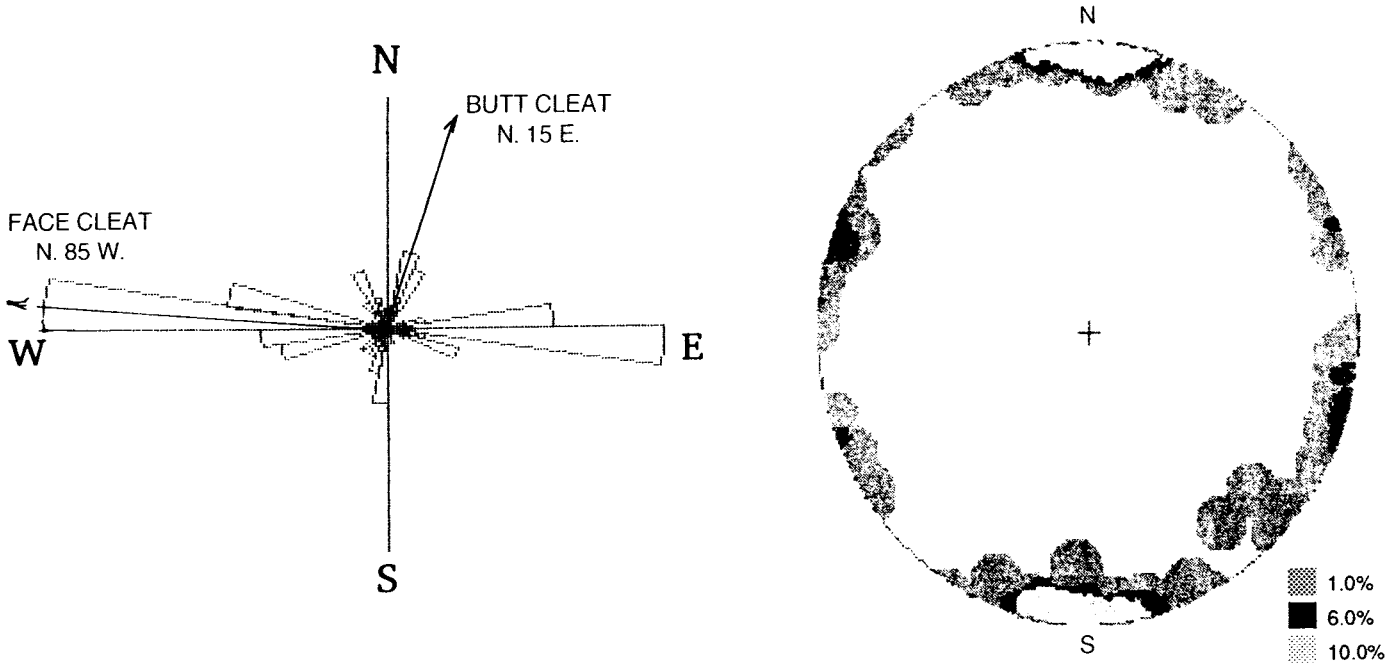


Figure 11a. *Cottonwood mine - Hiawatha seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 99.*

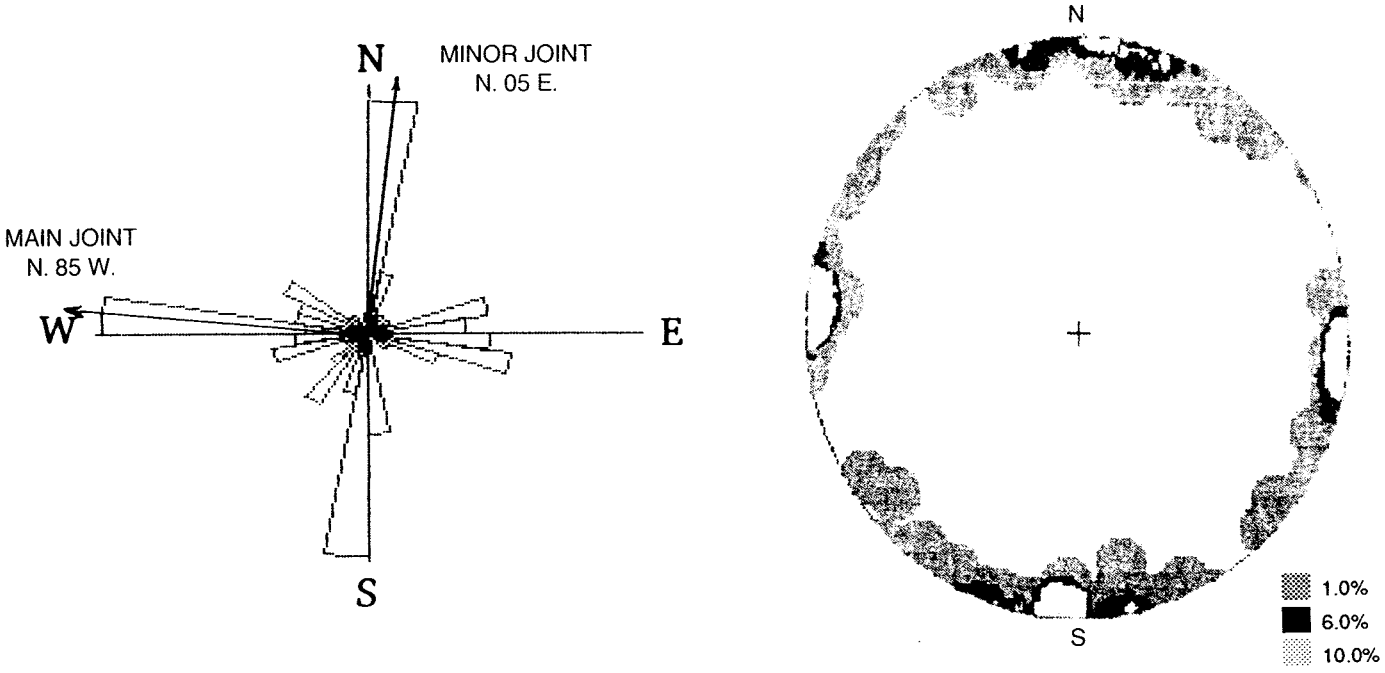


Figure 11b. *Cottonwood mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 98.*

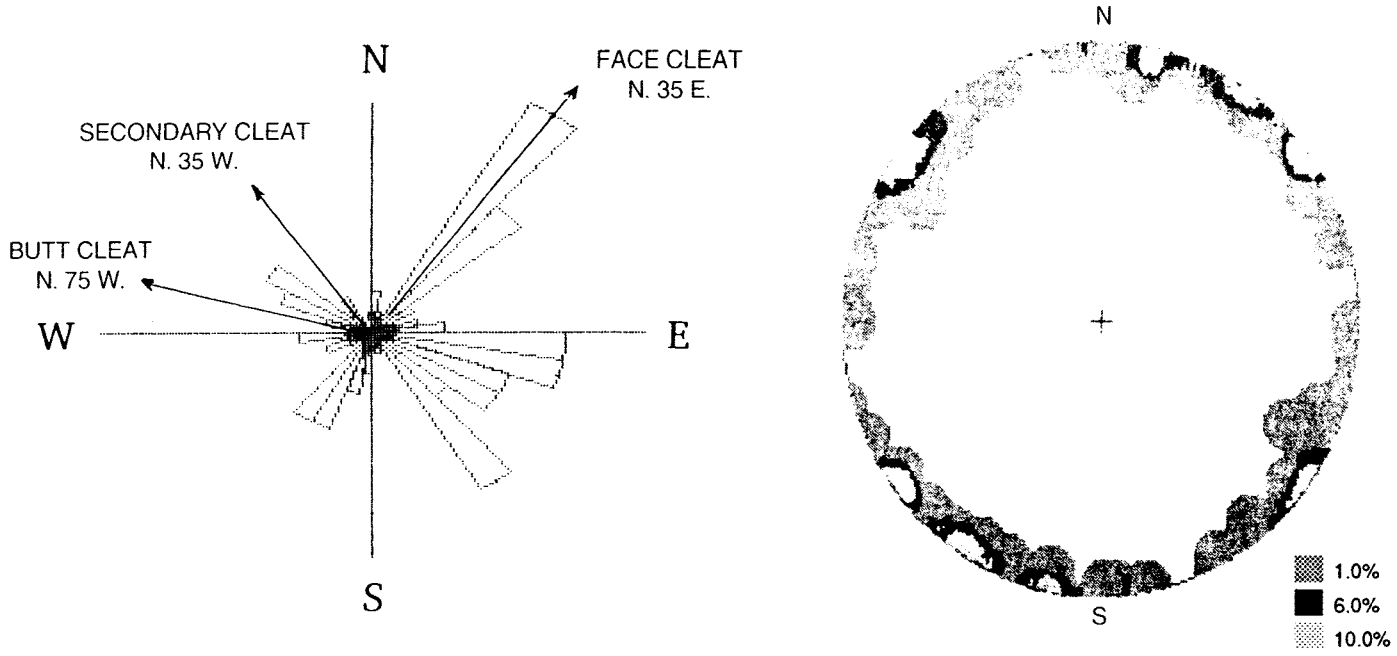


Figure 12a. *Deer Creek mine - Blind Canyon seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 100.*

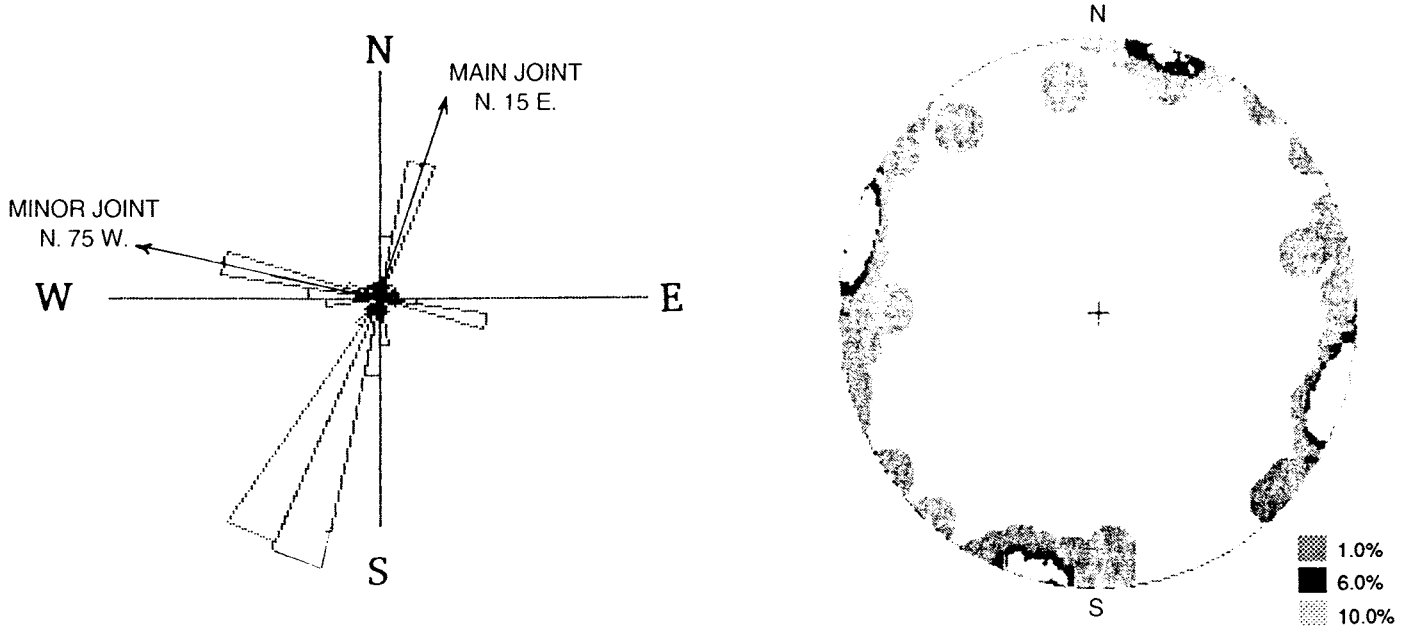


Figure 12b. *Deer Creek mine - rose diagram of surface joint, and lower hemisphere equal-area stereonet diagram; n = 90.*

Mine Name: **BEAR CANYON NO. 1**
Owner-Operator: CO-OP Mining Company
Location: Ten miles northwest of the town of Huntington, Emery County in the Bear Creek Canyon. (Portal: Section 24, Township 16 S., Range 07 E.)
Seam(s) mined: Upper Hiawatha and Hiawatha
Host unit: Blackhawk Formation (Upper Cretaceous).
Overlying unit: Castlegate Sandstone (Upper Cretaceous).
Underlying unit: Star Point Sandstone (Upper Cretaceous).
Coal field: Wasatch Plateau
Structure:
Attitude: Generally gently dipping strata become disturbed near the faults.
Faulting: Several faults of the north-south-trending Pleasant Valley fault zone.
Seam description:
Seam name: Upper Hiawatha and Hiawatha
Thickness mined: Upper Hiawatha seam - 13.7 feet
Hiawatha seam - 7.3 feet
Roof: Upper Hiawatha seam - immediate roof is roof coal overlain by sandstone
Hiawatha seam - carbonaceous shale
Floor: Upper Hiawatha - immediate floor is floor coal underlain by sandstone.
Hiawatha - Star Point Sandstone

The overburden thickness varies greatly from 0 to a maximum of 2000 feet. The interburden between the Upper Hiawatha and Hiawatha seams varies from 60-90 feet. Two to four feet of coal remain as roof coal and one foot as floor coal (Upper Hiawatha).

Megascopic description: The coal from both seams is mostly clarain. Upper Hiawatha seam is a semi-dull clarain with moderate percentage of durain and dull clarain and one thin rock parting in the upper part of the seam. Eighty percent of the Hiawatha coal is a bright clarain with vitrain and durain bands as the remaining components. The characteristic feature of this coal is its hardness.

Microscopic description: The maceral composition averages 74.4% vitrinite, 9.7% exinite and 15.9% inertinite for the Upper Hiawatha seam, and 86.6% vitrinite, 6.1% exinite and 7.3% inertinite for the Hiawatha seam. A higher percentage of vitrinite characterizes the coal of the Hiawatha seam and relatively high inertinite content the Upper Hiawatha seam. The rank of the coal is high volatile bituminous, determined through reflectance measurements completed on vitrinite which showed an average reflectance Ro = 0.52 for the Upper Hiawatha and Ro = 0.54 for the Hiawatha seam.

Cleat measurements:
Seam: Upper Hiawatha - 99 measurements
Hiawatha - 102 measurements
Major cleat direction: *Face:* N. 65 E. - Upper Hiawatha seam
Butt: N. 25 W. and N. 25 E.
Face: N. 65 W. - Hiawatha seam
Butt: N. 45 E.
Secondary cleat direction: *Face:* N. 65 W. - Upper Hiawatha seam (weak)

Cleat description: The cleat directions in the Upper Hiawatha seam differ from the cleat directions in the Lower Hiawatha seam. The butt cleats in the Upper Hiawatha seam display a bimodal distribution. Further, cleats with the N. 65 W. orientation are not as well expressed as those in the Hiawatha seam. The plane surfaces of the butt cleats are step-like. Secondary calcite fills predominantly the face cleat fractures.

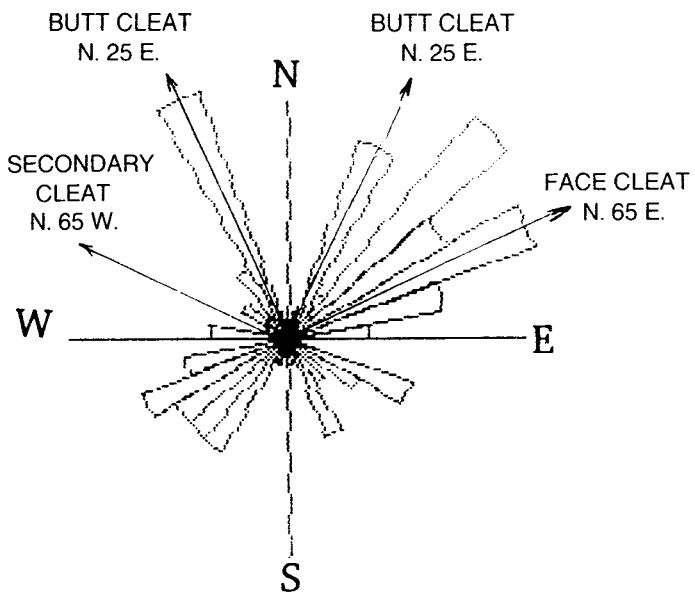
Cleat filling: Calcite, pyrite as disseminated grains or films on the cleat surfaces. Resin, occasionally abundant, forms the filling in the cleat fractures as well.

Cleat spacing: 0.25-1.5 inches for the more closely distributed cleats and 3 inches-1 foot for the wider distributed cleats in the coal.

Joint measurements in surface rocks surrounding the mine: 27 measurements
The small number of joint measurements is due to the sparsity of outcrop exposures in the vicinity of the mine.

Major joint direction: *Main:* N. 75 W.
Minor: N. 25 E.

Comments: The analytical results of the cleat and joint measurements are shown in figures 13a, 13b and 13c.



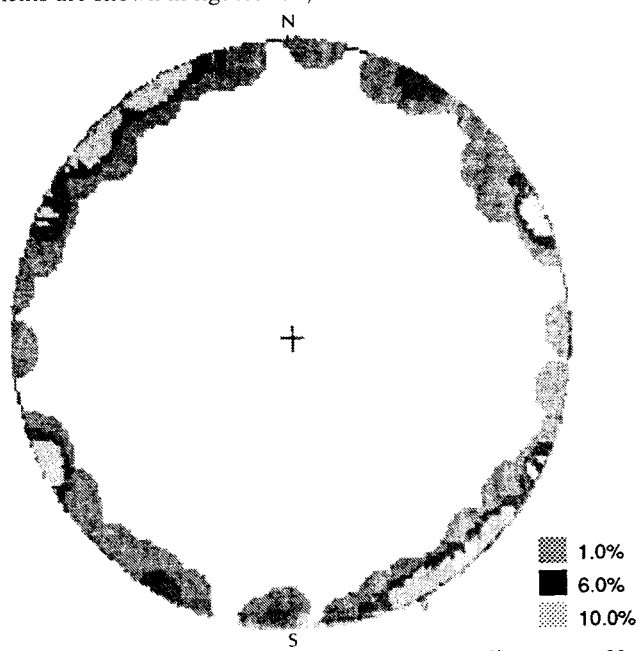


Figure 13a. *Bear Canyon No. 1 mine - Upper Hiawatha - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 99.*

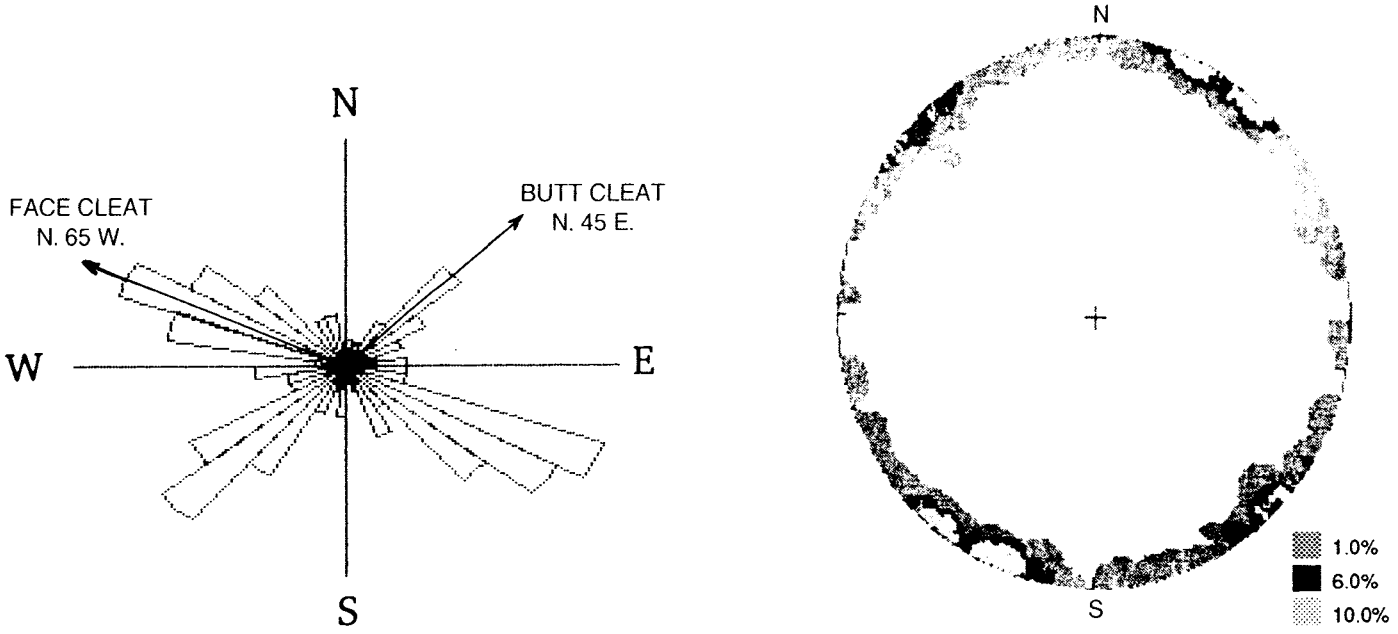


Figure 13b. *Bear Canyon No. 1 mine - Hiawatha seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 102.*

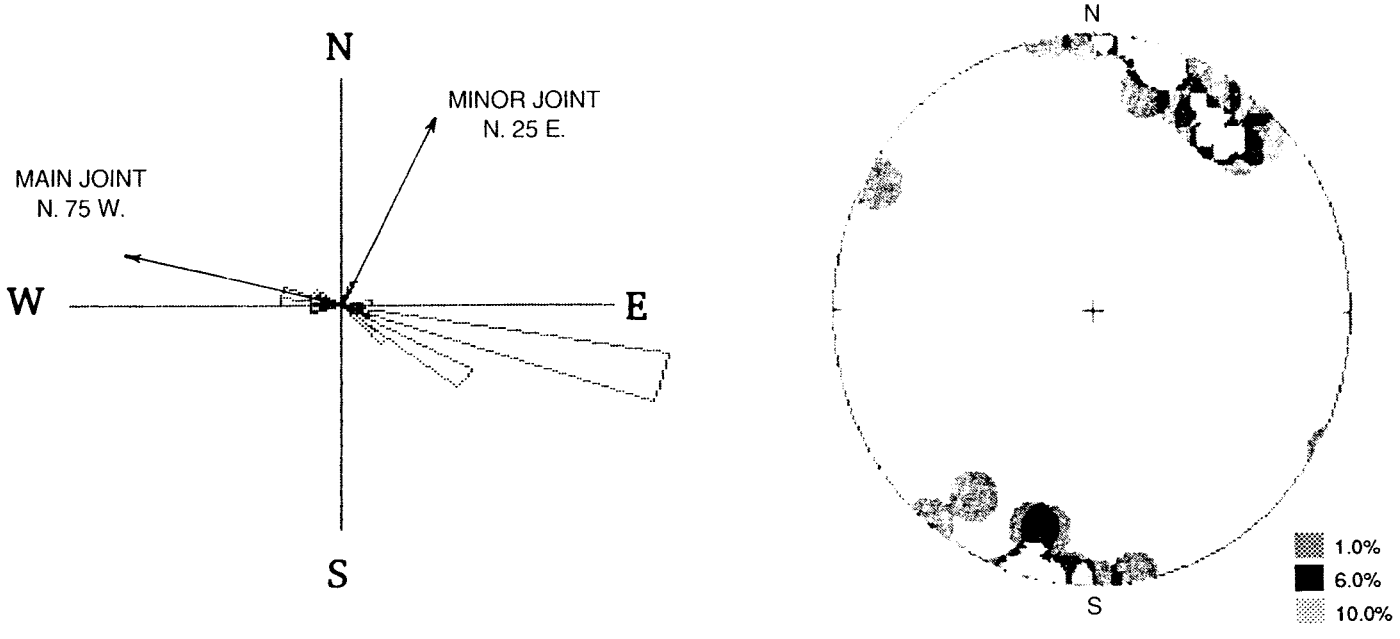


Figure 13c. *Bear Canyon No. 1 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 27.*

Mine Name: **CRANDALL CANYON**
Owner-Operator: Genwal Company
Location: Crandall Canyon in the Rilda Canyon quadrangle, 6 miles from the town of Huntington, Emery County. (Portal: Section 5, Township 16 S., Range 07 E.)
Seam mined: Hiawatha
Host unit: Blackhawk Formation (Upper Cretaceous).
Overlying unit: Castlegate Sandstone (Upper Cretaceous).
Underlying unit: Star Point Sandstone (Upper Cretaceous).
Coal field: Wasatch Plateau
Structure:
Attitude: Strata are gently dipping with dip rarely exceeding 3 degrees.
Faulting: Faults of the Pleasant Valley fault zone in the southeast corner of the quadrangle and the Joes Valley fault in the west corner of the quadrangle (Doelling, 1972, p. 189).
Seam description:
Seam name: Hiawatha
Thickness mined: 6.1 feet
Roof: Carbonaceous shale
Floor: Star Point Sandstone
The average overburden thickness is 800 feet.
Megascopic description: The coal is classified as moderately bright clarain composed of bright and dull clarain and durain bands. Vitrain bands form only a minor portion of the seam. The upper part of the seam is more resinous with one very thin rock parting; the lower part of the seam is composed mostly of bright clarain.
Microscopic description: The Hiawatha seam averages 85.1% vitrinite, 4.8% exinite and 10.1% inertinite. The maceral composition is uniform throughout the whole seam except in the lower part which shows considerably higher vitrinite content. Rank determined by reflectance measurements (Ro = 0.57) indicates high volatile bituminous B coal.
Cleat measurements:
Seam: Hiawatha - 61 measurements
Major cleat direction: Face: N. 65 W. *Butt:* N. 35 E.
Secondary cleat direction: N. 25 W.
Cleat description: The face cleat is better developed. Calcite film occurs on the plane surfaces of some of the cleats. Disseminated pyrite grains are present mostly in the upper part of the seam in the durain bands and on the surface planes of the cleats.
Cleat filling: Calcite, pyrite
Cleat spacing: No data were collected on cleat spacing.
Roof measurements: Main: N. 65 W. *Minor:* N. 35 E.
Roof description: The orientation of the joints in the roof strata coincide with the direction of cleats in the coal.
Joint measurements in surface rocks surrounding the mine: 24 measurements
Major joint direction: Main: N. 05 E.
Minor: Not expressed in the measurements
Joint spacing: 2-20 feet
Comments: The lack of sufficient exposure of outcrop rocks surrounding the mine resulted in a rather low number of joint measurements. They were obtained on a few small exposures of sandstone close to the mine portal.
The cleat, roof and sandstone joint data are summarized in figures 14a, 14b, and 14c.

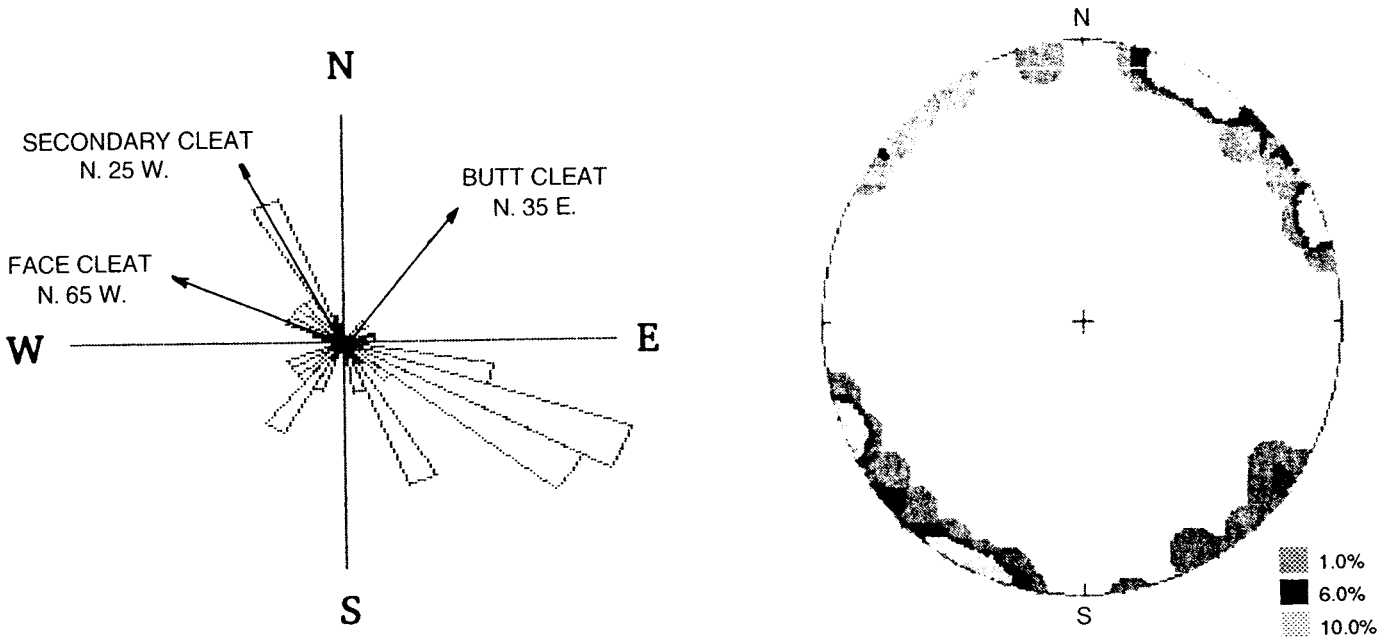


Figure 14a. *Crandall Canyon mine - Hiawatha seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 61.*

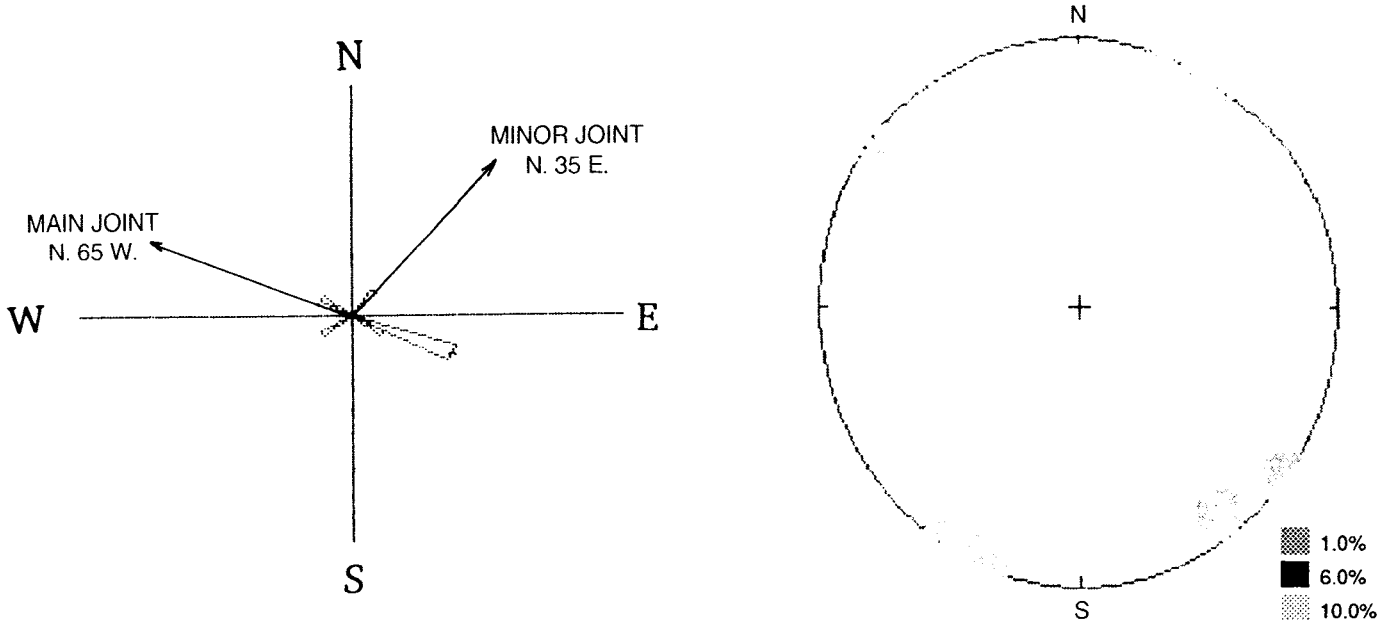


Figure 14b. *Crandall Canyon mine - rose diagram of roof joints, and lower hemisphere equal-area stereonet diagram; n = 7.*

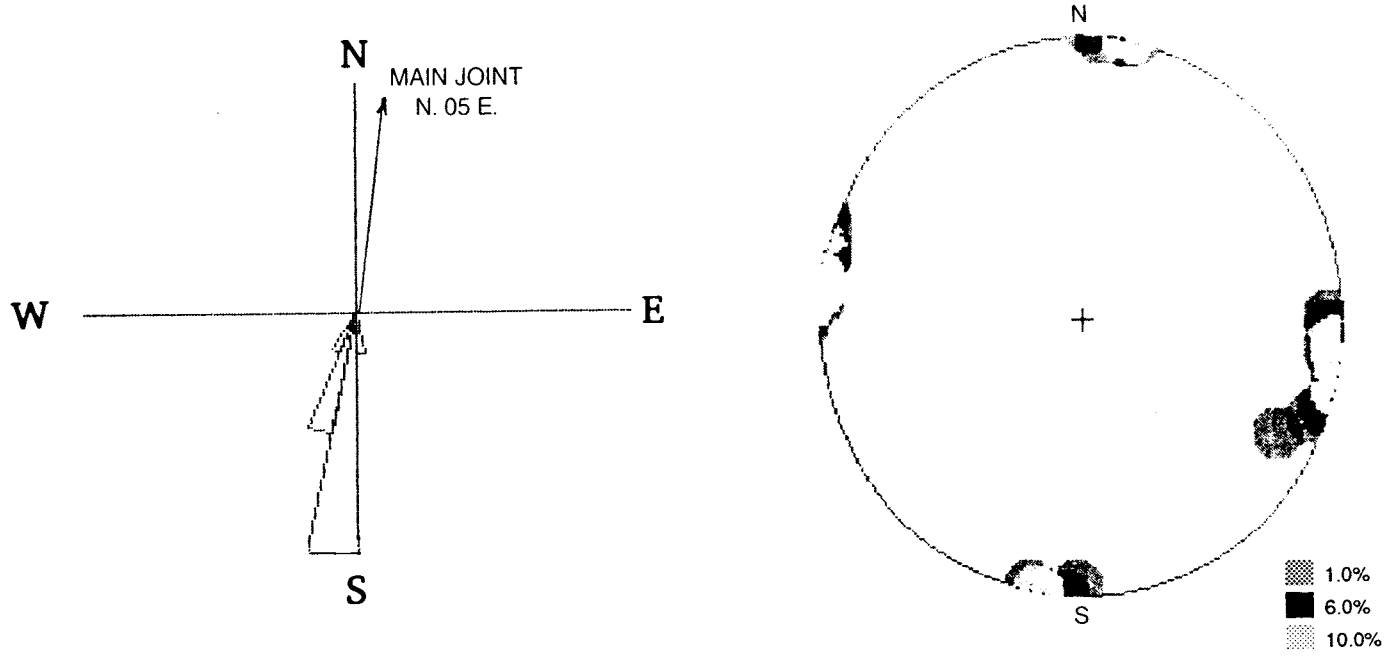


Figure 14c. *Crandall Canyon mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 24.*

Mine Name: **KING NOS. 4 AND 6**

Owner-Operator: United States Fuel Company

Location: Left and Middle Forks of Miller Creek Canyon, several miles from the town of Hiawatha, Carbon County. (Portals: Sections 30 and 32, Township 16 S., Range 08 E.)

Seam(s) mined: B-seam (Hiawatha B) and Hiawatha

Host unit: Lower part of the Blackhawk Formation (Upper Cretaceous) consisting of alternating sandstone, shale and coal.

Overlying unit: Castlegate Sandstone (Upper Cretaceous).

Underlying unit: Star Point Sandstone (Upper Cretaceous).

Coal field: Wasatch Plateau

Structure:

Attitude: Nearly flat strata become disturbed near the faults.

Faulting: N-S-trending faults of the Pleasant Valley fault zone (Doelling, 1972, p. 181).

Seam description:

Seam name: B-seam and Hiawatha

Thickness: 10.0 feet - B-seam
8.9 feet - Hiawatha

Thickness mined: 6 feet - B-seam
7.4 feet - Hiawatha

Roof: B-seam - carbonaceous shale
Hiawatha seam - immediate roof is top coal overlain by shale

Floor: B-seam - immediate floor is floor coal underlain by shale
Hiawatha - sandstone

Drill hole information indicates an overburden thickness of 38 feet for the stratigraphically highest seam - the B-seam. One hundred and thirty feet of interburden separates the B-seam from the basal Hiawatha seam. The two seams and a third seam, the Hiawatha A-seam, merge into one thick seam within the U.S. Fuel mine workings. (J. Semborski - personal communication).

Megascopic description: The B-seam is a semi-bright to bright coal. Near the roof vitrinized logs could be seen. The upper part of the seam is characterized by a high concentration of vitrain bands, occasionally 0.5 inch thick. These vitrain bands, alternating with clarain and very thin durain bands, have brilliant gloss and break easily into cube-like pieces. Two rock partings are present in the upper 2/3 of the seam. The coal has a high resin content, particularly the lower part. The Hiawatha seam is mainly dull-banded coal. Very thin vitrain bands are distributed more or less regularly throughout the whole seam. These bands alternate with semi-bright or dull bands of clarain and durain especially in the middle portion of the seam. The coal in the lower part is highly resinous. Overall, the Hiawatha coal is moderately resinous with a duller appearance, and a banded structure can readily be seen, whereas the B-seam is a semi-bright to bright coal, highly resinous, where banding is not so apparent.

Microscopic description: Significant differences in the maceral composition characterize the two seams with the B-seam averaging 84.8% vitrinite, 5.6% exinite and 9.6% inertinite, and the Hiawatha seam 75.4% vitrinite, 6.5% exinite and 18.1% inertinite, respectively. Vitrinite reflectance indicates that the B-seam coal rank is high volatile B bituminous (Ro = 0.58) and that of the Hiawatha seam high volatile bituminous C with a mean Ro = 0.55.

Cleat measurements:

Seam: B-seam - 100 measurements
Hiawatha - 109 measurements

Major cleat direction: *Face:* N. 75 W. - B-seam
Butt: N. 35 E.
Face: N. 75 W. - Hiawatha seam
Butt: N. 25 E.

Secondary cleat direction: N. 15 W. - B-seam

Cleat description: The face and butt cleat orientations of the Hiawatha seam closely resemble those of the B-seam. However, a secondary set of cleats with northwest/southeast orientation (N. 15 W.) is clearly present in the B-seam (but not so obvious in the Hiawatha seam), thus showing a bimodal face cleat distribution. Face cleats are well developed in both seams. Their surface planes are wide in comparison to the narrow surface planes of the butt cleats. In the Hiawatha seam, they intersect the coal throughout the whole seam and are abundantly filled with calcite. Further, calcite film also covers cleat surfaces, giving the coal a white appearance. Limonite staining or irridescent sulfide film occasionally cover the surface planes as well.

Cleat filling: Calcite, resin, minor pyrite

Cleat spacing: Average 1.5 inches; the more closely distributed cleats in the interlayers of lustrous coal (vitrain) average 0.3 inches.

Joint measurements in surface rocks surrounding the mine: 48 measurements on the left side of the King No. 4 mine portal; 100 measurements surrounding the portal of the King No. 6 mine portal

Major joint direction:
Main: N. 15 E. outside the King No. 4 Mine
Minor: N. 85 W.
Main: N. 15 E. outside the King No. 6 Mine
Minor: N. 85 W.

Comments: Figures 15a, 15b, 16a and 16b are graphic representations of the quantitative analyses.

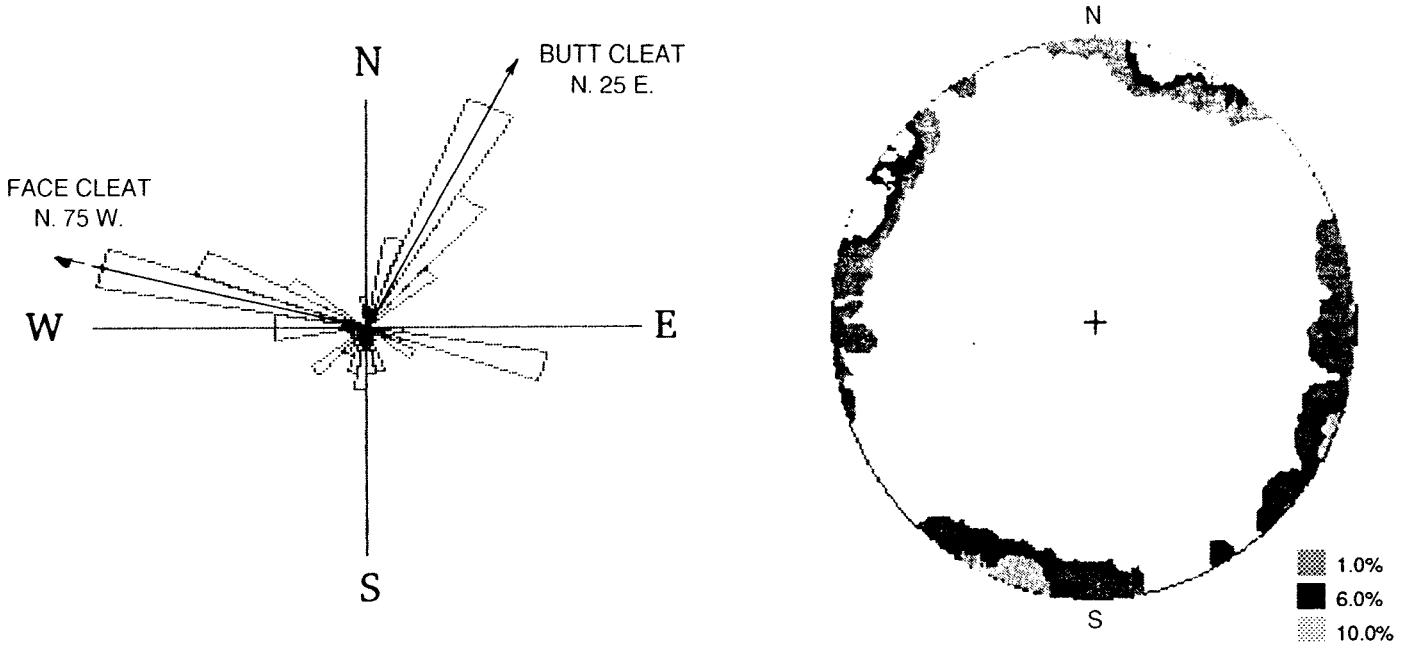


Figure 15a. *King No. 6 mine - Hiawatha seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 109.*

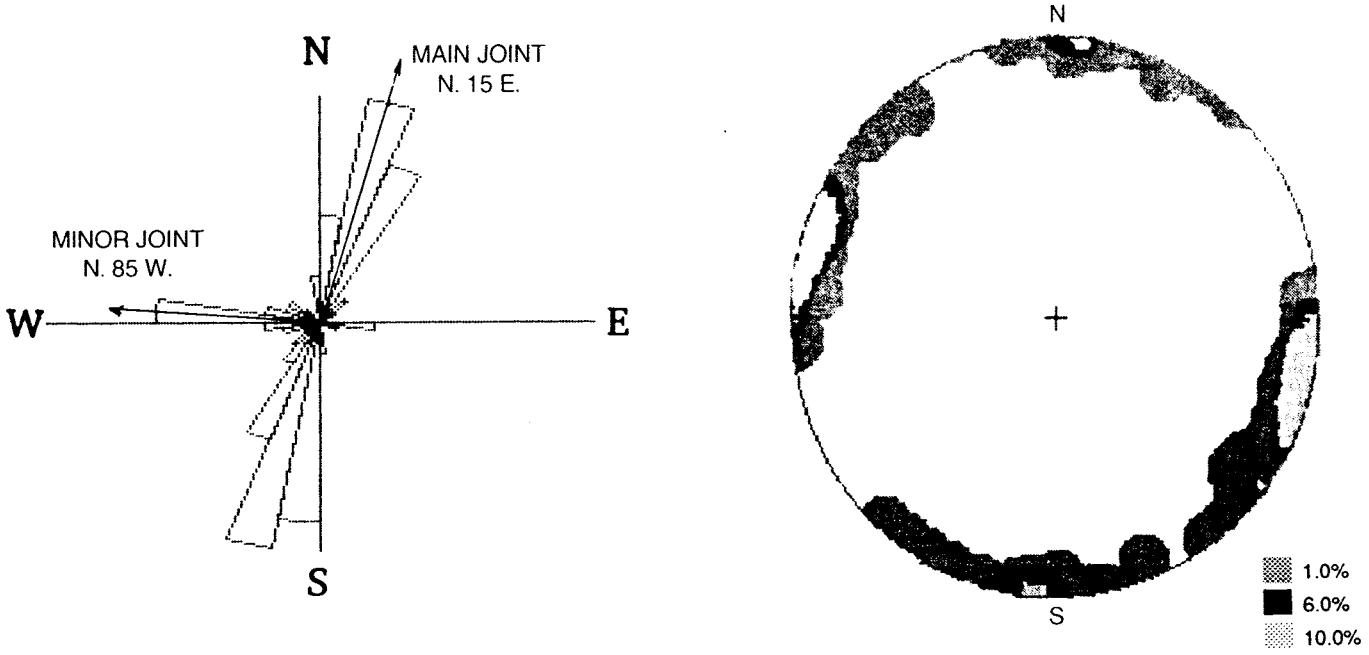


Figure 15b. *King No. 6 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 100.*

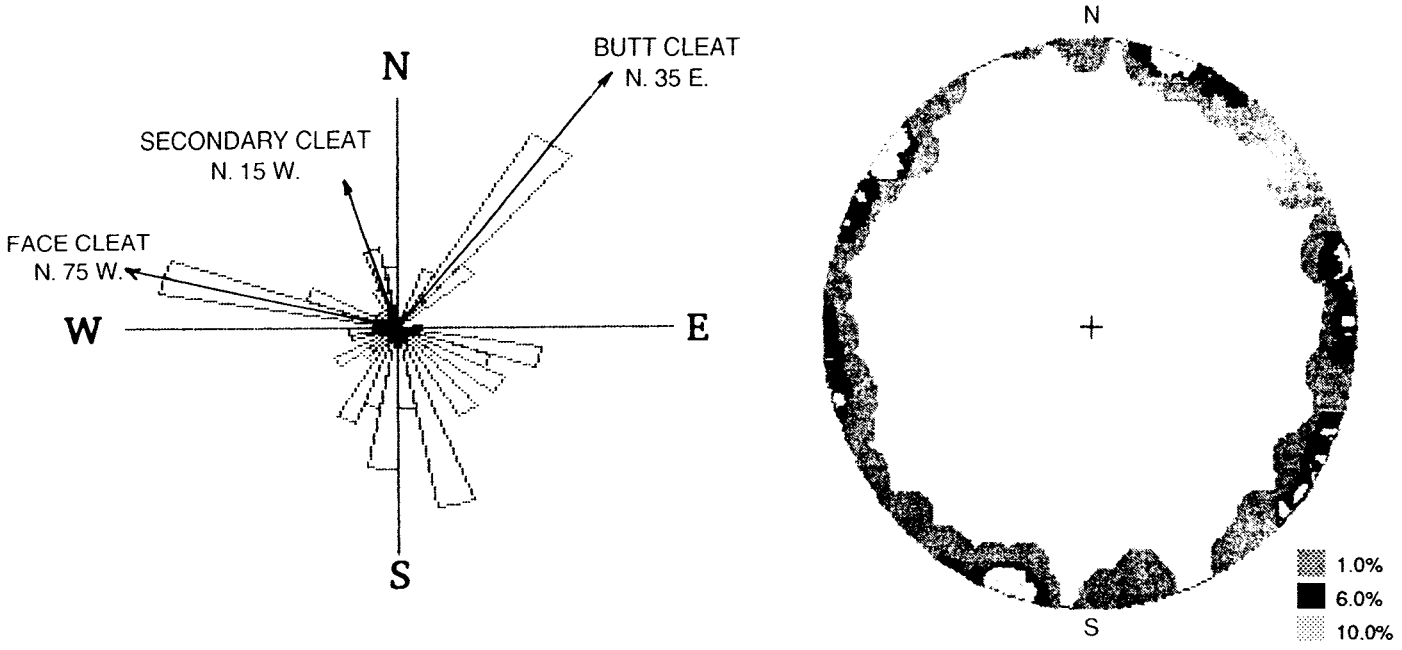


Figure 16a. *King No. 4 mine - B-seam - rose diagram of face and butt cleats and lower hemisphere equal-area stereonet diagram; n = 100.*

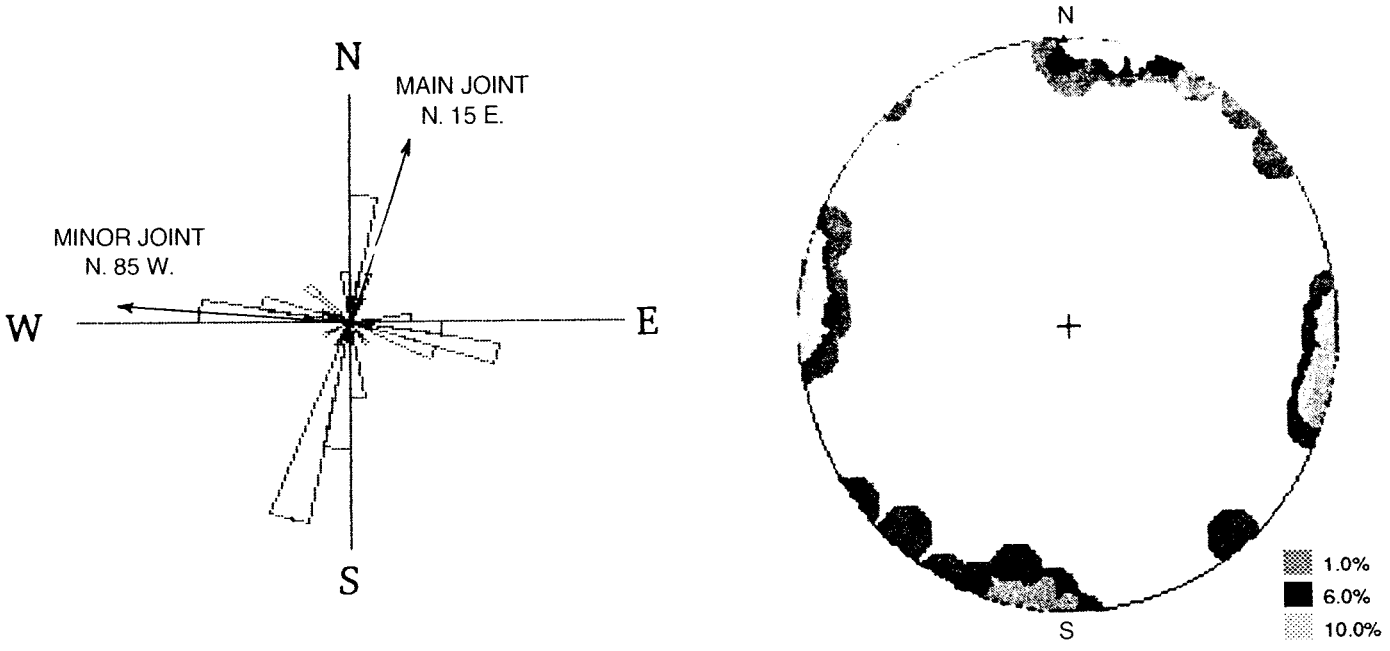


Figure 16b. *King No. 4 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 48.*

Mine Name: **STAR POINT NO. 2 (PLATEAU MINE)**

Owner-Operator: Plateau Mining Coal Company, a subsidiary of Cyprus Coal Company

Location: 12 miles southwest of Price, Carbon County. (Portal: Sec.16, Township 15 S., Range 08 E.)

Seam(s) mined: Wattis and Third (Middle or Blind Canyon) (The cleat investigation was conducted in the Wattis seam).

Host unit: Lower part of the Blackhawk Formation (Upper Cretaceous).

Overlying unit: Castlegate Sandstone (Upper Cretaceous).

Under-lying unit: Aberdeen Sandstone Member of the Blackhawk Formation (Upper Cretaceous).

Coal field: Wasatch Plateau

Structure:

Attitude: The rocks within the mine property dip gently southwest at an average of 3 degrees.

Faulting: The area is affected by the faults of the Gordon fault zone (Doelling, 1972, p. 225).

Seam description:

Seam name: Wattis

Thickness mined: 7.4 feet

Roof: Carbonaceous shale

Floor: Carbonaceous shale

Three economically mineable seams are found within the Plateau Mining leasehold. In ascending order they are: Hiawatha, Third (Middle or Blind Canyon) and Wattis. The thickness of the seams ranges from 6 to 13 feet, with an average thickness of 8 feet. At the present, only two seams are mined, Wattis and Third. The overburden thickness range is 100-1700 feet with an average of 900 feet. The interburden range is 50-60 feet between the Hiawatha and Third seam and 50 feet between the Third and the Wattis seam. Geologic features affecting the mining conditions include faulting, dikes, and channeling.

Megascopic description: 80% of the Wattis coal can be described as clarain, with dull clarain being the most abundant. Alternating layers of bright clarain and dull clarain and thin vitrain characterize especially the upper part of the seam. One larger parting (impure coal) can be seen in the upper half of the seam. The lower part is clarain with a high concentration of resin.

Microscopic description: The Wattis seam averages 79.3% vitrinite, 12.1% exinite and 8.6% inertinite. Rank determined by vitrinite reflectance (Ro = 0.51) classifies the coal as high volatile bituminous C.

Cleat measurements:

Seam: Wattis - 45 measurements

Major cleat direction: *Face:* N. 25 E. *Butt:* N. 75 W.
Average dip is 85 degrees.

Cleat description:

Cleats are generally well developed, with face cleat being better expressed. They traverse the entire thickness of the individual lithotypes with the exception of the impure coal where they are absent or indistinct. Slickensides have been recognized on the cleat surfaces on few occasions.

A dense network of cleats with conchoidal fractures is evident in the vitrain components of the clarain.

Cleats are commonly healed with calcite, and abundant, yellowish to dark, soft resin could be seen as cleat filling on the cleat plane surfaces or occasionally branching parallel to the bedding planes (average 0.25 inches in length).

Cleat filling: Calcite, resin

Cleat spacing: 0.08 inches in vitrain and 1.6 feet in clarain.

Joint measurements in surface rocks surrounding the mine: 100 measurements

Major joint direction: *Main:* N. 05 E. and N. 05 W.
Minor: N. 75 W. and N. 75 E.

Secondary joint direction: N. 25 W.

Comments: The results of the data obtained independently by the Plateau Mining Company's personnel (Hunt, personal communication, 1987) were compared with those of the author. The face and butt cleat orientations are similar.

Graphic interpretaion of the analytical data is shown in figures 17a and 17b.

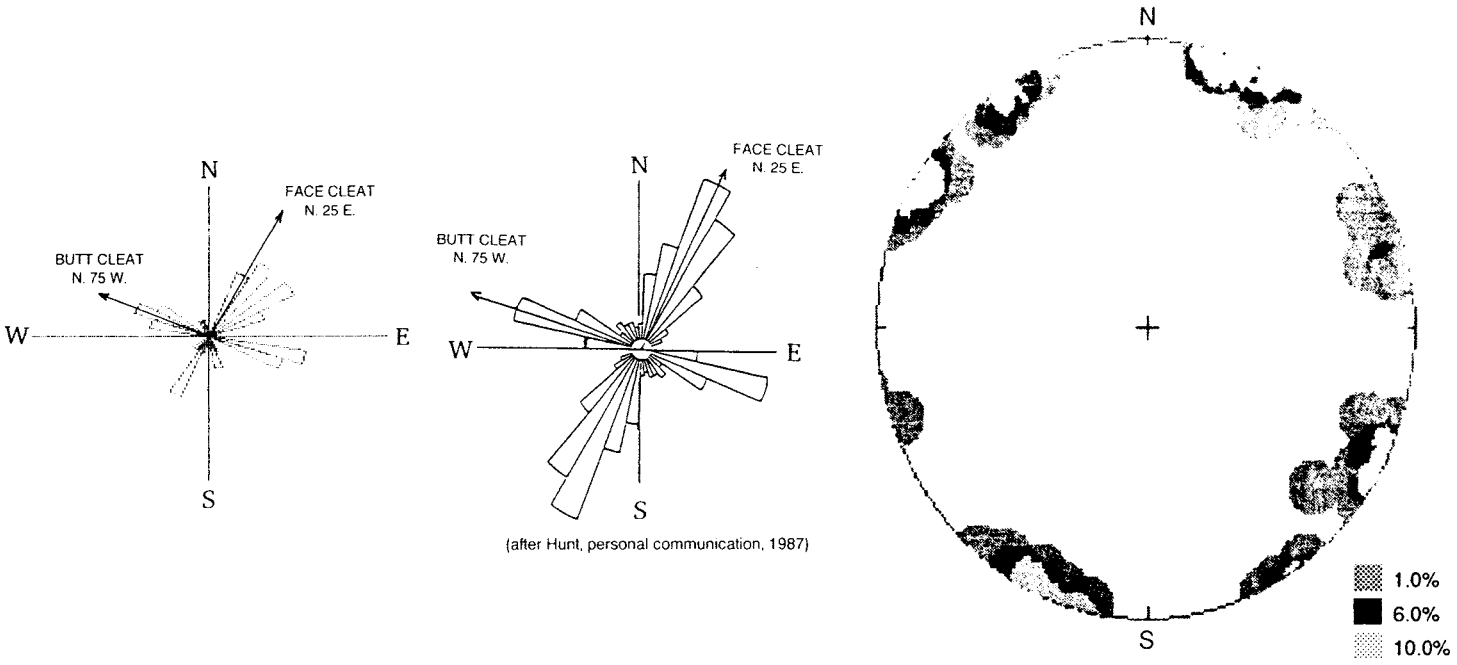


Figure 17a. *Star Point No. 2 mine - Wattis seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 45.*

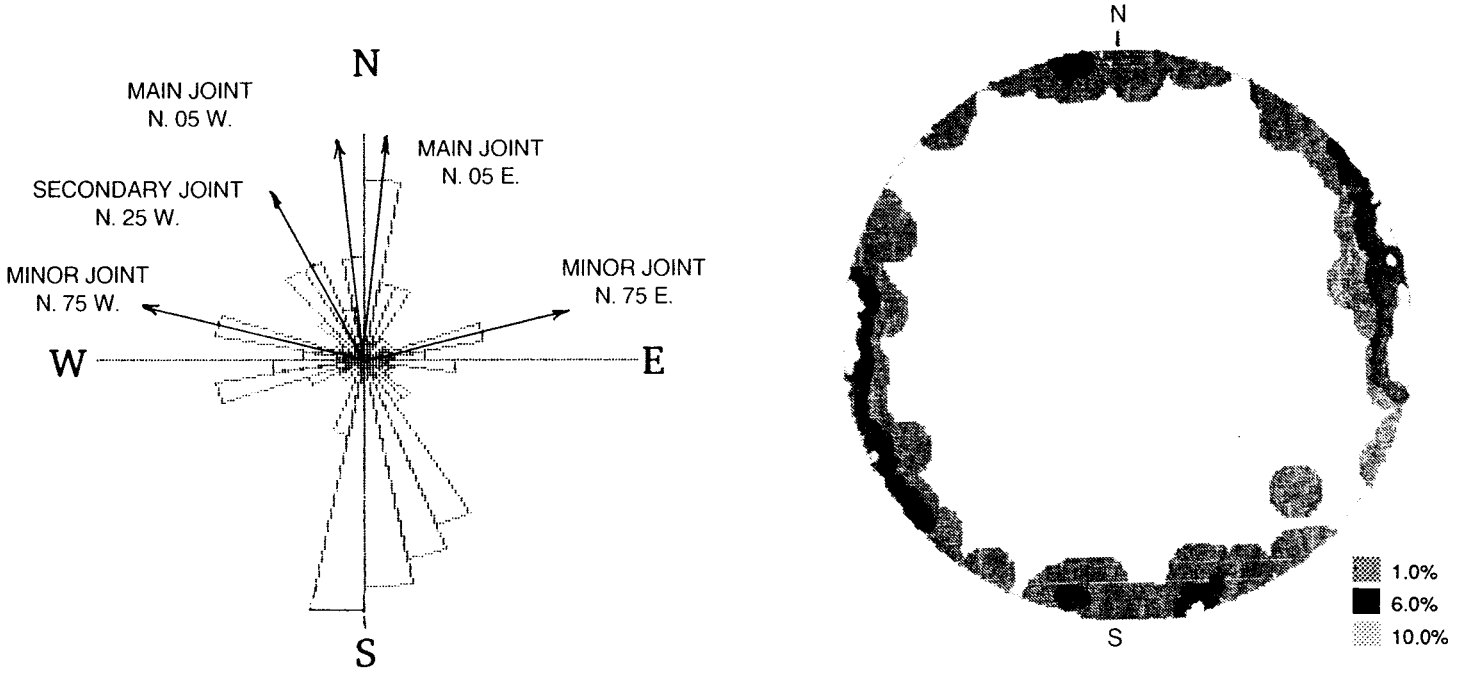


Figure 17b. *Star Point No. 2 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 100.*

Mine Name: **BELINA NOS. 1 AND 2**

Owner-Operator: Valley Camp of Utah Company

Location: South of Eccles Canyon, approximately 6 miles from the town of Scofield, Carbon County, Utah. (Portals: Section 25 and 30, Township 13 S., Range 06 E.)

Seam(s) mined: Belina No. 1 mine produces coal from the Upper O'Connor seam and Belina No. 2 mine from the Lower O'Connor seam.

Host unit: Lower part of the Blackhawk Formation (Upper Cretaceous).

Overlying unit: In the western and northern parts of the area (Scofield quadrangle) are the remnants of the Castlegate Sandstone and Price River Formation (Upper Cretaceous).

Underlying unit: Star Point Sandstone (Upper Cretaceous).

Coal field: Wasatch Plateau

Structure:

Attitude: The strata enclose a north-south-trending anticline with the exception of the faulted strata (Pleasant Valley fault zone) in the east.

Faulting: The N-S-trending Pleasant Valley fault zone consisting of several normal faults of considerable displacement is the major structure in the area (Doelling, 1972, p. 217).

Seam description:

Seam name: Upper and Lower O'Connor

Thickness: Upper O'Connor seam 21 feet *Thickness mined:* 9 feet
Lower O'Connor seam 17 feet *Thickness mined:* 9 feet

Roof: Upper O'Connor seam - Immediate roof consists of roof coal overlain by interbedded carbonaceous siltstone and shale
Lower O'Connor seam - sandstone

Floor: Upper O'Connor seam - sandstone
Lower O'Connor seam - immediate floor consists of floor coal

The overburden thickness range is 300-1100 feet with an interburden between the Upper and Lower O'Connor seams more than 100 feet (Tanner, personal communication, 1988). Actual mining thickness in both seams is 9 feet, the rest remaining as top and floor coal. Occasional water accumulation and faulting affect at times the mining conditions.

Megascopic description: The coal from the Upper O'Connor seam is classified as a vitrous clarain (clarovitrain with average vitrinite and exinite exceeding 95%). The Lower O'Connor seam is a bright clarain. A rock split less than 1 foot wide is present in both seams. The vitrain bands in the clarain average 0.4 inch.

Microscopic description: The coal maceral average for the Upper O'Connor seam is 91% vitrinite, 4.7% exinite and 4.3% inertinite and for the Lower O'Connor seam average is 83% vitrinite, 3% exinite and 14% inertinite. The Upper O'Connor seam shows uniformity in the maceral composition which also seems to be reflected in the hardness of the coal. The rank determined by reflectance averages Ro = 0.48 for the Upper O'Connor seam and Ro = 0.49 for the Lower O'Connor seam, classifying both coals as high volatile bituminous C.

Cleat measurements:

Seam: Upper O'Connor - 100 measurements
Lower O'Connor - 100 measurements

Major cleat direction: *Face:* N. 05 E. Upper O'Connor seam
Butt: N. 85 W.
Face: N. 05 E. Lower O'Connor seam
Butt: N. 85 W.

Cleat description: Overall, the coal from both seams is well cleated and hard, especially the coal of the Upper O'Connor seam. The surfaces of the face cleats are smooth, or lustrous. Occasionally, some evidence of microfaulting, with small dislocations in the Upper O'Connor seam, can be seen. These are filled with pulverized coal. Hematite and limonite staining can be observed as well.

Cleat filling: Secondary calcite and resin as cleat filling or surface coating of the cleat planes, pyrite as disseminated grains on the cleat surfaces.

Cleat spacing: Upper O'Connor seam - average 0.7 inch
Lower O'Connor seam - varies from 0.8-1 inch

Joint measurements in surface rocks surrounding the mine: 101 measurements

Major joint direction: *Main:* N. 05 E. *Minor:* N. 85 W.

Joint spacing: Varies from several inches to several feet.

Joint description: The measurements of systematic rock joints were obtained on buff, fine-grained sandstone, approximately 0.7 mile from the portal of the Belina No. 1 mine.

Comments: The results show remarkable parallelism between the face and butt cleat in the coal and the two dominant joint patterns in the sandstone. Close agreement of the cleat and joint patterns suggests that the area underwent a uniformly oriented direction of weakness. Graphic representation of the results is shown in figures 18a, 18b and 18c.

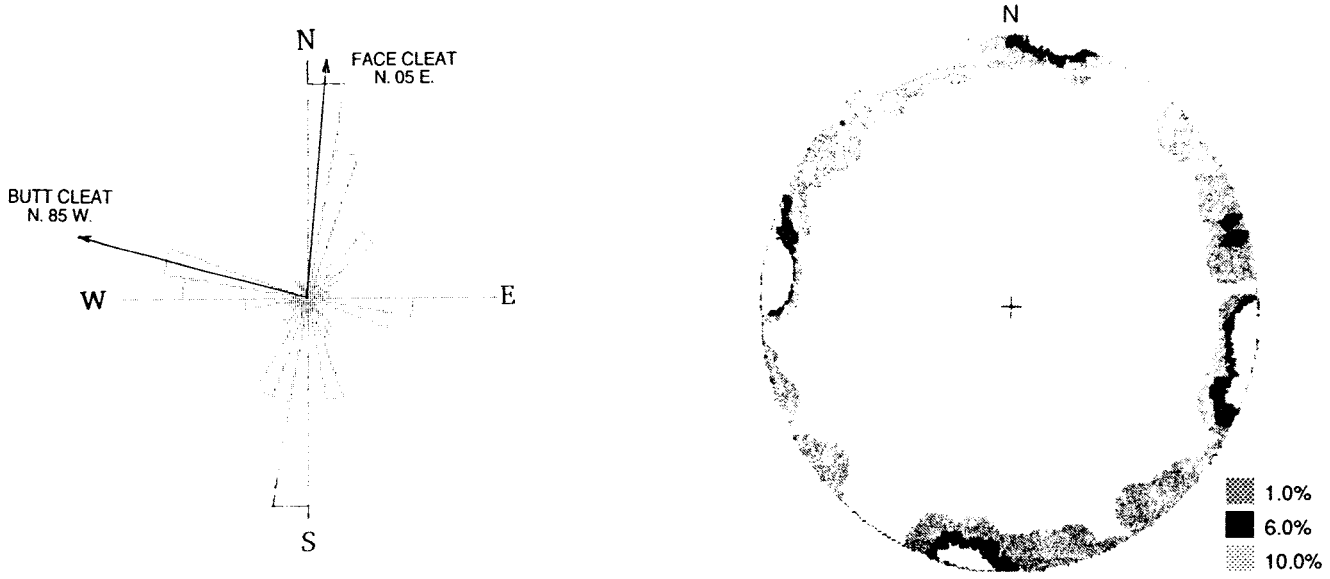


Figure 18a. *Belina No. 1 mine - Upper O'Connor seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 100.*

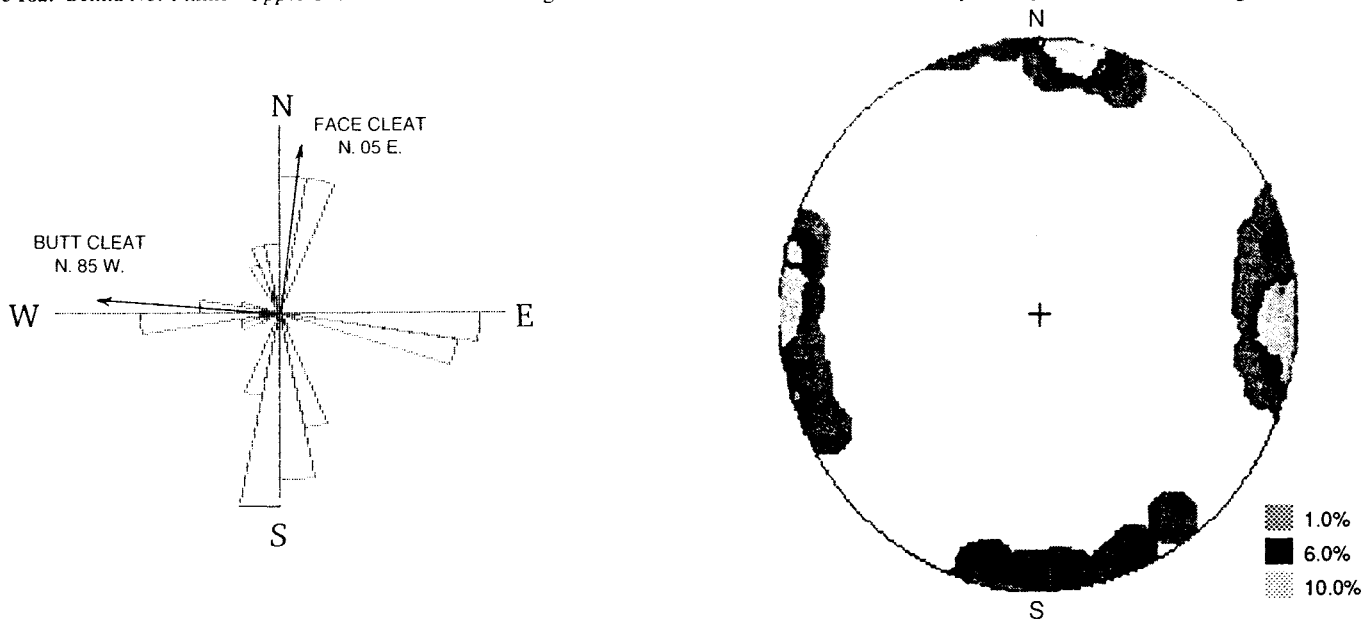


Figure 18b. *Belina No. 2 mine - Lower O'Connor "A" seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 100.*

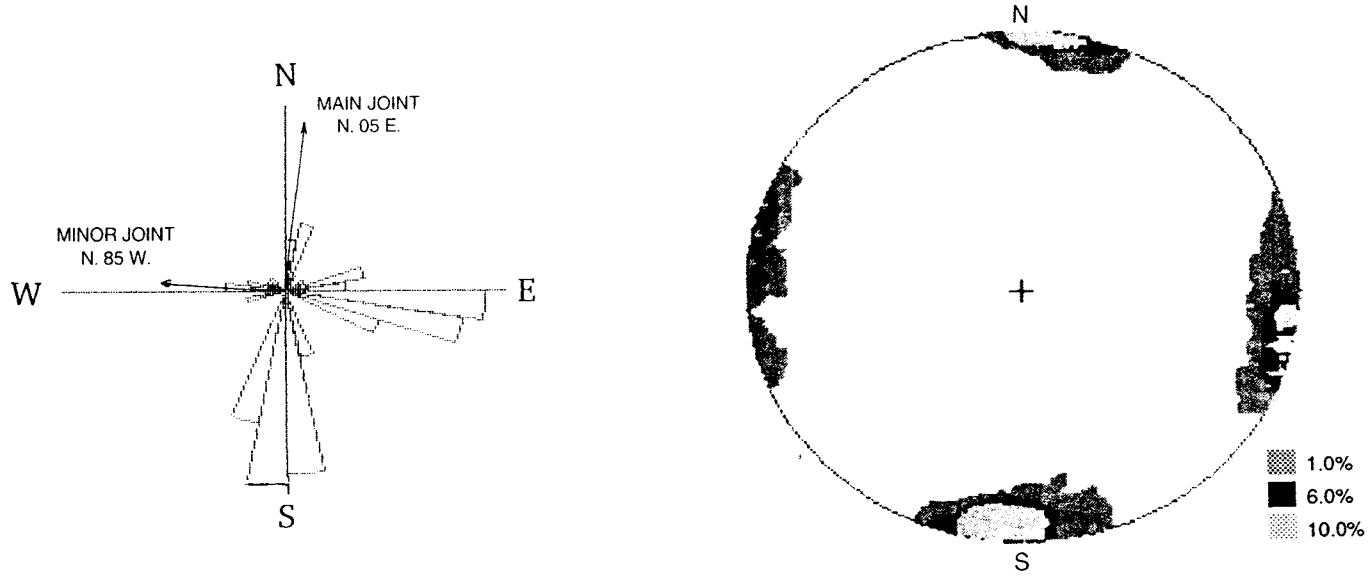


Figure 18c. *Belina Nos. 1 and 2 mines - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 101.*

Mine Name: **SKYLINE NOS. 1 AND 3**

Owner-Operator: Utah Fuel Company

Location: Eccles Canyon near Scofield, Carbon County, approximately midway between the towns of Fairview and Price. (Portals: Section 13, Township 13 S., Range 06 E.).

Seam(s) mined: Upper O'Connor (Skyline No.1) and Lower O'Connor "A" (Skyline No.3).

Host unit: Lower part of the Blackhawk Formation (Upper Cretaceous).

Overlying unit: Castlegate Sandstone and Price River Formation (Upper Cretaceous) exposed only north and west of the area.

Underlying unit: Storrs Tongue of the Star Point Sandstone (Upper Cretaceous).

Coal field: Wasatch Plateau

Structure:

Attitude: The strata in the area enclose a north-south-trending anticline with the exception of the east side where the strata are affected by the Pleasant Valley fault zone (Doelling, 1972, p. 217).

Faulting: The N-S trending faults of the Pleasant Valley fault zone.

Seam description:

Seam name: Upper O'Connor and Lower O'Connor "A"

Thickness mined: Upper O'Connor seam - 6.3 feet
Lower O'Connor "A" seam - 8.4 feet

Roof: Upper O'Connor seam - 6 inches of gray, carbonaceous siltstone overlain by interbedded sandstone, shale, and siltstone with sandstone being the predominant component.
Lower O'Connor "A" seam - carbonaceous siltstone.

Floor: Upper O'Connor seam - mudstone and claystone.
Lower O'Connor "A" seam - massive sandstone of the Storrs Tongue of Star Point Sandstone.

The overburden thickness averages 900 feet for the Upper O'Connor seam and 1200 feet for the Lower O'Connor "A" seam, the upper split of the Lower O'Connor seam. Geologic features encountered in the mines include faults, channel sandstones, and igneous dikes. The scouring of the sandstone into the coal seams and roof falls, caused by an intensely cleated roof, affect the mining conditions at times. Igneous dikes that intrude into the coal cause alteration to a natural coke. Microfaulting with small dislocations filled with powdered coal (gouge zone) can be seen as well.

Megascopic description: The Upper O'Connor coal is composed mostly of bright clarain and vitrain. It has a very high vitrinite content, so clarovitrain would be a more appropriate name. Durain is sparsely distributed throughout the seam, however, the bands are never thick enough to classify them as individual lithotype bands. The Lower O'Connor "A" coal is mostly semi-dull clarain interbedded with numerous variably thick vitrain bands or lenses. Two durain bands of measurable thickness can be observed as well. The overall appearance of the coal from the two seams is: a) Upper O'Connor seam: bright, very hard coal. b) Lower O'Connor "A" seam: semi-dull, hard coal.

Microscopic description: The Upper O'Connor seam averages 93.6% vitrinite, 3.5% exinite and 2.9% inertinite. The Lower O'Connor "A" seam average 82.9% vitrinite, 3.3% exinite and 13.8% inertinite. Maceral composition of both seams shows a very close correlation between the maceral composition of the Upper and Lower O'Connor seams in the Belina mines and the Upper and Lower O'Connor seams in the Skyline mines. The results of the reflectance analyses from measurements taken on vitrinite (Upper O'Connor seam Ro = 0.51 and Lower O'Connor "A" seam Ro = 0.50), classify the O'Connor coals as high volatile C bituminous. The coal of the Lower O'Connor "A" seam shows higher inertinite content, due to a higher percentage of thin durain bands. The composition consists mostly of semifusinite. The coal of the Upper O'Connor seam is characterized by very high vitrinite content and remarkable consistency in maceral composition throughout the whole seam, reflected also in greater hardness of the coal.

Cleat measurements:

Seam: Upper O'Connor - 104 measurements
Lower O'Connor "A" - 106 measurements

Major cleat direction: *Face:* N. 15 E. Upper O'Connor seam
Butt: N. 85 W.
Face: N. 05 E. Lower O'Connor "A" seam
Butt: N. 75 W.

Secondary cleat direction: *Face:* N. 25 W. Upper O'Connor seam
Butt: not expressed in the measurements

Cleat description: Both seams are well cleated. In general, their surfaces are smooth, silky, or with slickensides. Occasionally, the cleats extend into the roof rocks. Microfaults with small dislocations filled with powdered coal (same as in the Upper O'Connor-Belina No. 1 mine) can be seen. Calcite filling, sometimes thick in tabular form or coating, covers the fracture planes (more easily seen in the Upper O'Connor seam). Resin and pyrite are disseminated mostly in the form of small flakes or films. When oxidized, iron hydroxides in the form of irridescent sulfides can be seen on the surface planes.

Cleat filling: calcite, pyrite

Cleat spacing: 0.8-1.0 inches - Upper O'Connor seam
0.8 inches - Lower O'Connor seam

Joint measurements in surface rocks surrounding the mine: 100 measurements

Major joint direction: *Main:* N. 05 E.
Minor: N.65 W.

Joint description: The joint measurements were obtained on a buff fine-grained sandstone on the right side of the road less than a mile from the portal of the Skyline No. 3 mine.

Comments: Both mines show remarkable similarity in the orientation of the face and butt cleats even though more than one seam is involved. Furthermore, their orientations are almost in agreement with the results obtained in the Belina mines. Graphic representation of the results is shown in figures 19a, 19b and 19c.

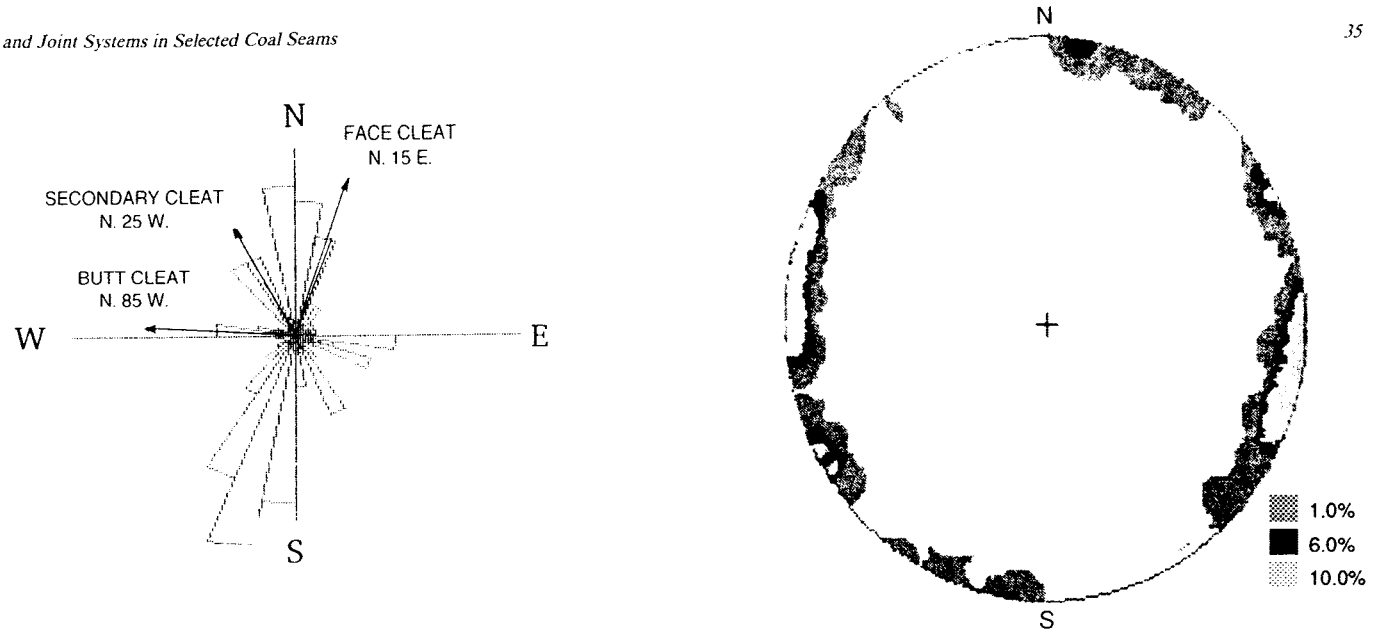


Figure 19a. *Skyline No. 1 mine - Upper O'Connor seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 104.*

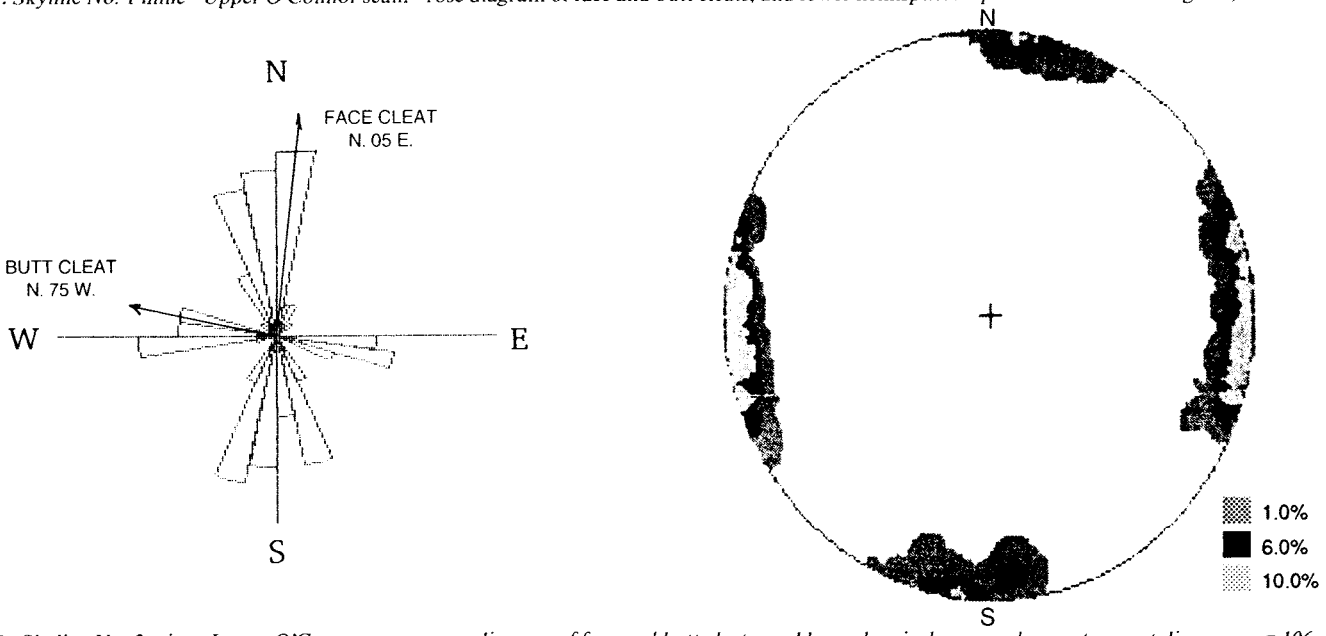


Figure 19b. *Skyline No. 3 mine - Lower O'Connor seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 106.*

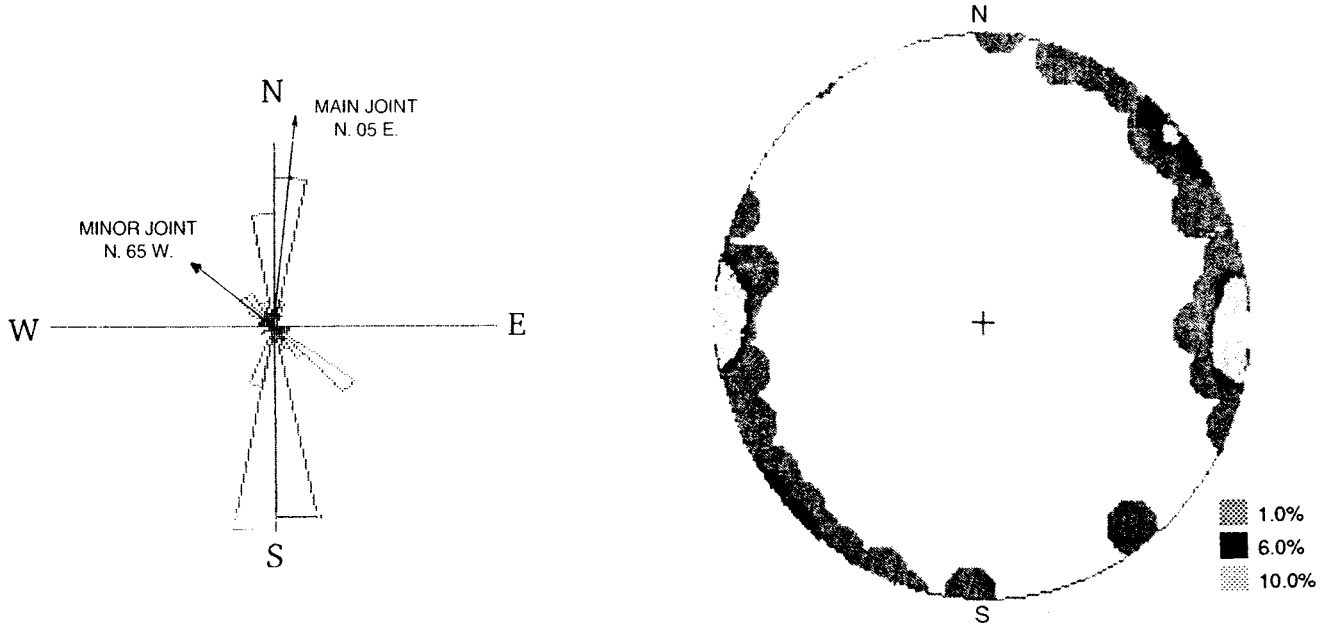


Figure 19c. *Skyline Nos. 1 and 3 mines - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 100.*

Mine Name: **BEAVER CREEK NO. 7**

Owner-Operator: Beaver Creek Coal Company, a subsidiary of ARCO Mountain Coal Company.

Location: Several miles west-northwest of the town of Price, Carbon County in Bryner Canyon (in the vicinity of the old Swisher mine). (Portal: Section 18, Township 13 S., Range 8 E.)

Host unit: Blackhawk Formation mining Castlegate "A" seam (i.e., lowest seam in the Castlegate coal group).

Overlying unit: Castlegate Sandstone (Upper Cretaceous).

Underlying unit: Aberdeen Sandstone Member of the Blackhawk Formation separates the Castlegate coal group from the basal group, the Spring Canyon coal group - both within the Blackhawk Formation (Upper Cretaceous).

Coal Field: Wasatch Plateau

Structure:

Attitiude: The area is structurally complex due to the numerous faults of the North Gordon fault zone, causing displacements of the surface and underground rocks (Doelling, 1972, p. 209).

Seam description:

Seam name: Castlegate "A"

Thickness mined: 8.2 feet

Roof: Carbonaceous shale

Floor: Silty shale

The overburden thickness ranges from less than 200 to 800 feet with average thickness of approximately 500 feet. Several N-S-trending faults of the Fish Creek Complex, clastic dikes ("spars"), and sandstone channels (scours) present only minor mining difficulty.

Megascopic description: The Castlegate "A" coal is a semi-bright, highly resinous clarain characterized by the absence of any partings (at the site where measurements were obtained). Bright clarain, dull clarain, and thin vitrain bands are the most abundant components. The usual banded texture due to bands of different lithotype components is not very distinct in this coal.

Microscopic description: The maceral composition of the Castlegate "A" seam averages 83.1% vitrinite, 9% exinite and 7.9% inertinite. The results reveal a fairly high concentration of exinite in comparison with other coals under study. The rank determined by means of reflectance measurements (Ro = 0.52) classifies the coal as high volatile C bituminous.

Cleat measurements:

Seam: Castlegate "A" - 105 measurements

Major cleat direction: *Face:* N. 65 W.
Butt: N. 35 E.

Cleat description: Generally, the cleats in the Castlegate "A" seam are poorly expressed. The two sets of cleats are approximately at right angles to each other. The cleats in the clarain show a regular pattern and their plane surfaces are uneven; in vitrain, cleats are smooth and lustrous. Resin is abundant, especially in the lower part of the seam.

Cleat filling: Calcite (also as coating on plane surfaces), pyrite and resin.

Cleat spacing: Average 0.7 inches in the clarain and 0.08 inches in the vitrain.

Joint measurements in surface rocks surrounding the mine: 100 measurements

Major joint direction: *Main:* N. 15 E.
Minor: N.45 W.

Comments: Graphic representation of the cleat and joint data is shown in figures 20a and 20b.

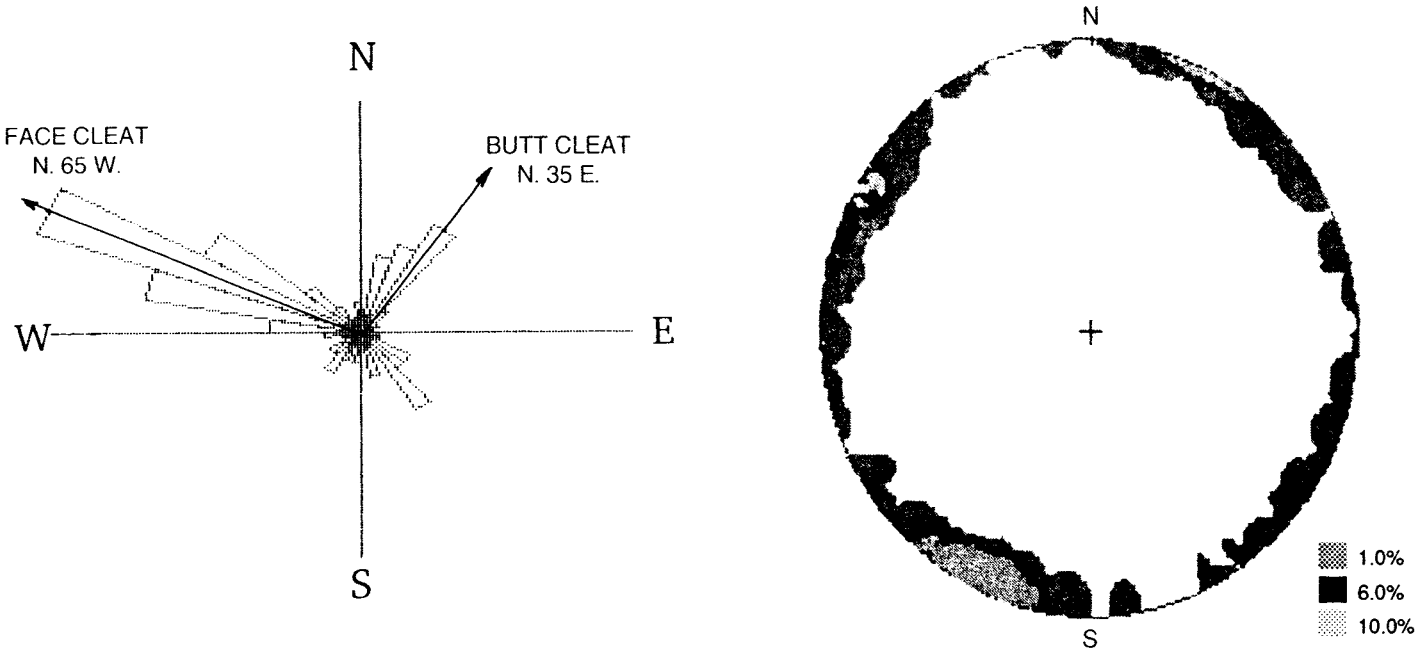


Figure 20a. *Beaver Creek No. 7 mine - Castlegate "A" seam - rose diagram face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 105.*

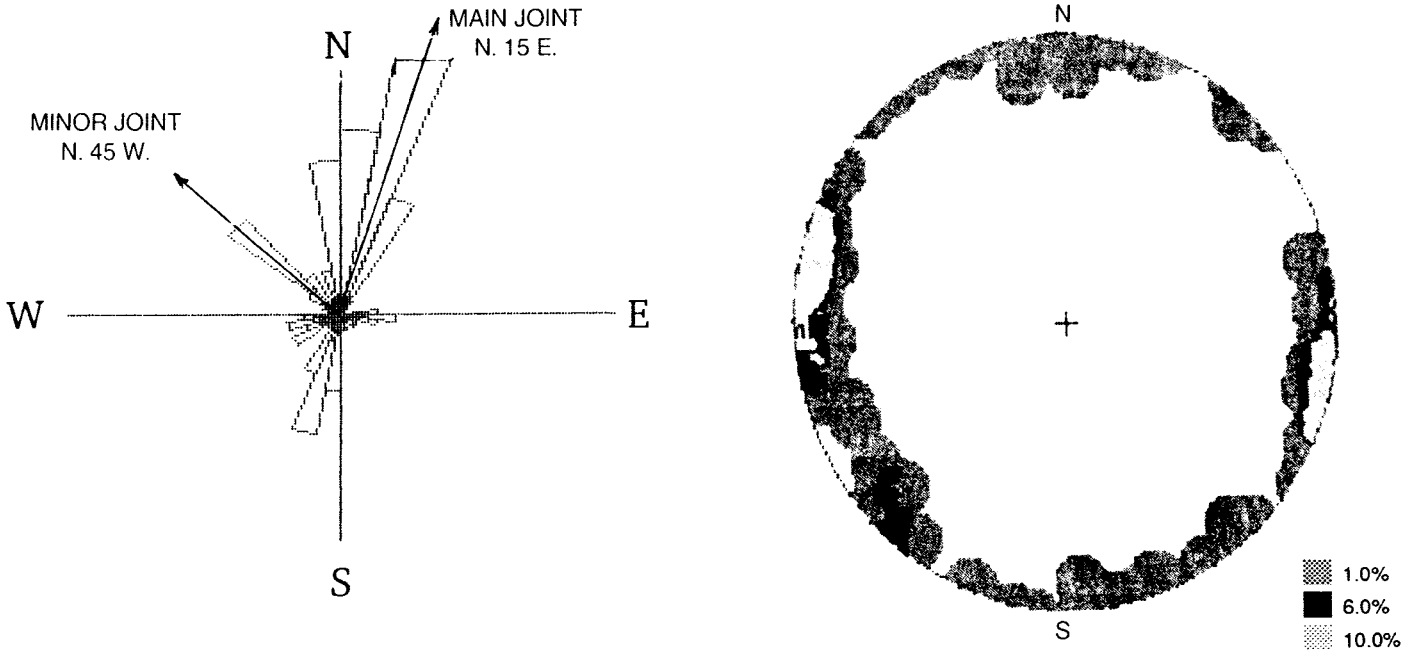


Figure 20b. *Beaver Creek No. 7 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 100.*

Mine Name: **CASTLE GATE NO.3**

Owner-Operator: Castle Gate Coal Company

Location: Hardscrabble Canyon near the town of Price, Carbon County. (Portal: Section 10, Township 13 S., Range 09 E.)

Host unit: Blackhawk Formation (Upper Cretaceous) mining Sub-3 seam (i.e., basal seam of the Spring Canyon group).

Overlying unit: Aberdeen Sandstone Member of the Blackhawk Formation (Upper Cretaceous).

Underlying unit: Spring Canyon Sandstone Tongue of the Blackhawk Formation (Upper Cretaceous).

Coal field: Book Cliffs

Structure:

Attitude: The dip of the surrounding strata averages 5 degrees to the northeast.

Faulting: No faults are known to be present in the immediate mine area (Doelling, 1972, p. 353).

Seam description:

Seam name: Sub-3 seam

Thickness mined: 5.9 feet

Roof: Carbonaceous shale; however the type of rocks varies within the mine.

Floor: Massive sandstone (Spring Canyon Tongue).

Overburden thickness varies greatly from a maximum of 2400 feet to less than 600 feet. Roof control problems encountered in the mine are due to the presence of channel-fill sandstone and overbank sandstone and siltstone deposits (Bunnell, 1987). The Sub-3 seam is also one of the gassy seams in Book Cliffs coal field.

Megascopic description: A characteristic feature of the coal is its hardness, probably due to the overall lithotype uniformity of the seam. The Sub-3 coal is classified as a bright, banded clarain with minor durain bands. Thin, very bright vitrain bands and minor fusain lenses are present throughout the seam. Two rock partings not exceeding 1 foot occur in the upper and lower part of the seam. Inorganic accessories include calcite and pyrite, mostly as cleat surface coating or filling (calcite) and as disseminated grains mainly on the cleat surfaces or in the durain bands (pyrite). Resin is present in small amounts.

Microscopic description: The Sub-3 seam has an average 85% of vitrinite, 6.5% of exinite and 8.5% of inertinite. The coal is classified as high volatile bituminous B by its average rank of Ro = 0.57, determined by vitrinite reflectance.

Cleat measurements:

Seam: Sub-3 seam - 47 measurements

Major cleat direction: *Face:* N. 55 W.
Butt: N. 30 E.
Average dip is 82.0 degrees

Cleat description: Both face and butt cleats are abundant and well developed in clarain and thin vitrain but conspicuously lacking in durain. The surfaces of the cleats are smooth and lustrous.

Cleat filling: Calcite, resin

Cleat spacing: 0.8-1.0 inch in clarain.

Joint measurements in surface rocks surrounding the mine: 100 measurements

The measurements were taken in a buff, fine-grained, calcareous sandstone, several hundred feet from the Castle Gate No. 3 portal.

Major joint direction: *Main:* N. 65 W.
Minor: N. 35 E.

Joint spacing: Varies between 1-1¼ feet with joints more closely spaced in gray siltstone.

Comments: The results are shown in figures 21a and 21b.

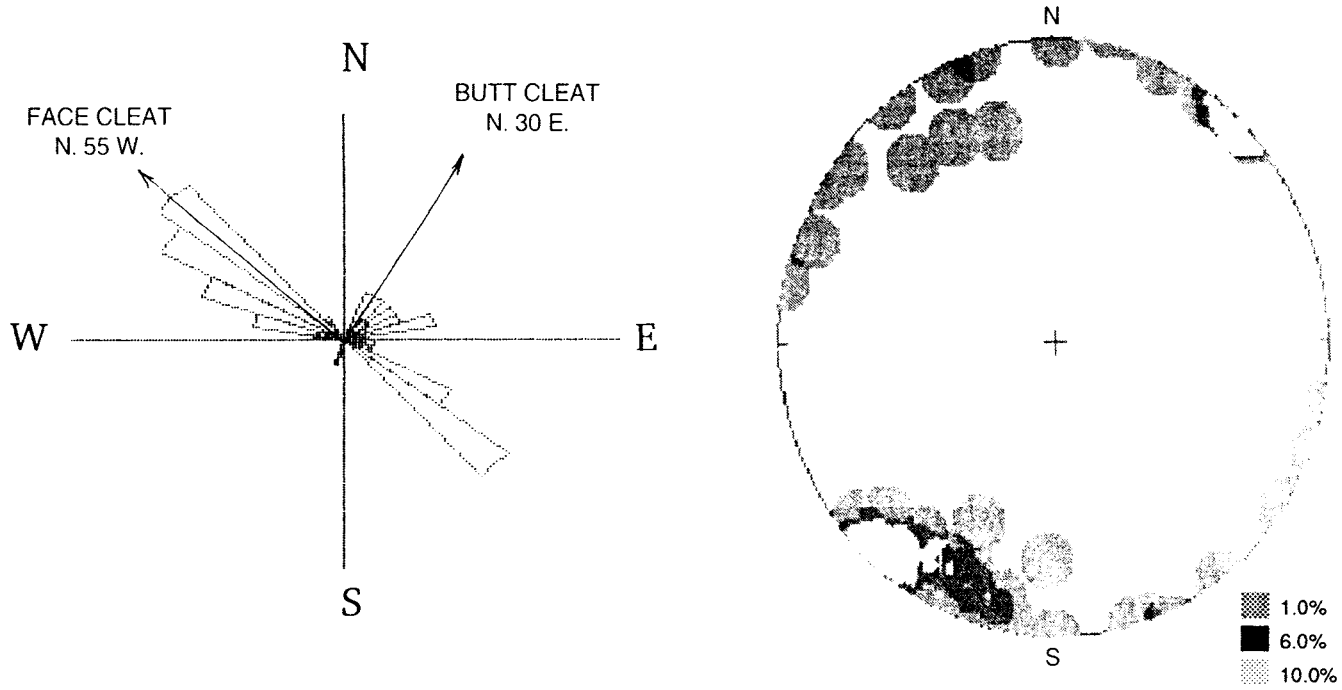


Figure 21a. *Castle Gate No. 3 mine - Sub-3 seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 47.*

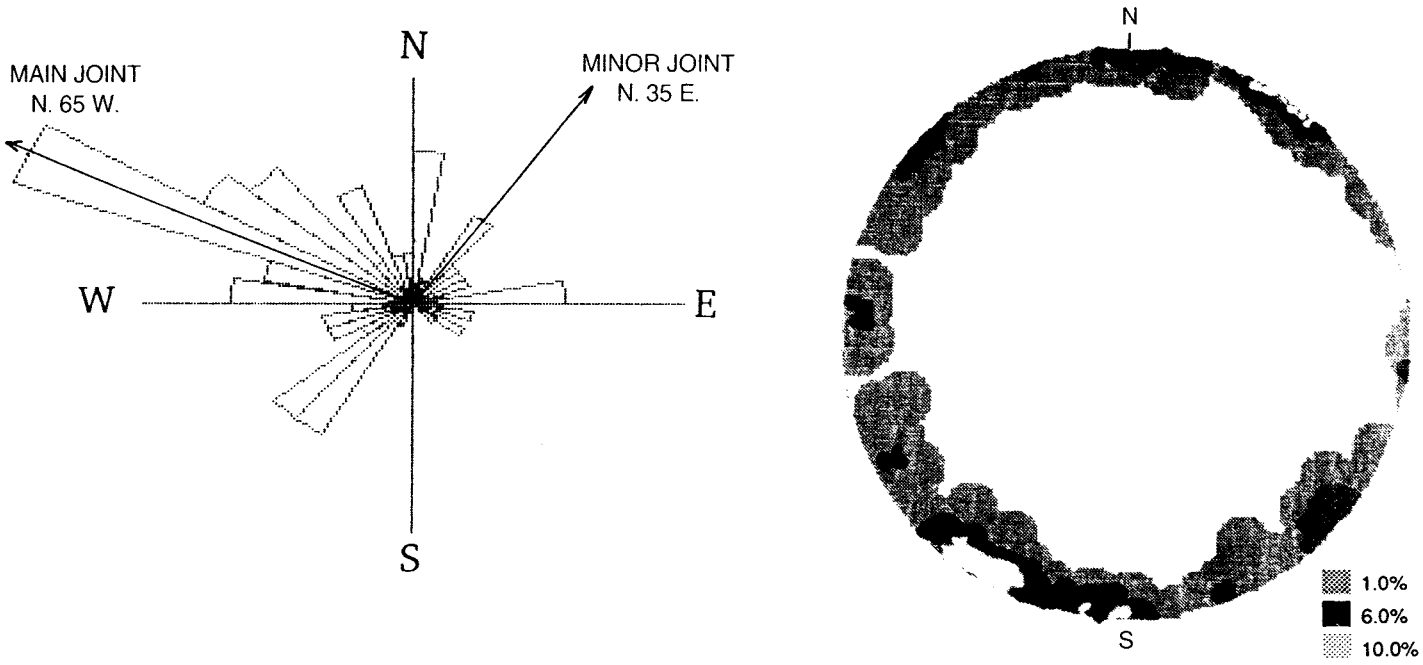


Figure 21b. *Castle Gate No. 3 mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 100.*

Mine Name: **PINNACLE AND APEX**

Owner-Operator: Andalex Resources Inc.

Location: Right Fork Canyon, several miles north from the town of Price, Carbon County. (Portals: Section 7, Township 13 S., Range 11 E.).

Seam(s) mined: Lower Sunnyside (Apex mine) and Gilson (Pinnacle mine)

Host unit: Upper part of the Blackhawk Formation (Upper Cretaceous).

Overlying unit: Castlegate Sandstone (Upper Cretaceous).

Underlying unit: Mancos Shale (Upper Cretaceous).

Coal field: Book Cliffs

Structure:

Attitude: The area is part of the simple northward-dipping Book Cliffs monocline which forms the southern rim of the Uinta Basin. The surface rocks dip gently at an average of 4 degrees (Clark, 1928)

Faulting: Few faults of small displacement; they do not affect mining conditions in the area.

Seam description:

Seam name: Lower Sunnyside and Gilson

Thickness mined: Lower Sunnyside seam 4.2 feet
Gilson seam 5.6 feet

Roof: sandstone - in both seams

Floor: sandstone - in both seams

The overburden thickness where measurements were taken is approximately 830 feet (Lower Sunnyside seam) and 1130 feet (Gilson seam). The sandstone roofs both the Lower Sunnyside and Gilson seams, and the sandstone forms the floor of both seams as well. The thickness of the Lower Sunnyside seam was little more than the 4-foot minimum at the site of the measurements.

Megascopic description: Both seams are banded coals. The Lower Sunnyside coal is a banded coal composed of bright clarain, thin vitrain bands, and minor fusain lenses. Durain bands are sparse; three bands of approximately equal thickness occur at different positions within the seam. The Gilson coal is a banded coal composed of semi-dull clarain with one moderately thick rock parting in the upper part of the seam. The duller appearance of the Gilson coal is due to the higher percentage of dull clarain and durain. The results of x-ray diffraction analysis (U.S. Bureau of Mines) conducted on a sample of the parting show granular kaolin-tonstein, probably as a result of air-fall volcanic ash. Further, the coal of the Gilson seam discharges gas when stored in a closed container.

Microscopic description: The Lower Sunnyside seam averages 80.1% vitrinite, 3.9% exinite and 16% inertinite; the Gilson seam averages 74% vitrinite, 4.7% exinite and 21.3% inertinite. Differences exist in the maceral composition, with the Gilson seam having a fairly high inertinite content. Based on the results of reflectance conducted on vitrinite (Ro = 0.60 and Ro = 0.59), both seams are of high volatile bituminous B rank.

Cleat measurements:

Seam: Lower Sunnyside seam - 100 measurements
Gilson seam - 112 measurements

Major cleat direction: *Face:* N. 55 W. - Lower Sunnyside seam
Butt: N. 45 E.
Face: N. 65 W. - Gilson seam
Butt: N. 35 E.
The dip varies between 70-90 degrees.

Cleat description: While the butt cleat in both seams is not clearly discernible, the face cleat is well developed and generally confined to the clarain and vitrain components of the coal. They lack in durain bands and in the rock split. In general, the cleats are narrow (width) and their density is higher in the Gilson seam. Cleat surfaces are either lustrous or striated and calcite coating is more frequent on the butt cleat surfaces.

Cleat filling: Calcite, pyrite

Cleat spacing: 0.25 - 0.50 inches - Lower Sunnyside seam
0.25 inch - Gilson seam

Joint measurements in surface rocks surrounding the mine: 104 measurements

Major joint direction: *Main:* N. 85 W.
Minor: N. 35 E.

Secondary joint direction: N. 45 W. (weak)

Comments: The results of the cleat data from the Lower Sunnyside and Gilson seams show close relation between the face and butt cleats of both seams (figures 22a, 22b and 22c).

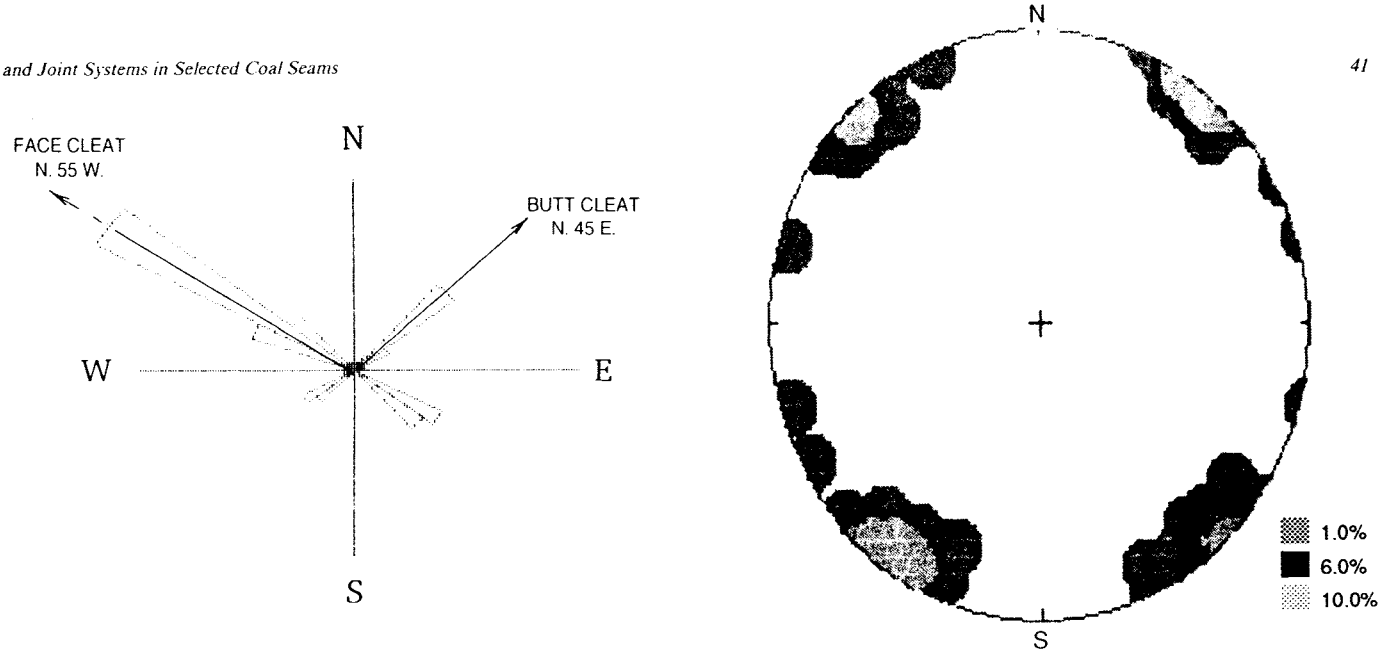


Figure 22a. *Apex mine - Lower Sunnyside seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 100.*

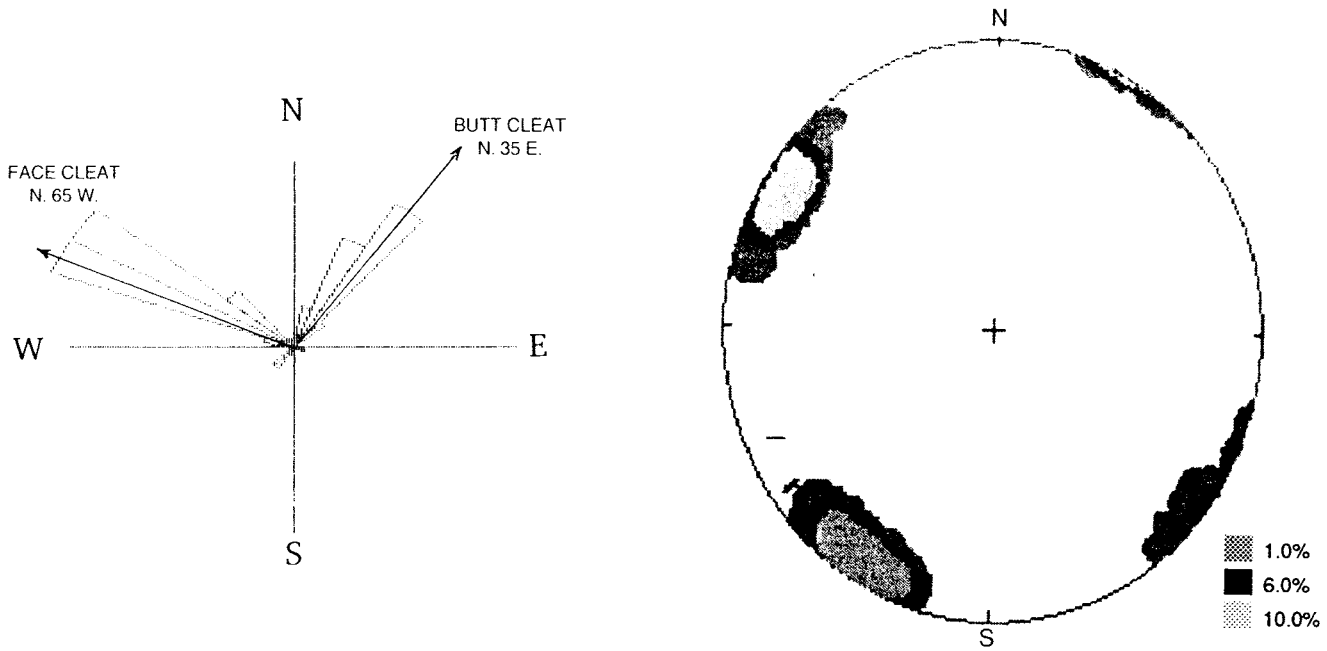


Figure 22b. *Pinnacle mine - Gilson seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 112.*

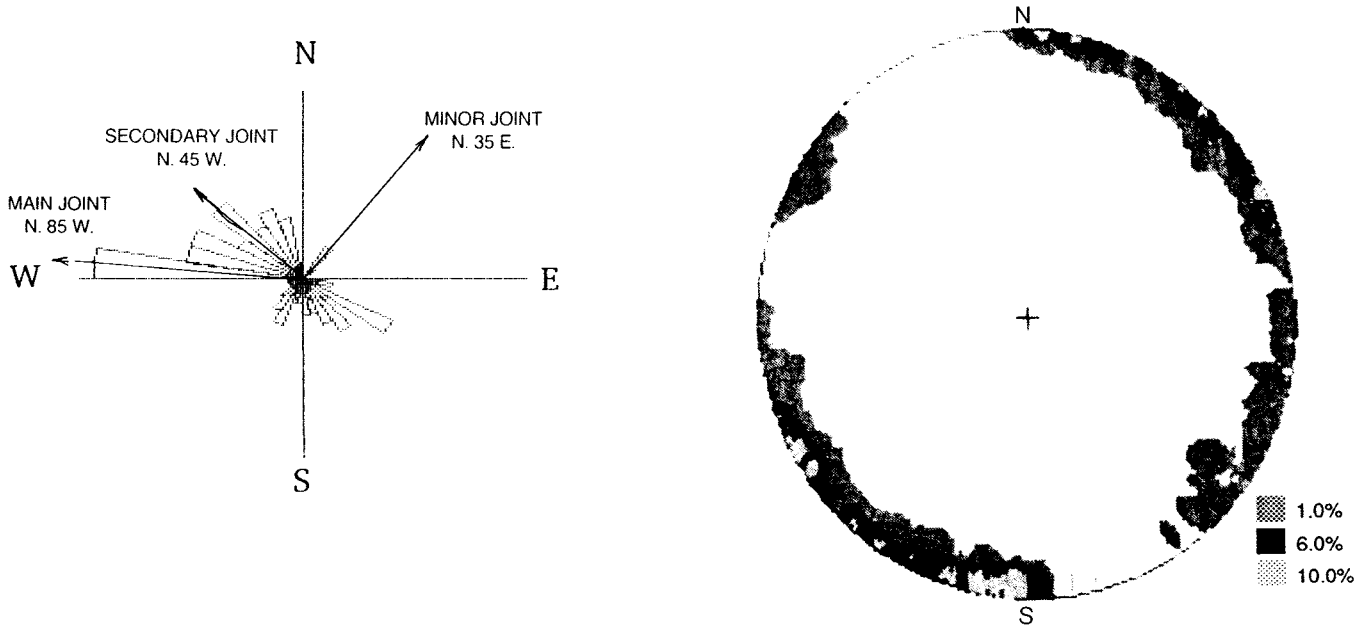


Figure 22c. *Pinnacle and Apex mines - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 104.*

Mine Name: **SOLDIER CANYON**

Owner-Operator: Soldier Creek Coal Company

Location: Soldier Creek Canyon, 30 miles NE from the town of Price, Carbon County. (Portal: Section 18, Township 13 S., Range 12 E.)

Host unit: Upper part of the Blackhawk Formation (Upper Cretaceous) mining the Rock Canyon seam.

Overlying unit: Castlegate Sandstone Member of the Price River Formation (Upper Cretaceous).

Underlying unit: Mancos Shale Formation (Cretaceous).

Coal field: Book Cliffs

Structure:

Attitude: The structure contours follow the trend of the cliff front, west by northwest. The northward-dipping rocks drop 500 feet per mile for an average of about 6-7 degrees (Doelling, 1972, p. 395).

Faulting: Few faults present are only of small displacement.

Seam description:

Seam name: Rock Canyon

Thickness mined: 9.2 feet

Roof: Carbonaceous shale overlain by interbedded sandstone and siltstone

Floor: Carbonaceous shale underlain by interbedded sandstone and siltstone.

Deep cover (0-3500 feet) and splitting of the seams characterize the area. On the measurement site, the overburden attains a thickness of approximately 1500 feet. The Rock Canyon seam splits into two benches called Rock Canyon and Fish Creek within the Soldier Creek Coal Company's leasehold. The stratigraphically higher seam — the Sunnyside seam — splits into Upper Sunnyside and Lower Sunnyside, as well. Further the coal of the Rock Canyon seam is considered as a gassy one.

Megascopic description: The coal is classified as semi-bright clarain consisting of fine-to medium-thick bands of bright and dull clarain alternating with durain bands. Sparsely distributed vitrain bands are present throughout the whole seam. Three rock partings that constitute approximately 0.4% of the total thickness were also present.

Microscopic description: The Rock Canyon seam averages 76% vitrinite, 4% exinite and 20% inertinite. Average vitrinite reflectance is Ro = 0.63, classifying the coal as high volatile bituminous B in rank. The coal is characterized by a uniform maceral composition and a relatively high percentage of inertinite. Inertinites (represented mostly by semifusinite and fusinite) are the predominant macerals in the durain bands.

Cleat measurements:

Seam: Rock Canyon - 49 measurements

Major cleat direction: Face: N. 65 W. *Butt:* N. 25 E.

Cleat description: Both systems of cleats are well developed. Parting between the cleat fractures is very small; as a result, secondary calcite occurs only as a very thin filling or coating on the cleat planes. The surface planes of the cleats are mostly uneven or striated.

Cleat filling: Minor calcite

Cleat spacing: Varies from 1.5-1.7 inch.

Joint measurements in surface rocks surrounding the mine: 101 measurements

Major joint direction: Main: N. 35 W.
Minor: N. 85 W.

Secondary joint direction: Main: N. 25 E.
Minor: not expressed

Joint description: Joint measurements were obtained in two successive beds consisting of gray, fine-grained, laminated, calcareous sandstone and dark gray, calcareous siltstone.

Joint spacing: Average 0.8 inches with more closely spaced joints in the dark gray siltstone.

Comments: Unpublished cleat data gathered by the mining company's personnel (Allen, written communications, 1987) show N-W orientation (N. 67.7 W.) for the cleat and N-E orientation (N. 25.9 E.) for the butt cleat.

Figures 23a and 23b show the results of the cleat and joint investigation.

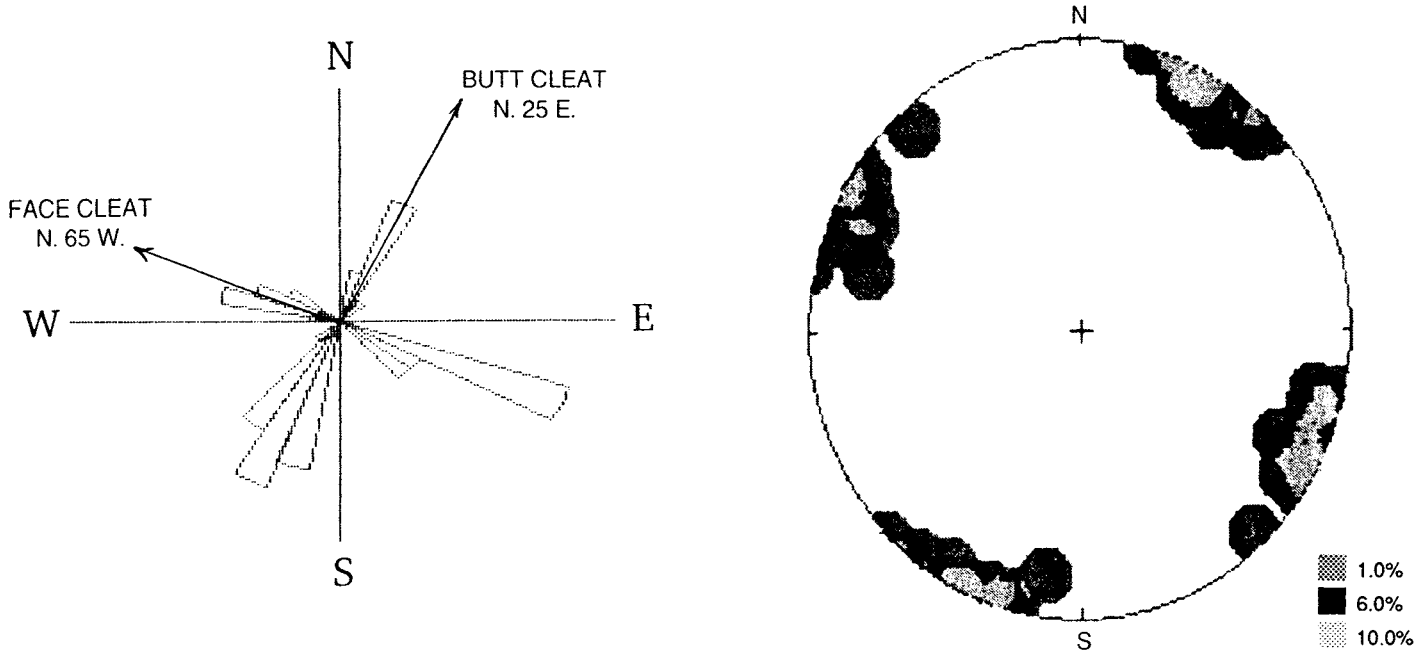


Figure 23a. *Soldier Creek mine - Rock Canyon seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 49.*

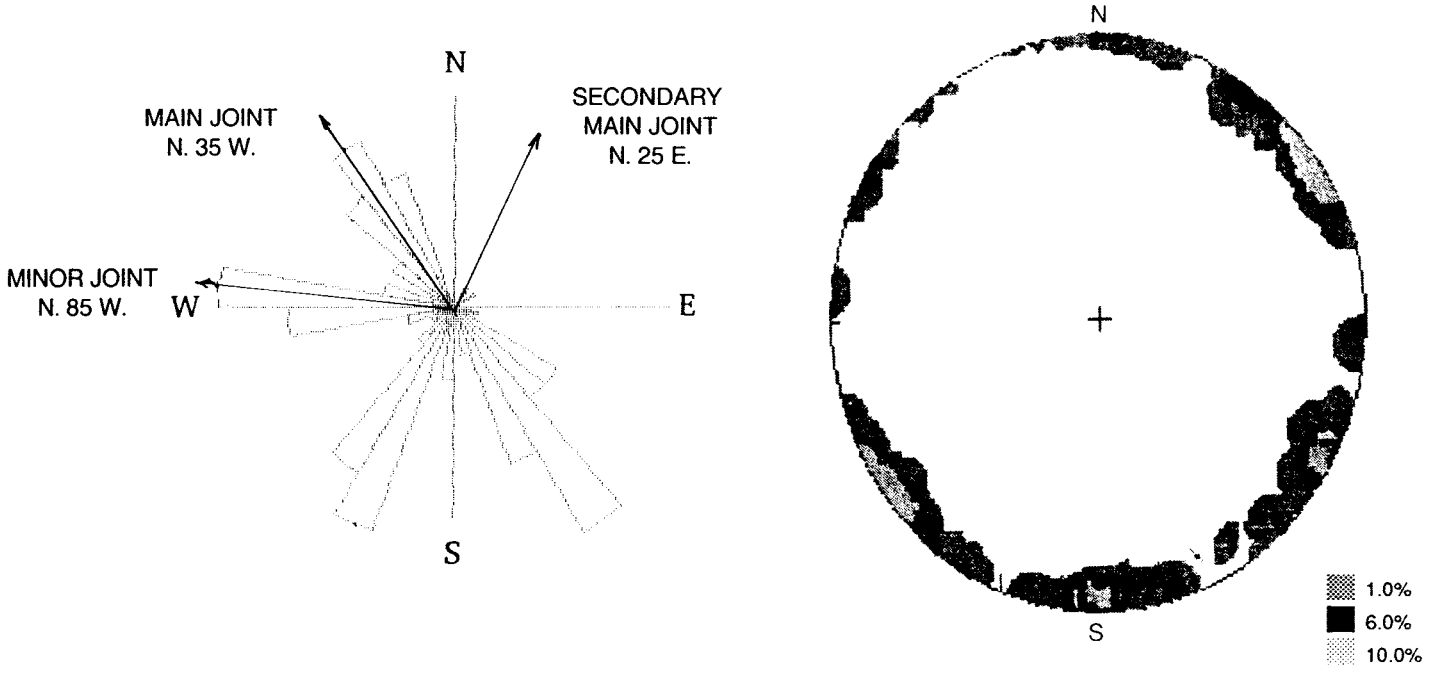


Figure 23b. *Soldier Canyon mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 101.*

Mine Name: **SUNNYSIDE NOS. 1 AND 3**

Owner-Operator: Kaiser Coal Company

Location: Near the mouth of the Whitmore Canyon, 27 miles southeast from the town of Price, Carbon County. (Portals: Section 05, Township 15 S., Range 14 E., and Section 32, Township 14 S., Range 14 E.

Seam(s) mined: Upper Sunnyside - Sunnyside No. 3 mine
Lower Sunnyside - Sunnyside No. 1 mine

Host unit: Upper part of the Blackhawk Formation (Upper Cretaceous).

Overlying unit: Castlegate Sandstone Formation (Upper Cretaceous).

Underlying unit: Thick, massive, cliff-forming sandstones or coarse-grained siltstones. A slope-forming unit of fine-grained siltstones and shales lithologically resembling the Mancos Shale separates these massive layers (Gray and others, 1966, p. 81-86).

Coal field: Book Cliffs

Structure:

Attitude: Strata dip 6-12 degrees eastward and northeastward.

Faulting: A cluster of northwest-trending faults in the Sunnyside area have a maximum displacement of 200 feet; faults are widely spaced and do not seriously affect mining conditions (Doelling, 1972, p. 383).

Seam description:

Seam name: Upper Sunnyside and Lower Sunnyside

Thickness mined: Upper Sunnyside seam - 6.7 feet
Lower Sunnyside seam - 6.0 feet

Roof: Lanminated sandstone - Upper Sunnyside seam
Carbonaceous shale - Lower Sunnyside seam

Floor: Siltstone in both seams

The overburden thickness ranges from 1500-2500 feet. The interburden consists of interbedded sandstone, siltstone, and shale and is approximately 40 feet thick within the Sunnyside mine workings. Occasional mining difficulty related to unstable roof conditions was noticed within the sampling area in the Lower Sunnyside seam. The unstable roof conditions in the Lower Sunnyside seam appear to be related to the character of the strata immediately overlying the coal. The roof stratum is a hard, carbonaceous shale called "caprock." The shale is highly jointed and shows evidence of slickensides. Separation of the coal along the joint planes results in loosening of the coal blocks and increased roof falls. On several occasions large slabs of vertically shattered coal were noticed as well.

Megascopic description: Bright clarain is the dominant lithotype constituent in both seams, interbedded with numerous bright, occasionally thick vitrain bands. Bands occur throughout the seams, though they are more numerous in the upper part of the Upper Sunnyside seam where a band more than 1 foot thick can be observed. Both seams are devoid of any large partings (at the site where measurements were taken). A characteristic feature of Sunnyside coals is their uniformity in lithotype composition, brightness, and semi-coking property. Furthermore, the coal is relatively hard and breaks with a huckly fracture into large lumps.

Microscopic description: The Upper Sunnyside coal averages 84% vitrinite, 3.2% exinite and 12.8% inertinite, the Lower Sunnyside 86% vitrinite, 3% exinite and 11% inertinite, respectively. The coal from both seams shows remarkable similarity in the maceral composition and is characterized by high percentage of pseudo-vitrinite (between 13-20% of the total vitrinite). The average reflectance for the Upper Sunnyside seam is Ro = 0.69 and for the Lower Sunnyside seam Ro = 0.72, classifying the two seams as high volatile bituminous B and A in rank.

Cleat measurements:

Seam: Upper Sunnyside - 109 measurements
Lower Sunnyside - 100 measurements

Major cleat direction: *Face:* N. 65 W. - Upper Sunnyside seam
Butt: N. 35 E.
Face: N. 75 W. - Lower Sunnyside seam
Butt: N. 05 W.

Secondary cleat direction: *Face:* N. 65 E. - Upper Sunnyside seam
Butt: N. 45 W.

Cleat description: Three types of cleats were distinguished in the Sunnyside seams:

Cleats striking N. 35 E. in the Upper Sunnyside seam traverse the entire thickness of the seam, sometimes penetrating into the roof rocks and showing presence of bending. They are characterized by large surface planes and smooth, even or brilliantly polished surfaces with traces of slickensides. Their orientation lack consistency and their spacing is variable, ranging from a few inches to several feet;

Cleats with striated and lustrous surfaces are confined to the bright components of the coal. They are densely distributed, causing the coal to break into small lenses (scaly appearance). In the upper part of the Lower Sunnyside seam, the cleats are entirely coated with calcite, giving the coal a white appearance. The surfaces of the most prominent cleats are uneven and they display a regular distribution.

Overall, the cleats show greater variation in orientations than in most coals under study. In the Upper Sunnyside the cleats are well developed and show considerably stronger development than those in the Lower Sunnyside seam. Traces of slickensides were observed in both the coal and roof strata.

Cleat filling: Calcite, resin

Cleat spacing: From a few inches to several feet for cleats striking N. 45 W. and N. 35 E.; 0.25 inch for cleats with striated and lustrous surfaces, and 0.5-1 inch for the most prominent cleats.

Joint measurements in surface rocks surrounding the mine: 100 measurements

Major joint direction: *Main:* N. 75 W.
Minor: N. 15 W.

Secondary joint direction: *Main:* N. 05 E.
Minor: not represented in the measurements

Comments: The quantitative analyses of the cleat data show little agreement in the orientation of the cleat systems in above-mentioned seams. Evaluation of the data from the Upper Sunnyside seam points to bimodal face and butt cleat distributions. The results of the analytical data are shown in figures 24a, 24b and 24c.

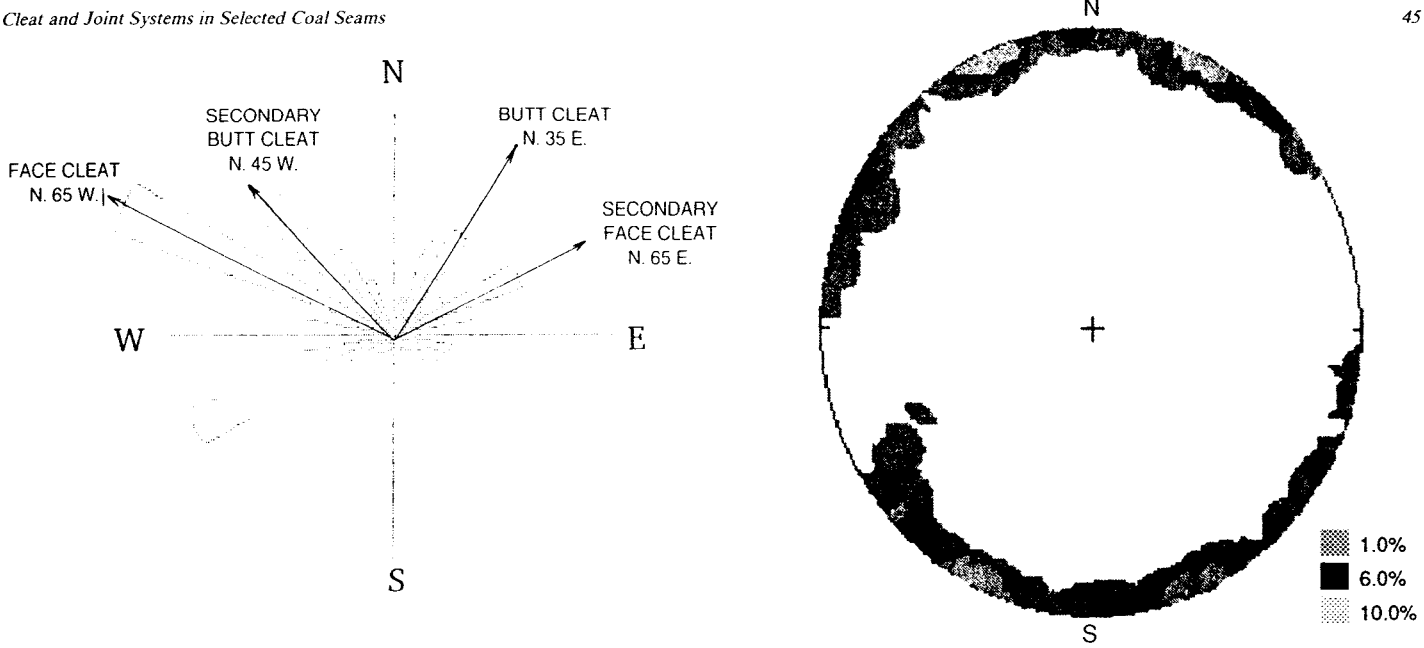


Figure 24a. *Sunnyside No. 3 mine - Upper Sunnyside seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 109.*

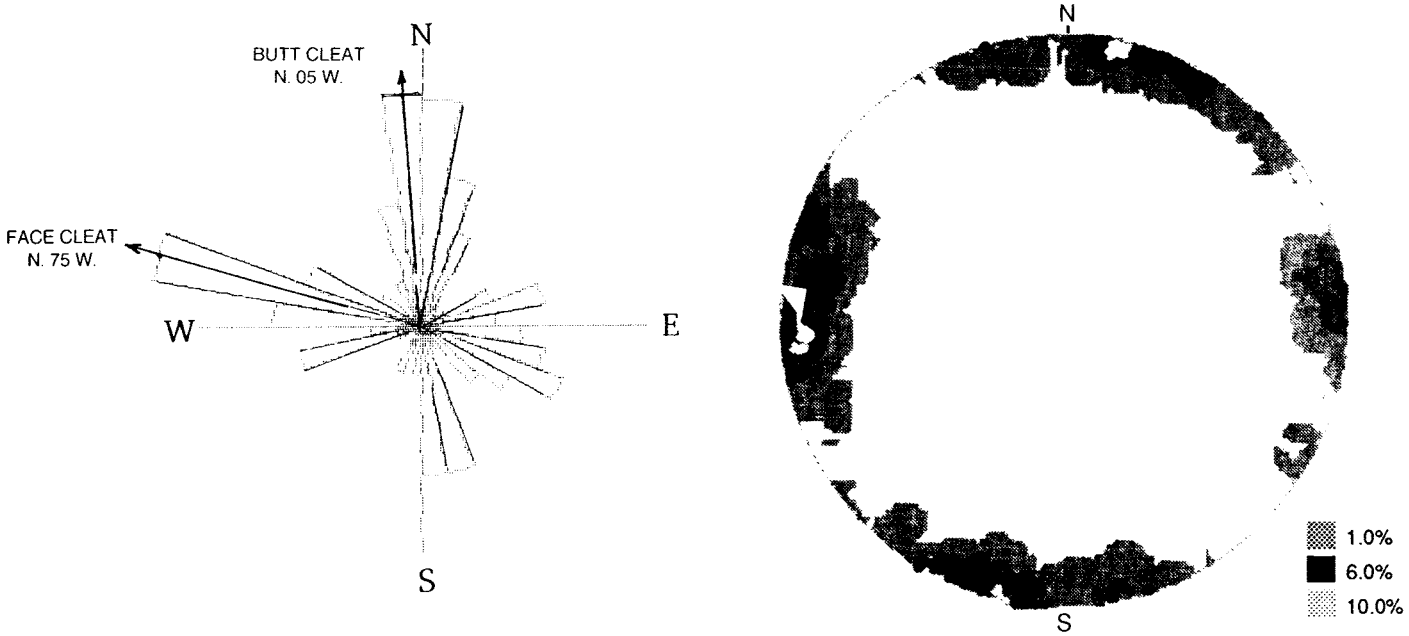


Figure 24b. *Sunnyside No. 1 mine - Lower Sunnyside seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 100.*

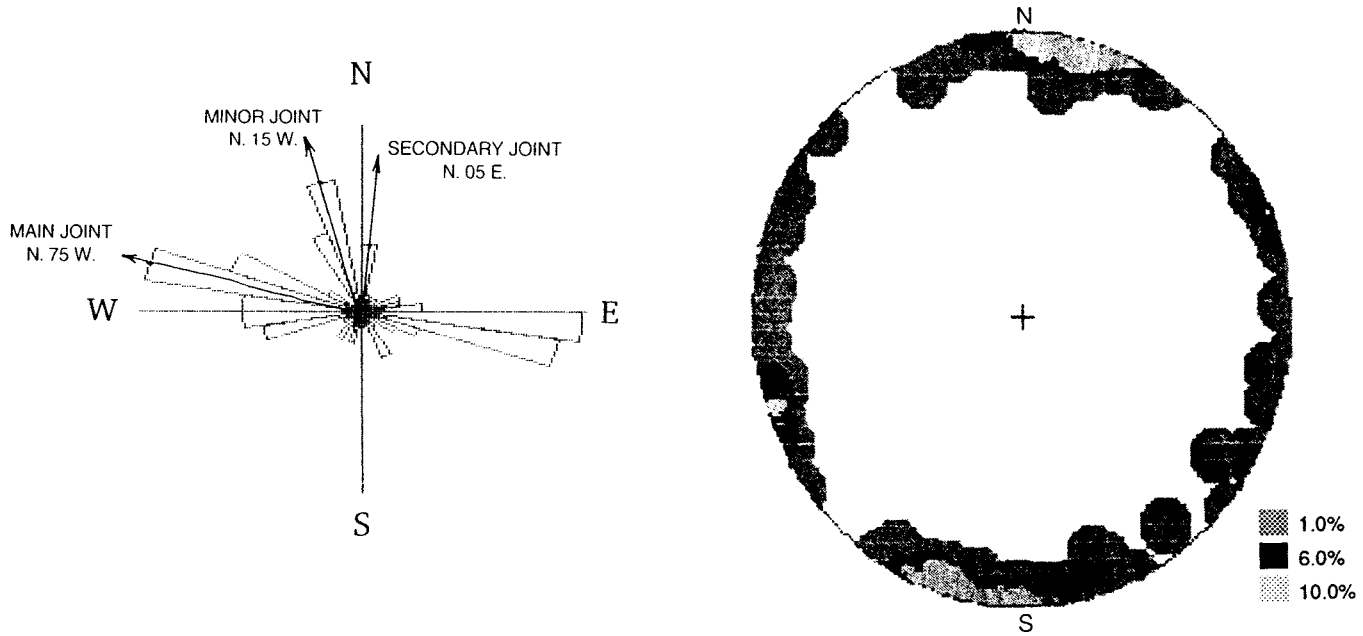


Figure 24c. *Sunnyside Nos. 1 and 3 mines - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 100.*

Mine Name: **BOYER**

Owner-Operator: Summit Coal Company

Location: About one mile from the town of Upton, Summit County, and approximately 40 miles from Salt Lake City, Utah. (Portal: Section 36, Township 3 N., Range 06 E.).

Seam mined: Wasatch

Host unit: Upper part of the Coalville Member of the Frontier Formation (Upper Cretaceous).

Overlying unit: Allan Hollow Shale of the Frontier Formation (Upper Cretaceous).

Underlying unit: Chalk Creek Member of the Frontier Formation (Upper Cretaceous).

Coal field: Coalville

Structure:

Attitude: The strata distributed around the Coalville anticline are moderately to steeply dipping (10 degrees to vertical).

Faulting: Faulted Coalville anticline (Doelling and Graham, 1972, p. 327).

Seam description:

Seam Name: Wasatch

Thickness: 8-12 feet (Wegemann, 1915)

Thickness mined: 6.7 feet

Roof: Root-penetrated carbonaceous shale

Floor: Mudstone.

The overburden thickness attains 300 feet where measurements were taken. The seam has relatively high dip (17%). Floor conditions are inferior due to the wet, soft floor rocks.

Megascopic description: The coal is classified as dull clarain. A moderately thick durain band and rock parting are present in the upper part of the seam. Towards the base the coal becomes friable and impure (clayey). Macroscopically, the coal has a dense appearance and disintegrates when exposed to air (high moisture content).

Microscopic description: The Wasatch coal seam averages 82.3% vitrinite, 4.0% exinite, and 13.7% inertinite. Average reflectance of Ro = 0.40 classifies the coal as subbituminous in rank.

Cleat measurements:

Seam: Wasatch - 109 measurements

Major cleat direction: *Face:* N. 75 E. *Butt:* N. 25 W.
Average dip is 84 degrees.

Cleat description: Both systems of cleats are very well developed with regular distribution. The plane surfaces of the cleats are mostly clean, and cleat filling or coating is rare. A few pyrite grains can be seen on the plane surfaces of cleats. The surfaces of the face cleats are smooth, dull and almost perpendicular to the bedding planes. The surfaces of the butt cleats are uneven or occasionally conchoidal along the end planes.

Cleat filling: Minor pyrite

Cleat spacing: 0.25 to 1 inch

Joint measurements in surface rocks surrounding the mine: 61 measurements

Major joint direction: *Main:* N. 65 E. *Minor:* N. 15 W.

Joint description: The minor set of cleats is not well expressed in the measurements.

Comments: From the obtained results, a certain degree of parallelism can be seen between the face and butt cleats in the coal and the main and minor joints in the outcrop rocks.

Graphic representation of the cleat and joint data are summarized in figures 25a and 25b.

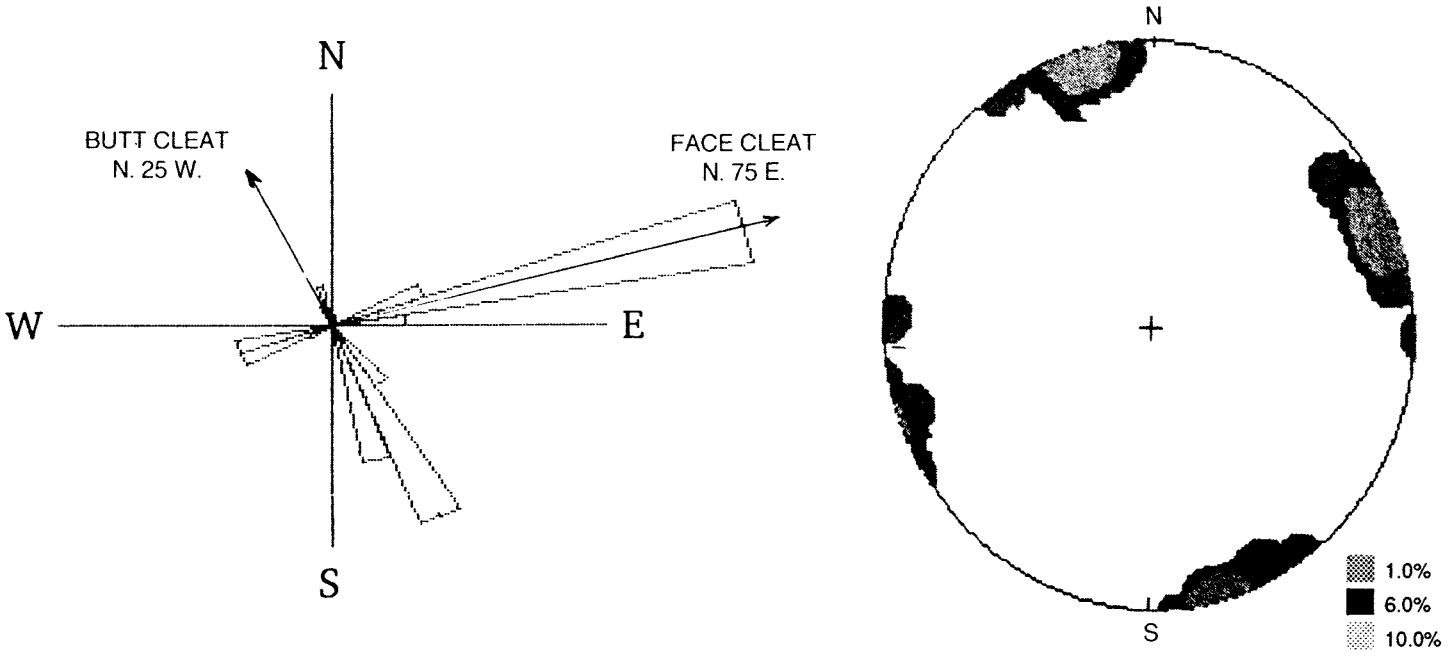


Figure 25a. *Boyer mine - Wasatch seam - rose diagram of face and butt cleats, and lower hemisphere equal-area stereonet diagram; n = 109.*

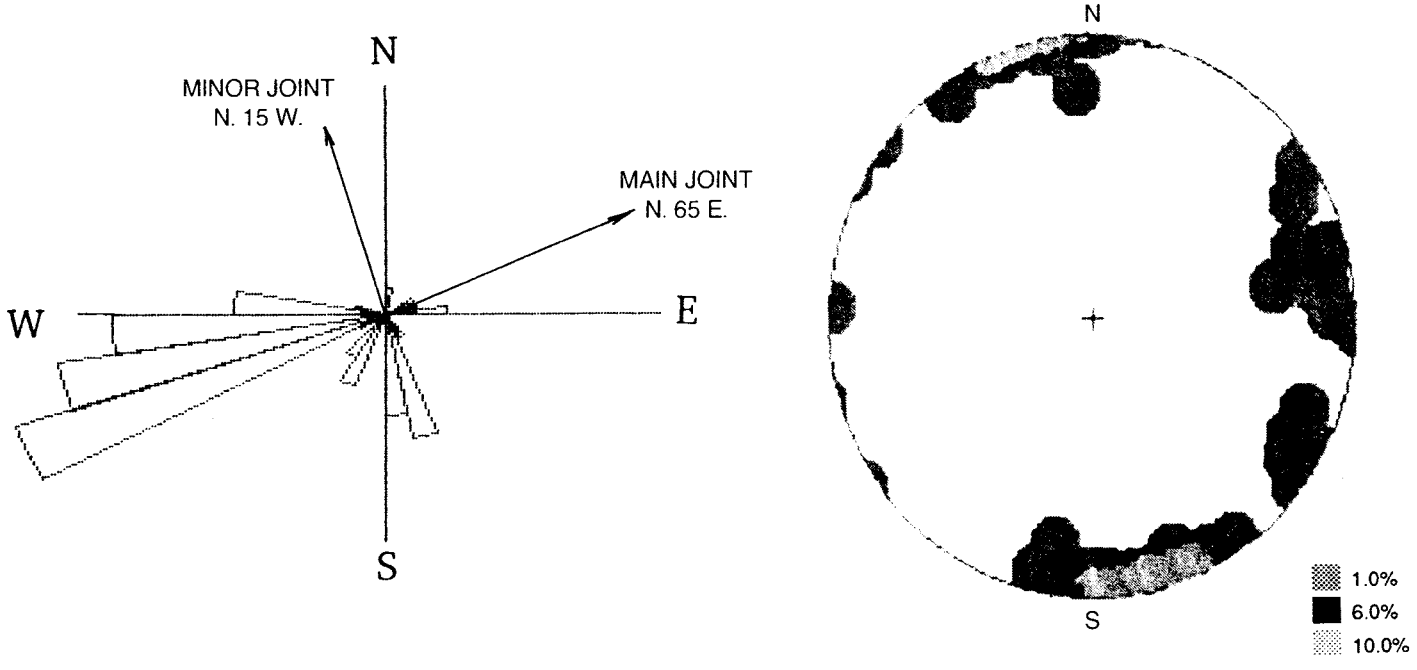
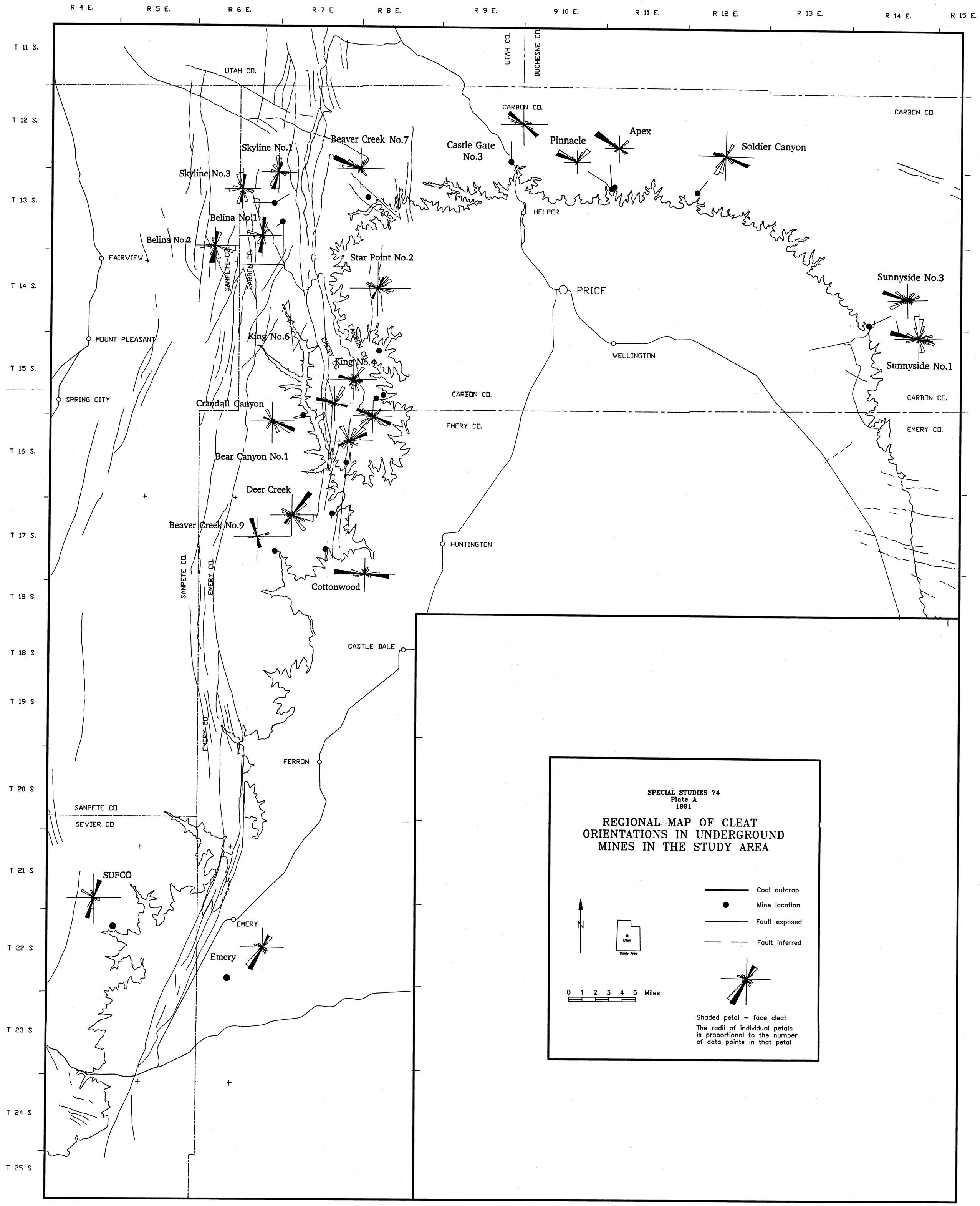
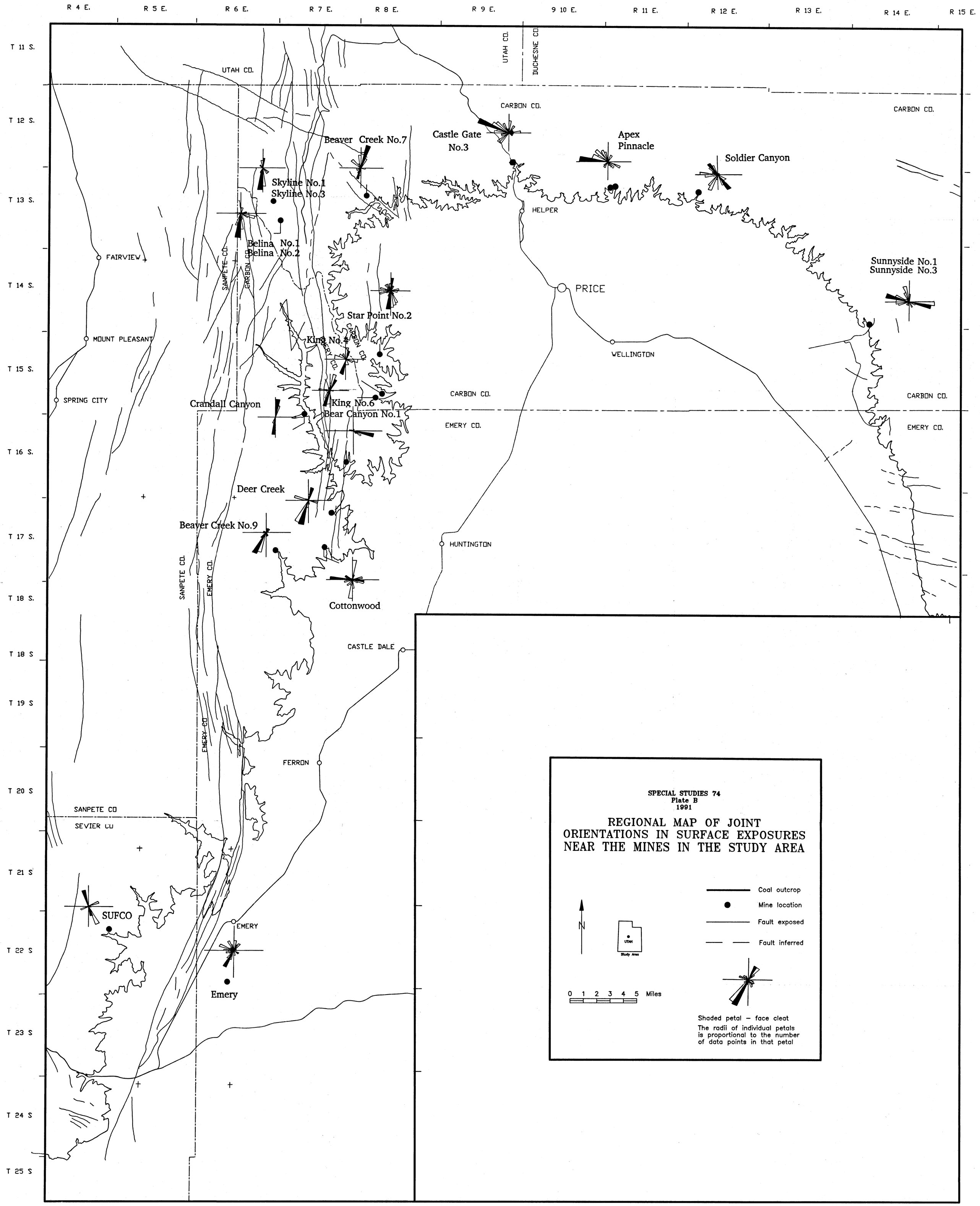


Figure 25b. *Boyer mine - rose diagram of surface joints, and lower hemisphere equal-area stereonet diagram; n = 61.*


R 4 E.
R 5 E.
R 6 E.
R 7 E.
R 8 E.
R 9 E.
9 10 E.
R 11 E.
R 12 E.
R 13 E.
R 14 E.
R 15 E.
T 11 S.
T 12 S.
T 13 S.
T 14 S.
T 15 S.
T 16 S.
T 17 S.
T 18 S.
T 18 S
T 19 S
T 20 S
T 21 S
T 22 S
T 23 S
T 24 S
T 25 S
UTAH CO.
DUCHESNE CO.
CARBON CO.
EMERY CO.
SANPETE CO.
SEVIER CO
HELPER
PRICE
WELLINGTON
FAIRVIEW
MOUNT PLEASANT
SPRING CITY
HUNTINGTON
CASTLE DALE
FERRON
EMERY
Skyline No.1
Skyline No.3
Beaver Creek No.7
Castle Gate No.3
Pinnacle
Apex
Soldier Canyon
Belina No.1
Belina No.2
Star Point No.2
Sunnyside No.3
Sunnyside No.1
King No.6
King No.4
Crandall Canyon
Bear Canyon No.1
Deer Creek
Beaver Creek No.9
Cottonwood
SUFCO
Emery
SPECIAL STUDIES 74
Plate A
1991
REGIONAL MAP OF CLEAT ORIENTATIONS IN UNDERGROUND MINES IN THE STUDY AREA
N
UTAH
Study Area
0 1 2 3 4 5 Miles
Coal outcrop
Mine location
Fault exposed
Fault inferred
Shaded petal – face cleat
The radii of individual petals is proportional to the number of data points in that petal


R 4 E.
R 5 E.
R 6 E.
R 7 E.
R 8 E.
R 9 E.
9 10 E.
R 11 E.
R 12 E.
R 13 E.
R 14 E.
R 15 E.
T 11 S.
T 12 S.
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T 24 S
T 25 S
UTAH CO.
DUCHESNE CO.
CARBON CO.
EMERY CO.
SANPETE CO.
SEVIER CO
Castle Gate No.3
Apex Pinnacle
Soldier Canyon
Beaver Creek No.7
Skyline No.1
Skyline No.3
Belina No.1
Belina No.2
Sunnyside No.1
Sunnyside No.3
Star Point No.2
King No.4
King No.6
Bear Canyon No.1
Crandall Canyon
Deer Creek
Beaver Creek No.9
Cottonwood
SUFCO
Emery
HELPER
PRICE
WELLINGTON
HUNTINGTON
CASTLE DALE
FERRON
EMERY
FAIRVIEW
MOUNT PLEASANT
SPRING CITY
SPECIAL STUDIES 74
Plate B
1991
REGIONAL MAP OF JOINT ORIENTATIONS IN SURFACE EXPOSURES NEAR THE MINES IN THE STUDY AREA
N
UTAH
Study Area
0 1 2 3 4 5 Miles
Coal outcrop
Mine location
Fault exposed
Fault inferred
Shaded petal – face cleat
The radii of individual petals is proportional to the number of data points in that petal