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Cleat Data for Coal Beds in the Southern Piceance Basin, Northwestern Colorado

by

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CONTENTS

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ABSTRACT

Data on field-observed characteristics of cleats (joints) in Upper Cretaceous coal beds and lenses in the southern Piceance basin, Colorado, are presented in this report. Included also are some data from coaly stringers in overlying strata of Paleocene and Eocene age. These data form part of a larger study, involving more than 900 localities, of the fracture history of the Piceance basin and surrounding uplifts. The data for 18 coal-measurement localities are presented in tabular form in the appendix; included is much information on the multiple physical and spatial characteristics of cleats that collectively permitted grouping the cleats into genetic sets for purposes of reconstructing the fracture history of the coal beds within the context of the already interpreted regional fracture history of the enclosing rocks.

INTRODUCTION

The Piceance basin is a late Laramide (Late Cretaceous to Eocene) structural and depositional feature (Tweto, 1975, 1980) on the northeastern part of the Colorado Plateau (fig. 1) which contains economically important reservoirs of methane gas (Choate and others, 1984; McFall and others, 1986; ICF Resources, Inc., 1989). Large undeveloped resources of natural gas reside in coal beds and tight sandstone reservoirs of Cretaceous age (Johnson and Rice, 1990). Most of the production has come from rocks of the lower part of the Upper Cretaceous Mesaverde Group, at depths of approximately 760-2280 m, where the methane is contained both in coal beds and in interbeds of sandstone, mudstone, and shale (Dunn, 1974; Donaldson and MacMillan, 1980).

Methane gas generally resides in the matrix of coal beds and, to a lesser extent, in their fractures (McFall and others, 1986), called cleats. Cleats generally are defined as the system of joints (generally two sets) that result from the fracturing of coal beds; a major (face cleat) and a minor (end or butt cleat) set commonly develop perpendicular to each other (Bates and Jackson, 1980) and to bedding.

In the southern Piceance basin, cleats are present in Mesaverde Group coal beds and in coaly stringers of the Paleocene and Eocene Wasatch Formation. These cleats can be correlated by their relative age, orientation, and style with joint sets in the enclosing host rocks. The same techniques that were used to interpret the fracture history of host rocks in the Piceance basin (Grout and Verbeek, 1983) were also used to decipher the fracture history of the interbedded coal layers and lenses (Grout, in press). The data evaluated in Grout (in press) are reported here in detail (see appendix). The terminology used in the appendix is described in a following section.

CLEAT STUDIES IN THE PICEANCE BASIN

Most cleat studies in the Piceance basin have focused on cleat orientations. The orientations of cleats in coal beds of the Mesaverde Group along the rim of the southern Piceance basin were discussed by Geological Services of Tulsa, Inc. (1980) and Boreck and Strever (1980). Cleat orientations in cores from correlative strata at the Gas Research Institute's Red Mountain Site in the west-central part of the basin (fig. 1) were reported in Seccombe and Decker (1986) and Horner (1986). Lorenz and Hill (1991) mentioned that numerous coal cleats occur in core at the Department of Energy's Slant Hole Completion Test Well (SCHT-1) in the vicinity of their Multiwell Experiment (MWX) Site (fig. 1), east central Piceance basin. Open cleats were found in coal beds at depths of 2275 m and 2305 m; the face cleats are oriented northwest and west-northwest, respectively.

The fracture study by the U.S. Geological Survey has involved the collection of fracture data from more than 900 outcrops and man-made cuts in the Piceance basin and surrounding uplifts, in strata that range in age from

Precambrian through Quaternary. Of these, about 750 stations are in the Upper Cretaceous through Eocene rocks of the Mesaverde Group and overlying Wasatch, Green River, and Uinta Formations. The coal-cleat data in this report are part of that study. Other reports resulting from the USGS basinwide fracture study include those of Grout and Verbeek (1983, 1985, and in press), and Verbeek and Grout (1983, 1984a, b, 1986, 1987). The tectonic history of the eastern part of the basin is related to thrusting along the eastern basin margin, which is part of the Laramide orogenic boundary between the Colorado Plateau and the Rocky Mountain foreland (Grout and others, 1991).

FRACTURE STATIONS IN THE STUDY AREA

This report contains data on field-observed characteristics of coal cleats studied at 18 localities (stations) in Mesaverde and Wasatch rocks in the southern Piceance basin (fig. 1). With the exception of three stations, all are located in the Upper Cretaceous Mesaverde Group that crops out along the southern rim of the basin and along the Grand Hogback monocline, the eastern margin of the basin. The three remaining stations are in the Paleocene and Eocene Wasatch Formation on the Divide Creek anticline. The data from all of the stations are tabulated in the appendix and augment a report by Grout (in press) on the history of coal-cleat formation in the southern Piceance basin. The data presented in this report are also referred to in two other reports: (1) Grout and Verbeek (in press), an interpretation of the fracture history of rocks of the Divide Creek and Wolf Creek anticlines, including coaly stringers of the Wasatch Formation, in relation to tectonic development of the eastern margin of the basin; and (2) Grout and Verbeek (1985), a summary and interpretation of the fracture history of Upper Cretaceous and Tertiary strata in the Plateau Creek and Colorado River area, western Piceance basin, which includes the Red Mountain site.

FRACTURE TERMINOLOGY

In this report, fracture is used as a general term to denote all internal rock surfaces across which cohesion has been lost through mechanical failure induced by differential stress. Fractures along which appreciable shear displacement has occurred--from a few centimeters to kilometers (Bates and Jackson, 1980)--are termed faults, whereas fractures associated with amounts of movement greater than a few centimeters normal to the fracture walls are best termed fissures, in keeping with common English usage. All other fractures--those associated with little or no displacement in any direction--are termed joints or, if in coal beds, cleats.

The various terms as defined above are nongenetic and imply nothing about mechanisms of fracture. A fault, for example, is not synonymous with a shear fracture, nor a joint with an extension fracture, though the mistake commonly is made. Although many faults in the Piceance basin can be shown to have originated as shear fractures, others are extension fractures that were reactivated in shear. Both types of structure conform to historic definitions of "fault" (see Dennis, 1967). Similarly, joints apparently can initiate either as extension or shear fractures but are termed joints in either case if the net offset is very small. Fault, joint, and fissure, then, are field terms whose usage, as established through long precedent, is based on observed amounts and senses of offset. Shear fracture, extension fracture, and related expressions are rock-mechanical terms that denote genetic types of fractures formed through specific mechanisms of failure. Where the mode of failure of a particular fracture has been determined, an appropriate modifier conveys that fact, as in <u>extension</u> joint.

Of the various types of fracture mentioned above, extension joints are by far the most plentiful in the Piceance basin. Most occur in <u>sets</u>, a term used to denote groups of parallel to subparallel joints (Dennis, 1967) whose common orientation generally (though not necessarily) reflects a common genesis. Two to four sets of joints cut most outcrops in the southern Piceance basin and collectively define the joint or fracture <u>system</u> of the area.

FRACTURE NOTATION

Sets of joints have been given the designation F_X or MV_X to agree with the notation established earlier for the northern and central parts of the basin (Verbeek and Grout, 1983, 1984a). F_x refers to all joints that formed during the x^{th} period of fracture in the basin, from F_1 (oldest) to F_5 (youngest), including coal cleats in the southern Piceance basin (Grout, in press). These sets, which are referred to as the <u>Piceance system</u> of fractures, are in basin and pre-basin rocks as old as Late Cretaceous. Older sets of joints, collectively termed the <u>Hogback system</u>, have been found only in pre-basin rocks ranging in age from Mississippian through Paleocene along the Grand Hogback monocline (Verbeek and Grout, 1984a, b). Because these older joint sets are found mostly in strata of the Mesaverde Group, they are designated as the MV_x sets. In addition to these regional sets are local joints related to basin-margin thrusting and associated intrabasin folding. These joints, older than those of the Piceance system but younger than the Hogback system, are restricted to the area of the Divide Creek, Wolf Creek, and Coal Basin anticlines (fig. 1). They strike about parallel to the fold axes and for that reason are designated FP (fold-parallel).

One additional feature of the fracture notation deserves mention here, which is best illustrated by the treatment of F_1 joints. In many outcrops, F_1 fractures are nearly vertical in well-cemented beds but are inclined at 60°-70° in associated, more weakly cemented beds. In these weakly cemented beds the F_1 joints form not one but two sets of inclined fractures that have similar strikes but opposing dips, thereby dividing the rock into diamond-shaped blocks. Abutting relations and the mineralization history of these fractures suggest that they are at least roughly contemporaneous and thus formed during the same (F_1) period of fracture in the basin. To convey these relations, we refer to the two sets of moderately steeply dipping fractures as F_{1A} and F_{1B}, and to the vertical fractures as F_{1C}. In many outcrops the distinction between the three sets is clear and the orientation data do not overlap, but in some areas the sets appear to be gradational and they are simply called F_1. A similar notation is employed where appropriate for other periods of fracture, particularly those formed during basin-margin thrusting (FP sets). The origin of related fracture subsets is to some extent problematical (see, for example, Verbeek and Grout, 1983; Grout and Verbeek, in press).

FIELD METHODS

Joints in the southern Piceance basin have been grouped into genetic sets, not simply into geometric sets based on orientation. The difference is fundamental to accurate interpretations of fracture history. Although geometric and genetic sets commonly are equivalent, exceptions are known. The F_2 and F_5 sets in the basin, for example, have nearly identical orientations but differ markedly in all other observed characteristics, such as size, shape, age relative to other fractures, and mineralization history. In this case a single geometric set is the combined expression of two discrete periods of fracture widely separated in time. All fracture data presented in this report are grouped into <u>genetic</u> sets.

Field methods used for collecting fracture data in the Piceance basin are described in Grout and Verbeek (1983). At each locality, and within all beds studied, only the largest and most planar joints of each set were selected for orientation measurements, as it is these that most accurately reflect ambient paleostress orientations as they existed immediately prior to fracture; the later members of each set, which tend to be both more irregular and shorter than those formed earlier, formed in increasingly anisotropic rock and thus may reflect local, discontinuity-related stress perturbations to a greater degree than their predecessors. For fracture properties other than orientation, however, all fractures present were studied to document the characteristics of each set as a whole. For any station where the bedding dip exceeds about 6° and evidence exists that the fractures predate the bed rotation, the fracture planes were stereographically rotated about the bedding strike to reconstruct their original pre-tilt orientations.

The manner in which fractures of coexisting sets terminate is the prime information from which the relative ages of the sets can be determined. Fractures of the earliest set commonly die out laterally as tapering hairline cracks because no earlier fractures existed to impede lateral growth. Fractures of successively younger sets, if they are extension joints as in the study area, abut all older fractures unless those older fractures have been healed through mineralization. Younger extension joints, then, either terminate against or cut across older ones, depending on the degree of cohesion between the walls of each older joint. Conversely, younger shear fractures generally cut across and offset older fractures; and for these, the conventional rules for determining relative ages of intersecting faults apply. Fuller discussions of relative-age criteria are found in Kulander and others (1979) and Grout and Verbeek (1983).

The mode of failure—by extension or shear—is most directly and rigorously determined through observation of the detailed structure of the fracture surface. Kulander and others (1979) summarized much of the available data on this topic, known as fractography. Surface structures such as twist-hackle fringes, plumose structure, and arrest lines are common among fractures in the study area and are diagnostic of failure in extension. In contrast, slickenside striations—either as true scratches on the fracture surface or as fibrous mineral coatings—indicate slip parallel to the striation direction. Such slip, however, must not be taken as proof of a shear mechanism of failure. More commonly the shear is secondary and indicates renewed movement along an original extension fracture.

Fracture-surface structures also indicate the direction that the fracture propagated. In the southern Piceance basin, the fractures in all of the sets propagated laterally, parallel to bedding, while maintaining a vertical to moderately steeply dipping profile.

DATA-SHEET TERMINOLOGY

The data sheets in the appendix summarize the characteristics of each joint set measured in the field. The terminology on the data sheets is explained below.

Station Number—An identification number given to each station where data were collected, keyed to the map of the study area (fig. 1). Identification numbers such as 818U and 818L refer to separate data sets gathered in the upper and lower parts of a thick coal bed, respectively. All fracture stations in the Piceance basin and adjacent uplifts are numbered in the order in which they were studied. Fracture stations in coal layers include only 18 of the more than 900 stations studied, in part because the coal is exposed only around the southern rim of the basin, but also because the coal that is exposed generally is highly weathered and mostly covered.

Quadrangle—Name of 7.5' topographic quadrangle on which the station is located.

Twp, Range, Section—Shorthand notation is used in the data tables to indicate station location. For example, T9S, R90W, NW1/4 sec. 1 = Township 9 South, Range 90 West, northwest quarter of section 1.

Exposure Description—Includes information on exposure elevation, aspect, size, topography, location relative to nearby physiographic and cultural features, and exposed rock types. Abbreviations used: Elev. = elevation, Hwy = highway, Rd = road, FS = Forest Service.

Stratigraphic Unit—Formal map name of rock group, formation, or member (Tweto and others, 1978) where data were collected.

Lithology (General)—General rock type(s) of the specific bed(s) within which the majority of data were collected, including obvious facies changes. The field rank or grade of the coal is indicated by inspection and from Johnson (1983). The following terms describe specific aspects of the lithology:

> **Cement**—Brief description of nature of cement and estimated degree of induration of rock, based on field inspection with hand lens and HCl acid. Not used for coal.
> **Color, fresh**—Informal field color of a freshly broken, dry piece of rock. Not used for coal.

Color, weathered—Informal field color of the outer, weathered surface of naturally exposed rock. Not used for coal.
Grain size, sorting, and roundness—Grain characteristics as observed with a hand lens in the field. Not used for coal.

Bed orientation and thickness—The average orientation of the strata at each exposure (n = number of measurements) and the thickness(es) of the bed(s) studied. SO readings beneath the equal-area plots indicate the orientation of bedding where the beds are conspicuously tilted; elsewhere, where beds dip less than about 5°, measurements were made but bedding is described simply as subhorizontal.

F_X (MV_X)—Fracture set number designation. The following information applies to each fracture set:

Orientation—The average orientation of the fractures measured in each set as estimated visually from Schmidt equal-area plots of the poles to their planes. The number of joints measured in each set (n) is indicated also. (Note that if there are very few data points for a given set, the average should not be considered meaningful.) For stations where the poles to joints in dipping beds have been rotated to reconstruct their original, bed-horizontal orientations, the rotated average is indicated by (R). However, the actual (unrotated) data are listed for each station entry and are displayed on the accompanying lower-hemisphere equal-area plots.

Spacing—The perpendicular distance between adjacent fractures of the same set within the measured bed(s). The data may be given as any one or a combination of several measures of spacing: total range (tr) refers to the observed maximum and minimum spacings, common range (cr) to the most frequently observed spacings, and (avg) to the mean spacing. Spacings of fractures in some beds define such broad, skewed, and irregular distributions that the concept of an average spacing has little merit, and the total range (tr) gives little clue as to what constitutes "normal" or "common" values. For such beds the common range (cr) is the most informative measure of spacing, though it corresponds to no rigorously defined statistic. The data in any case should be viewed as only semiquantitative: they are meant to convey an informal impression of fracture abundance as based on a limited number of measurements, and are not intended as accurate measures of the shapes of the actual frequency distributions of spacings.

Height—The dimension of a fracture as measured perpendicular to its length (see below) and within the plane of the fracture. Where only partial heights were observable the symbol > is used. The data may also be given as any one or a combination of several measures of height: (tr) refers to the observed maximum and minimum heights, (cr) to the most frequently observed heights, and (avg) to the mean height.

Length—The dimension of a fracture as measured parallel to bedding. Where only partial lengths were observable the symbol > is used. The data may also be given as any one or a combination of several measures of length: (tr) refers to the observed maximum and minimum lengths, (cr) to the most frequently observed lengths, and (avg) to the mean length.

Structures—Structures on the walls of fractures can be grouped into two general types: (1) those that resulted from the progressive advance of an extension-joint front through previously intact rock, such as the joint origin, plumose structures (or plumes), arrest lines, and twist-hackle faces and associated steps (collectively termed twist hackle or twist-hackle fringe); and (2) those that indicate slip between the fracture walls, such as slickenlines scratched on the rock surface, or fibrous to platy or columnar mineral coatings and fillings. Structures of both groups locally are seen in combination, as where an extension joint later has been reactivated in shear.

Shape—The overall configuration of the fracture surface, regardless of its size. Three general categories are recognized: planar, subplanar, and nonplanar. Also included are comments on additional shape characteristics, such as sinuosity along strike, hooking into adjacent fractures, deviation in dip in different beds, and the splitting of fractures into separate segments along lithologic discontinuities.

Termination—The manner in which the individual fractures of a given set terminate within the rock. Common types include gradual tapering of hairline cracks to zero aperture, lateral terminations against other fractures, and vertical terminations against lithologic discontinuities (bedding) or bed-parallel partings. From such information the order in which the various sets formed can be determined.

Mineralization—A brief description of the identity and character of various minerals, if any, that fill or coat the fractures of each set.

Remarks—A brief summary of the most diagnostic characteristics of each fracture set plus additional information unsuitable for list format.

Geologist(s)—The personnel responsible for data collection in the field, listed for each station in order of responsibility. MAG, Marilyn A. Grout; ERV, Earl R. Verbeek; HDN, H.D. Nowak; DBY, Douglas B. Yager; CWJ, Caren W. Johannes; EJM, Edward J. McKay; REM, Ruth E. M'Gonigle.

Data Date—Date(s) of visitation to exposure for data collection.

EXPLANATION OF DATA FORMAT

The fracture data in the appendix are listed in tabular format, from oldest to youngest set, for each coal-cleat station in the southern Piceance basin. The actual (unrotated) fracture-orientation data collected at each station in the field are plotted on a lower-hemisphere equal-area (Schmidt) projection using the MicroNET program of Guth (1987) and are listed in tabular format at the end of each data sheet in the appendix.

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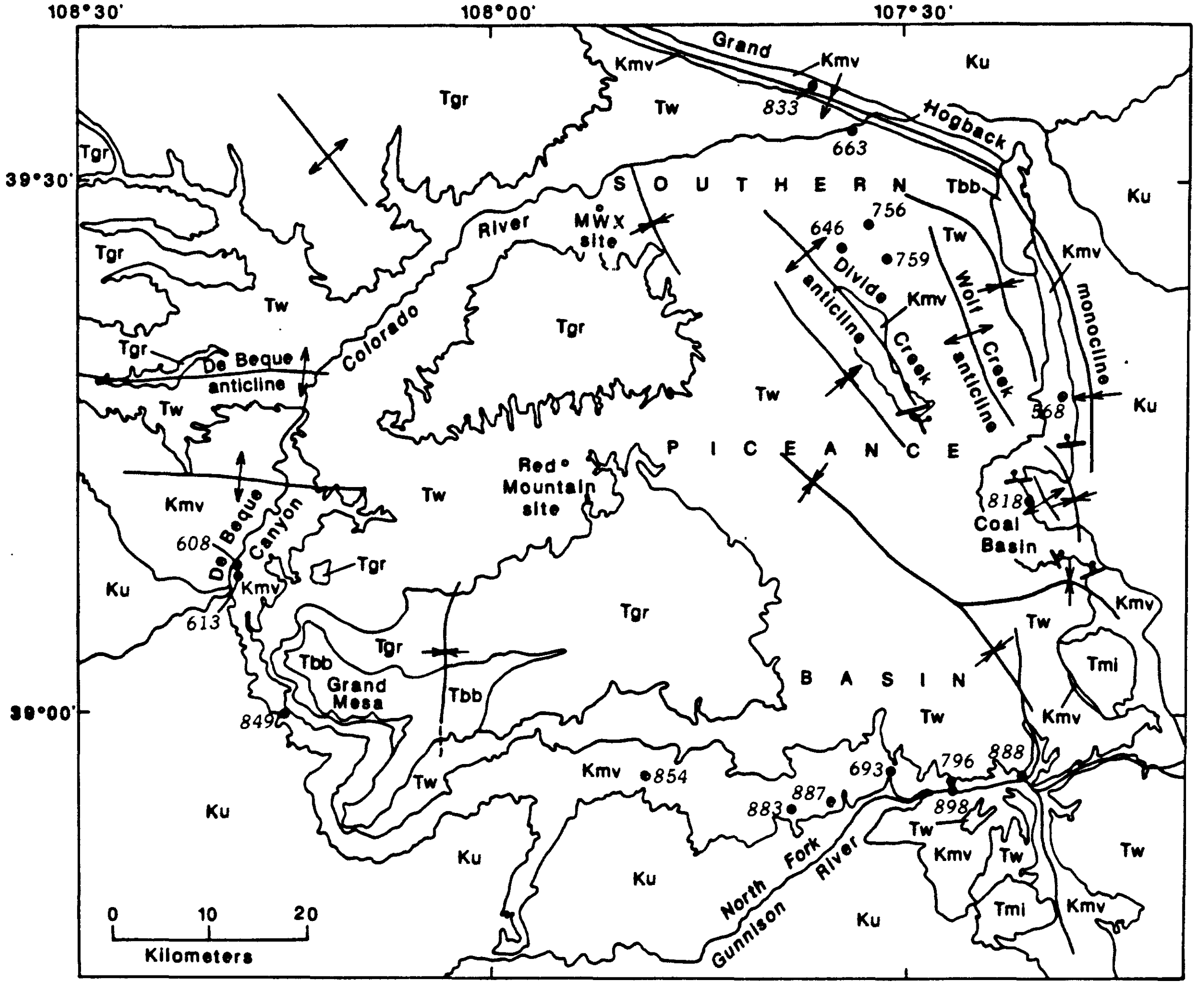
Figure 1--Generalized geologic map of the southern Piceance basin, Colorado, showing major folds, major stratigraphic units, locations of the cleat stations (numbered solid circles), and oriented-core sites (small open circles). Geology from Tweto and others (1978), Cashion (1973), Williams (1964), Tweto and others (1976), and Johnson (1983). The fracture data for the numbered stations are listed in numerical order in the Appendix.



EXPLANATION

Tbb	Basalt (Pliocene and Miocene)
Tmi	Intrusive rocks (Miocene)
Tgr	Green River Formation (Eocene)
Tw	Wasatch Formation (Eocene and Paleocene)
Kmv	Mesaverde Group (Upper Cretaceous)
Ku	Upper Cretaceous and older rocks, undifferentiated, includes Mancos Shale

Lithologic contact

Anticline - Showing crestline

Syncline - Showing troughline

Monocline - Showing anticlinal crestline of steep limb

Fault - Bar and ball on downthrown side

•854 Cleat data station

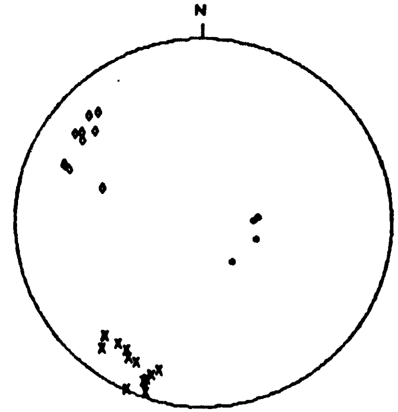
APPENDIX

CLEAT DATA

Station Number	568
Quadrangle	Stony Ridge 7.5'
Twp, Range, Section	T9S, R89W, NE 1/4, NW 1/4, SE 1/4, SE 1/4, sec. 3
Exposure Description	Elev. 7920 ft. Road cut, N side FS Rd 306 and Middle Thompson Creek, across creek from the Anderson Mine. Coal, 0.75 m thick; overlain by a 6-m thick sandstone with mudstone partings, which in turn is overlain by interlayered coal and sandstone. Measured along 15 m of cut.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	(1) Sandstone--characterized below (2) Coal, bituminous--described in remarks
Cement	Noncalcareous; well indurated
Color, fresh	Light medium gray
Color, weathered	Light orange gray
Grain size	Very fine to fine
Grain sorting	Moderately well
Grain roundness	Subangular to subrounded
Bed Orientation	N14E/22NW (n=4)
Bed Thickness	6 m
MV1 Orientation	N58W/80NE (R) (n=13)
Spacing	0.05-1.5 m (tr); 0.5-0.75 m (cr)
Height	1.5-2 m; 6 m (zones)
Length	Exposed lengths of only 2 m
Structures	Coarse plumose, arrest lines, and twist hackle
Shape	Planar to subplanar; slightly sinuous along strike
Termination	Against no other fractures
Mineralization	None seen
MV2 Orientation	N32E/89SE (R) (n=9)
Spacing	0.25-1.5 m (cr)
Height	2 m or less
Length	0.05-1.5 m (tr); 0.5-0.75 m (cr)
Structures	Coarse plumose structure and arrest lines common
Shape	Subplanar to irregular; numerous hooks
Termination	Against MV1
Mineralization	None seen
Remarks	The first-formed joints in the sandstone correlate with the MV1 set. They are prominent and in narrow zones of vertically overlapping individual joints that cut as much as 6 m of outcrop; the individual joints in each zone are much shorter. Orientations of face cleats in the overlying coal are similar to the MV1 joints in the sandstone. The second-formed set of joints in the sandstone correlates with the MV2 set of the Hogback system. End cleats in the coal comprise at least two sets-one is about perpendicular to MV1 face cleats and probably correlates with the MV2 set. The other cleat set strikes north-northwest and may correlate with the F1 regional joint set of the Piceance system. The roadcut was oriented such that actual cleat measurements in the overlying coal were difficult to obtain; cleat orientations therefore are not displayed on the equal-area plot.
Geologist(s)	MAG
Data Date	06/18/85

STATION 568

n = 26



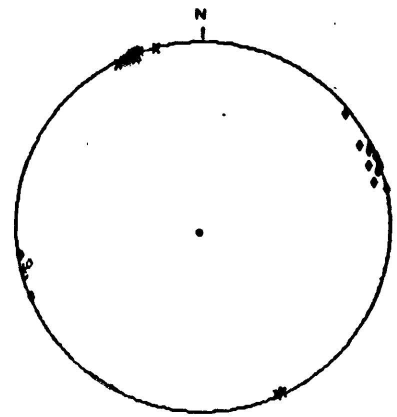
x 568MV1 n = 13
◊ 568MV2 n = 9
• 568SO n = 4

Schmidt net, lower hemisphere projection

568MV1	568MV2	568SO
N60W70NE	N19E47SE	N01W22SW
N65W73NE	N44E73SE	N55E22NW
N60W70NE	N41E65SE	N05W24SW
N74W73NE	N22E66SE	N18E24NW
N72W77NE	N47E71SE	
N50W70NE	N37E70SE	
N70W81NE	N35E72SE	
N52W76NE	N23E69SE	
N66W89NE	N35E67SE	
N62W73NE		
N56W69NE		
N72W87NE		
N71W80NE		

Station Number	608
Quadrangle	Cameo 7.5'
Twp, Range, Section	T10S, R98W, NW 1/4, NW 1/4, NW 1/4, SE 1/4 sec. 34
Exposure Description	Elev. 4800 ft. Coal seams, 1 and 2 m thick, separated by 1.5 m of massive sandstone, W-facing cut on access road to Powderhorn Mine, E side of Colorado River. Measured along 35 m of cut, on both sides of mine air intake. Interbedded thin shaly mudstone and siltstone.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N68W/3.5 NE
Bed Thickness	1-2 m
F1 Orientation	N14W/88NE (n=1)
Height	Exposed for only a few cm; true height unknown
Length	Exposed for 42 cm; true length unknown
Structures	None observed
Shape	Subplanar; curved laterally and locally split
Termination	Against no other fractures
Mineralization	Thin coating of probable gypsum
F3 Orientation	N66E/89SE (n=19)
Spacing	3-11 cm (cr)
Height	Exposed for only 55 cm; true heights unknown
Length	Exposed for only 16 cm; true lengths unknown
Structures	Arrest lines
Shape	Planar
Termination	Against F1
Mineralization	Thin coatings of probable gypsum on some near dike
F4 Orientation	N19W/90 (n=17)
Spacing	2-9 cm (cr)
Height	33 cm or less
Length	3-11 cm (cr)
Structures	None seen
Shape	Subplanar; curved along strike and sinuous in dip
Termination	Against F3
Mineralization	None seen
Remarks	A 1.5-cm wide, N27W/28NE mudstone dike cored with discontinuous, thin calcite cuts the coal. Nearby is a large, N14W/88NE face cleat that correlates with the F1 joint set in clastic rocks. All of the other face cleats strike ENE and correlate with the F3 joint set in clastic rocks. Many F3 face cleats abut the F1 face cleat and some appear to cut the dike, but the outcrop is weathered and terminating relations are difficult to see near the dike. Care had to be taken to dig into the cut to avoid measuring cleats on the weathered face. End cleats terminate at about right angles against the F3 face cleats and correlate with the F4 joint set in clastic rocks. F4 cleat heights are controlled by mudstone partings within the coal seams and thus are shorter than the face cleats, which cut across the partings. Note that the F1 cleats fall within the orientation range of the much-later F4 cleats, as is common in this part of the basin, but that abutting relations and joint style (large F1, small F4, F4 reduced in height by mudstone partings and in length by F3 cleats) show that three and not just two fracture events are manifested in this outcrop.
Geologist(s)	MAG
Data Date	08/12/85

n = 38



- 608F1 n = 1
- 608F3 n = 19
- 608F4 n = 17
- 608SO n = 1

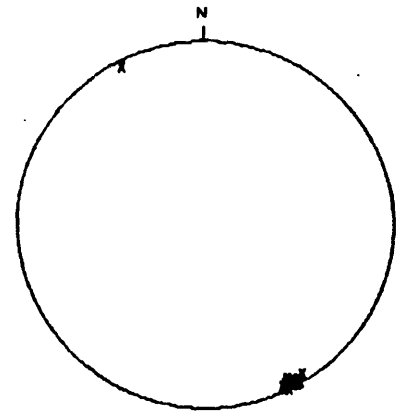
Schmidt net, lower hemisphere projection

608F1	608F3	608F4	608SO
N14W88NE	N70E90SE	N18W88SW	
	N68E90SE	N21W84SW	
	N69E88SE	N13W84NE	
	N68E88SE	N26W89SW	
	N64E88SE	N39W87SW	
	N65E87SE	N16W88NE	
	N68E87SE	N19W90SW	
	N59E90SE	N23W89NE	
	N66E87SE	N12W90SW	
	N67E88SE	N19W89SW	
	N67E90SE	N20W90SW	
	N66E88SE	N10W89NE	
	N62E88SE	N23W90SW	
	N75E89SE	N15W84SW	
	N68E88SE	N28W84SW	
	N66E89NW	N10W88NE	
	N65E88SE	N25W87SW	
	N54E89NW		
	N62E89SE		

Station Number	613
Quadrangle	Palisade 7.5'
Twp, Range, Section	T11S, R98W, SE 1/4, NW 1/4, NW 1/4, SE 1/4 sec. 2
Exposure Description	Elev. 5000 ft. Coal layer, 0.1 km WSW of Go Boy Mine. Exposed in road cut, N side of road, and in mechanically stripped area. Measured along 4 m in cut and on stripped pavement. At back of stripped area, coal is overlain by a sandstone layer, 3-m thick with interbedded mudstone, 1/4-m thick.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	Subhorizontal
Bed Thickness	>0.2 m
F3 Orientation	N62E/87NW (n=20)
Spacing	1-23 cm (tr); 5-12 cm (cr)
Height	Exposed for only 20 cm; true heights unknown
Length	Not determined
Structures	Rare twist hackles
Shape	Planar
Termination	Against no other fractures
Mineralization	Gypsum on many surfaces
Remarks	The face cleats correspond to the regional F3 joint set. True heights of the face cleats could not be measured for the road cut was stripped 1/2 m above road level and the coal was covered in the unstripped area. The face cleats are prominently formed, however, and easily visible. The exposure was too weathered to be sure which of the numerous minor fractures were end cleats and which were due to weathering of the coal. Numerous fractures terminate at nearly right angles to the face cleats, however, and probably correlate with the F4 regional set, but were not measured.
Geologist(s)	MAG
Data Date	08/13/85

STATION 613 CLEATS

n = 20



x 613F3 n = 20

Schmidt net, lower hemisphere projection

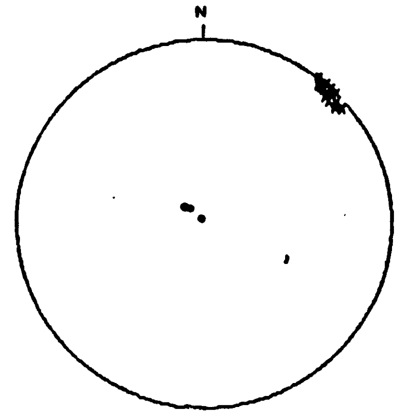
613F3

N60E87NW
N63E84NW
N62E86NW
N64E89NW
N64E86NW
N60E90NW
N63E87NW
N58E86NW
N61E90NW
N65E87NW
N65E89NW
N64E90NW
N62E89NW
N62E89NW
N63E86SE
N60E89NW
N62E89NW
N60E89NW
N60E87NW
N64E86NW

Station Number	646
Quadrangle	Gibson Gulch 7.5'
Twp, Range, Section	T7S, R91W, NW 1/4, NE 1/4, SE 1/4, NW 1/4, sec. 20
Exposure Description	Elev. 6620 ft. Small blebs, stringers, and lenses of coaly material in a 3-m thick sandstone layer in a road cut, NW side of East Divide Creek Road, immediately SW of milepost 3. The largest coal lens is 8 cm high x 18 cm long. Cut faces SW and is 5 m high; sandstone is in upper 3 m of cut.
Stratigraphic Unit	Paleocene and Eocene Wasatch Formation
Lithology (General)	Coal, subbituminous to bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N48E/75E (n=3)
Bed Thickness	0.02-0.08 m
FP Orientation	N47W/87SW (n=16)
Spacing	0.1-0.12 cm (cr)
Height	2-8 cm
Length	1.5 cm max exposed length; true lengths unknown
Structures	Not determined
Shape	Planar
Termination	Against no other fractures
Mineralization	None seen
Remarks	The face cleats correspond to fold-parallel fractures that developed in the outer arc of the Divide Creek anticline during folding, and that predate the regional F1-F5 sets. Although most of the face cleats cut only the coaly lenses, some cleats extend a few millimeters above and below the lenses into the enclosing sandstone layer. A set of irregularly shaped and cleats in the coaly lenses probably correlates with the F4 regional set, but the orientations of these fractures are such that were out of reach on the vertical face for measurement. The long axes of the coaly blebs are diversely oriented and not everywhere parallel to bedding; despite the diverse orientations of the blebs, the cleats are subvertical.
Geologist(s)	MAG, DBY
Data Date	03/28/86

STATION 646

n = 19



× 646FP n = 16
• 646SD n = 3

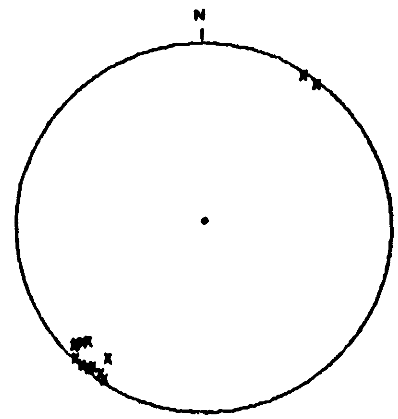
Schmidt net, lower hemisphere projection

646FP	646SD
N43W86SW	N50E02SE
N42W84SW	N46E09SE
N51W88SW	N38E11SE
N51W87SW	
N50W87SW	
N49W87SW	
N47W84SW	
N47W89SW	
N52W90SW	
N47W90SW	
N46W87SW	
N50W88SW	
N49W90SW	
N40W86SW	
N45W90SW	
N45W84SW	

Station Number	663
Quadrangle	New Castle 7.5'
Twp, Range, Section	T6S, R91W, NW 1/4, NE 1/4, NE 1/4, NE 1/4 sec. 8
Exposure Description	Elev. 5520 ft. Coaly lenses and stringers in mudstone interlayered with thick, cross-bedded sandstone, N-facing slope, immediately S of Colorado River and road between Garfield and Divide Creeks. Coaly lenses are 1-3 cm high x 6-10 cm long. Cut, 1 km W of mouth of Garfield Creek, is 40 m long.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N85W/3.5 SW (n=1)
Bed Thickness	0.01-0.03 m
F2 Orientation	N51W/86NE (n=13)
Spacing	Several millimeters on average
Termination	Against no other fractures
Mineralization	None seen
Remarks	Only the face cleats could be reached for measurement in this vertical cut. They are small and spaced only a few millimeters apart; only their orientations were measured. The face cleats correlate with the F2 regional set in the enclosing sandstone, which also contains joints that correlate with the F3 regional set. No cleats in the coal correlate with the F3 set, however. The end cleats correlate with the F4 regional set in the sandstone, but are oriented such that they could not be reached for measurement in the vertical cut. They strike about perpendicular to the F2 face cleats to form a rectangular system of cleats at this locality.
Geologist(s)	MAG
Data Date	06/17/86

STATION 663 CLEATS

n = 14



x 663F2 n = 13
• 663SO n = 1

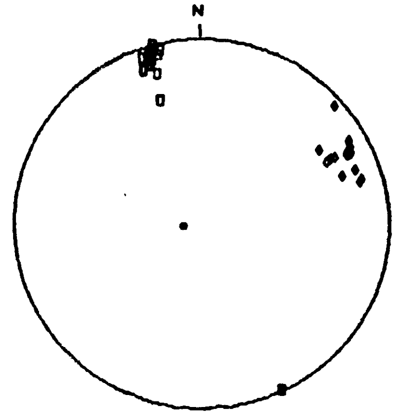
Schmidt net, lower hemisphere projection

663F2	663SO
N52W86NE	N85W03SW
N45W77NE	
N49W89NE	
N55W86NE	
N52W88SW	
N43W85NE	
N57W88SW	
N54W77NE	
N57W88NE	
N44W80NE	
N51W88NE	
N43W83NE	
N46W89NE	

Station Number	693
Quadrangle	Bowie 7.5'
Twp, Range, Section	T13S, R91W, NW1/4, SE1/4, NW1/4, SE1/4 sec. 2
Exposure Description	Elev. 6060 ft. Coal seam, 69 cm thick, at vent portals of Blue Ribbon Mine, E side Hubbard Creek and road, 0.9 km SW of mine. Overlain by cross-bedded sandstone, about 60 cm thick. Scoured coal/sandstone contact. Underlain by carbonaceous shale.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N5W/8NE (n=1)
Bed Thickness	0.69 m
F3 Orientation	N75E/82SE (R) (n=16)
Spacing	0.2-7.5 cm
Height	25-69 cm
Length	Exposed for only 8 cm; true lengths unknown
Structures	Not determined
Shape	Planar; locally broadly curved along strike
Termination	Against no other fractures
Mineralization	None seen
F4 Orientation	N26W/84SW (R) (n=15)
Spacing	0.2-3 cm
Height	2-5 cm
Length	0.2-7.5 cm
Structures	Not determined
Shape	Subplanar; slightly curved along strike
Termination	Against F3 face cleats
Mineralization	None seen
Remarks	The face cleats are prominent and abundant and correlate with the F3 joint set in clastic rocks. The end cleats are smaller and more irregular in shape than the face cleats and correlate with the F4 joint set in clastic rocks. Note the extreme difference in height between the two cleat sets; the end cleats terminate vertically against bed-parallel fractures within the coal seam.
Geologist(s)	HDN
Data Date	08/08/88

STATION 693 CLEATS

n = 32



- 693F3 n = 16
- 693F4 n = 15
- 693SO n = 1

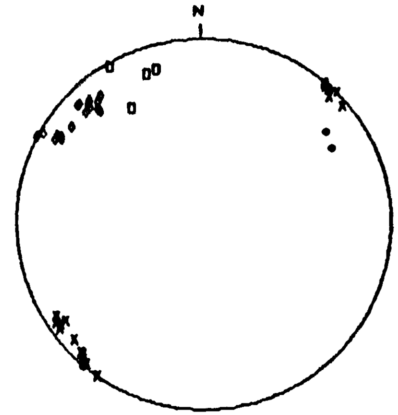
Schmidt net. lower hemisphere projection

693F3	693F4	693SO
N74E83SE	N26W76SW	N05W08NE
N65E89NW	N20W76SW	
N72E79SE	N15W76SW	
N73E84SE	N30W80SW	
N76E84SE	N27W64SW	
N74E86SE	N26W78SW	
N74E82SE	N27W76SW	
N75E90SE	N42W85SW	
N76E84SE	N33W64SW	
N77E86SE	N19W68SW	
N71E85SE	N16W78SW	
N73E80SE	N27W66SW	
N70E78SE	N26W75SW	
N70E79SE	N27W69SW	
N74E74SE	N28W79SW	
N72E60SE		

Station Number	756
Quadrangle	Gibson Gulch 7.5'
Twp, Range, Section	T7S, R91W, SE 1/4, NW 1/4, NE 1/4, SW 1/4 sec. 10
Exposure Description	Elev. 7220 ft. SSE-facing sandstone ledge, 4-7 m thick, exposed for hundreds of m along N side of Gibson Gulch, 150 ft above Amoco New Castle Unit No. 3. Planar to low-angle crossbedded sandstone; local rip-up clasts and coaly stringers, mudstone partings. Encased in variegated mudstone.
Stratigraphic Unit	Paleocene and Eocene Wasatch Formation
Lithology (General)	(1) Sandstone--characterized below (2) Local coaly stringers--described in Remarks
Cement	Highly calcareous; well indurated
Color, fresh	Light gray
Color, weathered	Light tan gray
Grain size	Very fine to coarse fine-grained
Grain sorting	Moderately poorly sorted
Grain roundness	Subrounded to subangular
Bed Orientation	Subhorizontal
Bed Thickness	0.1-4 m
FP Orientation	N45W/89NE (n=19)
Spacing	0.04-3.5 m (tr)
Height	1-4 m (tr)
Length	4->6 m
Structures	Arrest lines, crude twist hackle; possible plumes
Shape	Subplanar; sinuous along strike, lateral hooks
Termination	As hairline cracks in rock
Mineralization	Elongated, euhedral, small, white calcite crystals
F3 Orientation	N65E/75SE (n=4)
Termination	None seen
Mineralization	None seen
F4 Orientation	N44E/77SE (n=18)
Spacing	<0.01-4 m (tr)
Height	0.25-4 m (tr); 0.25-1 m (cr)
Length	0.02-4 m
Structures	Not determined
Shape	Subplanar to nonplanar; locally large and planar
Termination	Against or across min. FP; F3
Mineralization	None seen
F5 Orientation	N33W/69SW (n=2)
Termination	Against F4
Mineralization	None seen
Remarks	Joints of the first-formed set in the sandstone may correlate with the local fold-parallel sets. They are large, prominent, and sinuous along strike; many are filled with calcite. The orientation of face cleats in coaly stringers within a 10-cm thick sandstone layer parallels that of the fold-parallel joints in the sandstone, but could not be reached for measurement. A few joints in the sandstone correlate with the F3 regional set. Others correlate with the F4 regional set and are small, layer confined, and either terminate against, or cut across the once calcite-filled FP joints. The end cleats are not similar in orientation to the F4 joints in the sandstone, unlike elsewhere the basin, but instead appear to correlate with the F3 set in clastic rocks. At this locality, then, the F3 joints, which usually form the face cleats over much of the southern basin, instead correspond to the end cleats. The early face-cleat formation here is due to basin-margin tectonism. Note also that the face and end cleats are not perpendicular to each other but instead enclose an angle of about 70°.

Geologist(s) MAG, REM
Date Date 08/06/86

n = 43



x 756FP n = 19
• 756F3 n = 4
♦ 756F4 n = 18
• 756F5 n = 2

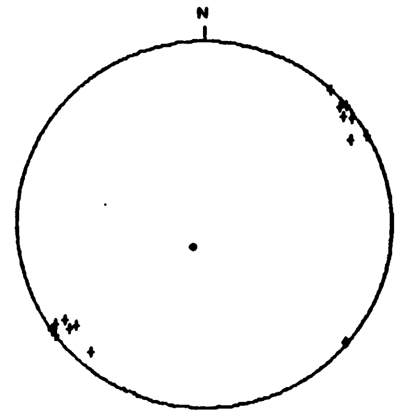
Schmidt net, lower hemisphere projection

756FP	756F3	756F4	756F5
N48W88SW	N70E75SE	N30E88SE	N30W68SW
N42W83NE	N74E76SE	N50E75SE	N36W70SW
N47W85NE	N60E88SE	N47E78SE	
N50W89NE	N59E62SE	N30E80SE	
N45W85SW		N31E77SE	
N36W85NE		N32E78SE	
N44W90SW		N32E80SE	
N55W90NE		N28E90SE	
N35W80NE		N44E81SE	
N49W89NE		N44E81SE	
N40W87SW		N37E76SE	
N34W85NE		N48E72SE	
N47W88SW		N48E79SE	
N32W83NE		N44E75SE	
N46W85NE		N46E75SE	
N49W89SW		N52E77SE	
N35W83NE		N45E81SE	
N50W88NE		N48E70SE	
N48W87NE			

Station Number	759
Quadrangle	Gibson Gulch 7.5'
Twp, Range, Section	T7S, R91W, NW 1/4, SE1/4, SW 1/4, SE 1/4 sec. 23
Exposure Description	Elev. 7960 ft. Stringers and lenses of coaly material interbedded with rip-up clasts of mudstone within thick, crossbedded sandstone, S side Crown Peak, near E end of ledges at top of peak. The lenses are diversely oriented and <1 cm thick. Many are <1 cm sq in area on the vertical face.
Stratigraphic Unit	Paleocene and Eocene Wasatch Formation
Lithology (General)	Coaly material
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N66W/11NE (sandstones)
Bed Thickness	<0.01 m
FP Orientation	N38W/88NE (n=15)
Spacing	<1 cm
Height	<1 cm
Length	Not determined
Structures	None seen
Shape	Planar
Termination	Against no other fractures
Mineralization	None seen
F4 Orientation	N40E/89NW (n=1)
Termination	Against the face cleats
Mineralization	None seen
Remarks	The face cleats correlate with fold-parallel fractures that developed in the outer arc of the Divide Creek anticline during folding, and that predate the regional F1-F5 joint sets. The face cleats are vertical with an average strike of N38W despite the diverse orientations of the long axes of the coaly lenses. End cleats also are numerous but most could not be reached for measurement. They terminate at about right angles to the face cleats and correlate with the F4 regional joint set in the clastic rocks.
Geologist(s)	MAG, REM
Data Date	08/07/86

STATION 759 CLEATS

n = 17



759FP	n =	15
759F4	n =	1
759SO	n =	1

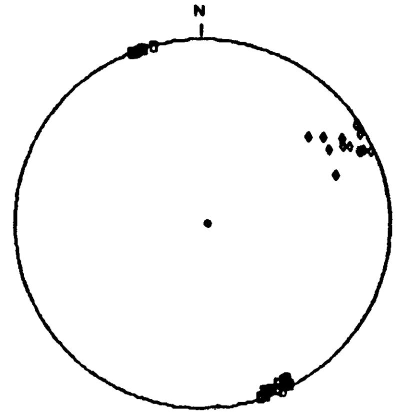
Schmidt net, lower hemisphere projection

759FP	759 F4	759SO
N30W90SW	N40E89NW	N66W11NE
N40W77NE		
N36W80NE		
N50W82NE		
N42W86SW		
N39W84SW		
N39W81NE		
N36W90NE		
N35W86NE		
N48W90SW		
N36W89NE		
N38W90NE		
N37W88SW		
N41W90SW		
N31W80SW		

Station Number	796
Quadrangle	Somerset 7.5'
Twp, Range, Section	T13S, R90W, NE 1/4, SW 1/4, SE 1/4, NW 1/4 sec. 10
Exposure Description	Elev. 6500 ft. Coal seam, 22.5 cm thick, underlies thick, massive sandstone, E side Coal Gulch in jeep trail road cut, 0.5 km N of State Hwy 133 and North Fork Gunnison River. Coal grades to carbonaceous shale at base; local laminae of lustrous vitrain(?).
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N8E/2NW (n=1)
Bed Thickness	0.225 m
F3 Orientation	N69E/89SE (n=17)
Spacing	0.2-6 cm (tr)
Height	2.5-20 cm
Length	Exposed for only 8-12 cm; true lengths unkown
Structures	Smooth except for local splits along interbeds
Shape	Planar; locally broadly curved or sinuous in dip
Termination	Against no other fractures
Mineralization	None seen
F4 Orientation	N30W/77SW (n=13)
Spacing	0.1-4 cm (cr)
Height	0.5-5 cm (cr)
Length	0.2-6 cm
Structures	None seen
Shape	Planar to nonplanar; broadly curved
Termination	Against F3
Mineralization	None seen
Remarks	The face cleats correlate with the F3 joint set in clastic rocks. The cleats do not cut the full thickness of the coal layer, but are planar, smooth, and well-formed. The end cleats terminate at about right right angles to the face cleats and correlate with the F4 joint set in clastic rocks. The end cleats are smaller, more irregular in shape, and relatively crudely formed compared to the face cleats.
Geologist(s)	MAG, HDN
Data Date	09/05/88

STATION 796 CLEATS

n = 31



- 796F3 n = 17
- 796F4 n = 13
- 796S0 n = 1

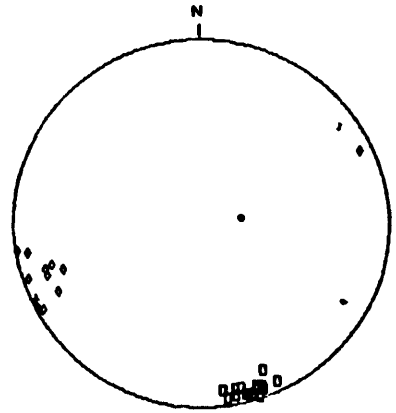
Schmidt net, lower hemisphere projection

796F3	796F4	796S0
N62E89NW	N25W82SW	N08E02NW
N63E85NW	N24W88SW	
N65E85NW	N28W78SW	
N69E87NW	N29W75SW	
N65E90NW	N25W83SW	
N70E89NW	N33W88SW	
N68E87NW	N30W87SW	
N70E86NW	N32W77SW	
N72E89NW	N25W85SW	
N72E89SE	N31W68SW	
N70E89SE	N36W69SW	
N71E90SE	N20W65SW	
N66E88NW	N40W63SW	
N69E89SE		
N75E89SE		
N62E85NW		
N68E90SE		

Station Number	818L
Quadrangle	Placita 7.5'
Twp, Range, Section	T10S, R89W, SE 1/4, NE 1/4, SW 1/4, SE 1/4 sec. 8
Exposure Description	Elev. 10,180 ft. Coal seam, lower 1 m of 2.5 m, in SSE-facing mine road cut, 0.25 km S of No. 3 Mine, 0.1 km N of Dutch Creek, Coal Basin area. Second seam above the Rollins Sandstone. Overlain by interbedded sandstone and mudstone, 9 m thick.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N8W/17SW (n=1)
Bed Thickness	2.5 m
F1 Orientation	N25W/87NE (n=1)
Termination	Against no other fractures
Mineralization	None seen
F3 Orientation	N73E/85NW (n=18)
Spacing	2-8 cm (cr)
Height	Exposed for only 15 cm; true heights unknown
Length	25 cm or greater
Structures	Not determined
Shape	Subplanar; locally broadly curved in strike
Termination	At F1 and fold-parallel cleats
Mineralization	None seen
F4 Orientation	N19W/84NE (n=11)
Length	2-8 cm (cr)
Structures	Not determined
Shape	Subplanar to irregular
Termination	Against F3 face cleats
Mineralization	None seen
Remarks	The most prominent cleats in the lower part of the coal seam strike N73E on average and correlate with the F3 regional set in clastic rocks. F3 cleats in the upper part of the coal (Station 818U) terminate at two sets of inclined cleats that appear to correlate with earlier-formed fold-parallel fractures. Only one N25W face cleat was measured, although more are present; they correlate with the F1 regional set in clastic rocks. Several F3 cleats terminate at these joints. The end cleats are small, subplanar to irregular in shape, and confined by the F3 face cleats. They correlate with the F4 joint set in clastic rocks. The end cleats are so similar in orientation to the F1 face cleats that great care must be taken in deciphering the relative ages of the various cleat sets.
Geologist(s)	MAG
Data Date	08/20/87

STATION 818L CLEATS

n = 31



♦ 818LF1 n = 1
▪ 818LF3 n = 18
♦ 818LF4 n = 11
• 818SO n = 1

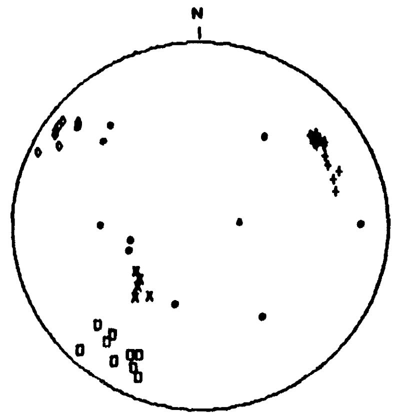
Schmidt net, lower hemisphere projection

818LF1	818LF3	818LF4	818SO
N25W87NE	N72E84NW	N09W89NE	N08W17SW
	N76E85NW	N25W83SW	
	N79E81NW	N19W76NE	
	N83E81NW	N28W89NE	
	N76E85NW	N18W87NE	
	N68E75NW	N29W86NE	
	N82E86NW	N16W72NE	
	N76E85NW	N10W83NE	
	N79E85NW	N17W76NE	
	N75E85NW	N26W74NE	
	N72E82NW	N19W67NE	
	N77E81NW		
	N72E84NW		
	N74E86NW		
	N72E89NW		
	N70E83NW		
	N70E85NW		
	N65E84NW		

Station Number	818U
Quadrangle	Placita 7.5'
Twp, Range, Section	T10S, R89W, SE 1/4, NE 1/4, SW 1/4, SE 1/4 sec. 8
Exposure Description	Elev. 10,180 ft. Coal seam, upper 1.5 m of 2.5 m, in SSE-facing mine road cut, 0.25 km S of No. 3 Mine, 0.1 km N of Dutch Creek, Coal Basin area. Second seam above the Rollins Sandstone. Contains dewatering structures and kink bands. Overlain by interbedded sandstone and siltstone, 9 m thick.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N8W/17SW (n=1)
Bed Thickness	2.5 m
FPA Orientation	N40W/54SW (R) (n=16)
Spacing	20-100 cm (cr)
Height	33 cm or less
Length	Exposed for 33 cm; true lengths unknown
Structures	None seen
Shape	Planar; slightly sinuous downdip
Termination	Against cone-in-cone fractures
Mineralization	None seen
FPB Orientation	N37W/54NE (R) (n=5)
Spacing	20-100 cm (cr)
Height	25 cm or less
Length	Exposed for only a few cm; true lengths unknown
Structures	None seen
Shape	Planar; slighlty undulatory in dip
Termination	Against cone-in-cone fractures
Mineralization	None seen
F2 Orientation	N56W/81NE (R) (n=9)
Termination	Against no other fractures
Mineralization	None seen
F4 Orientation	N35E/82SE (n=8)
Termination	Against F2 face cleats
Mineralization	None seen
Remarks	The earliest fractures to form in the upper 1.5 m of the coal seam are diversely oriented, but all dip moderately, are broadly curved, and form nested cone-in-cone (CIC) structures that developed during dewatering of the coal (see equal-area plot)). Fractures that dip moderately steeply in opposite directions and terminate at the CIC fractures formed next. They have a common strike and appear to correlate with fold-parallel sets that predate the F1-F5 regional joint sets. The SW-dipping set is more abundant. Face cleats that strike WNW predate the F4 cleats; age relations with other sets are unknown and it is uncertain if they correlate with the F2, the MV1, or FP sets in the clastic rocks. These cleats were rotated with the beds, however, and thus may correlate with the MV1 set. The F4 end cleats are oriented somewhat differently from those in the lower part of the coal because they terminate at about right angles against WNW-striking cleats rather than ENE ones.
Geologist(s)	MAG
Data Date	08/20/87

STATION 818U CLEATS

n = 49



• 818UCIC	n =	10
+ 818UFPA	n =	16
x 818UFPB	n =	5
■ 818UF2	n =	9
◊ 818UF4	n =	8
• 818USO	n =	1

Schmidt net, lower hemisphere projection

818UFPA	818UFPB	818UF2	818UF4	818UCIC
N22W69SW	N55W39NE	N62W69NE	N38E82SE	N40E75SE
N37W69SW	N42W36NE	N52W65NE	N34E82SE	N72W37NE
N35W70SW	N49W44NE	N58W76NE	N33E81SE	N42E59SE
N36W66SW	N45W39NE	N52W70NE	N36E82SE	N01W75SW
N34W68SW	N36W35NE	N45W66NE	N25E85SE	N55W50SW
N37W68SW		N65W67NE	N36E82SE	N49E62SE
N39W66SW		N65W74NE	N30E76SE	N00W44SE
N37W65SW		N68W78NE	N11E75SE	N12W31NE
N15W64SW		N47W83NE		N19W33NE
N35W65SW				N56E50NW
N20W65SW				
N40W66SW				
N30W66SW				
N39W69SW				
N34W69SW				
N26W65SW				

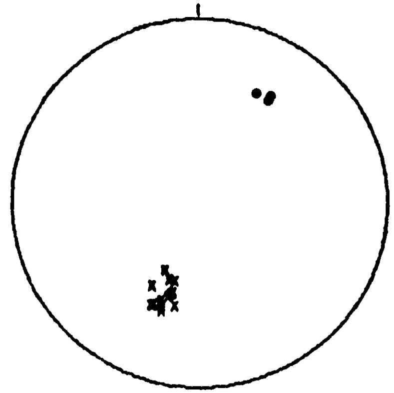
818USO

N08W17SW

Station Number	833
Quadrangle	New Castle 7.5'
Twp, Range, Section	T5S, R91W, SW1/4, SE1/4, SE1/4, SW1/4 sec. 21
Exposure Description	Elev. 6780 ft. Coal layer, 1/3-m thick, at vertical mine shaft, Burning Mtn., 0.75 km due W. of anticlinal crest of Grand Hogback monocline. NE-facing wall of mined-out pit. Interbedded clayey siltstone, 2 cm thick. Overlain by clayey siltstone, 1 m thick, and massive sandstone, 2.5 m th.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N59W/58SW (n=3)
Bed Thickness	0.33 m
MV1 Orientation	N65W/77SW (R) (n=16)
Spacing	2-3 cm (cr)
Height	5-20 cm
Length	Exposed for only 5 cm
Structures	None seen
Shape	Not determined
Termination	Vertically against shale
Mineralization	Light coating of gypsum
Remarks	The coal bed is highly weathered, fractured, and very friable. Face cleats are the only set that can be recognized with confidence. The face cleats are consistently and distinctly different in orientation from the NNW-striking first-formed set in the clayey siltstone layers interbedded with, and overlying, the coal layer. The face cleats correlate with the MV1 regional joint set of the Hogback system in clastic rocks. The NNW-striking joints in the clayey siltstone appear to correlate with an older set of the Hogback system chiefly found in lower Createaceous and older rocks exposed in the southern Grand Hogback.
Geologist(s)	ERV, MAG
Data Date	06/07/88

STATION 833 CLEATS

n = 19



x 833MV1 n = 16
• 833SO n = 3

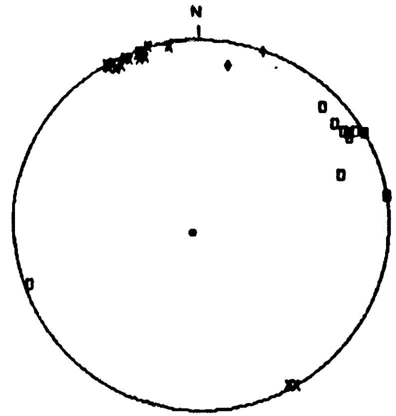
Schmidt net, lower hemisphere projection

833MV1	833SO
N65W51NE	N57W57SW
N71W52NE	N57W59SW
N77W48NE	N63W57SW
N73W43NE	
N73W37NE	
N64W34NE	
N74W43NE	
N69W47NE	
N69W49NE	
N74W42NE	
N72W45NE	
N66W51NE	
N69W37NE	
N70W50NE	
N61W43NE	
N72W44NE	

Station Number	849
Quadrangle	Palisade 7.5'
Twp, Range, Section	T12S, R97W, SW 1/4, NW 1/4, SE 1/4, SE 1/4 sec. 17
Exposure Description	Elev. 6810 ft. Coal layer, 30 cm thick, WSW-facing mined-out cut, N side of North Fork Kannah Creek. Above and 10 m SE of Kannah Creek Mine, Opening 1. Contains reddish brown amber(?) partings. Overlain and underlain by carbonaceous shale. Measured along a 3 m long x 2/3 m high cleaned-off area.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, subbituminous with lustrous reddish brown amber(?) partings
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	N50W/5NE (n=1)
Bed Thickness	0.3 m
F2 Orientation	N70W/89SW (n=1)
Termination	Against no other fractures
Mineralization	None seen
F3 Orientation	N64E/88SE (n=17)
Spacing	0.1-8 cm (tr); 2-6 cm (cr)
Height	20-30 cm (individual); 66 cm (zones)
Length	Exposed for 0.5 m; probably close to true lengths
Structures	Arrest lines and delicate hooks
Shape	Planar to subplanar; local hooks on one end
Termination	Against F2
Mineralization	None seen
F4 Orientation	N31W/90 (n=11)
Spacing	1-5 cm (cr)
Height	1-10 cm (cr); 20 cm max
Length	0.1-8 cm (tr); 2-6 cm (cr)
Structures	Not determined
Shape	Subplanar; locally planar or irregularly shaped
Termination	Against F3
Mineralization	None seen
F5 Orientation	N80W/76SW (n=1)
Termination	Against F4
Mineralization	None seen
Remarks	One large face cleat, 20 cm high x 18 cm long, was found against which smaller, differently oriented face cleats abut. It strikes WNW and correlates with the F2 set. The smaller face cleats strike ENE and correlate with the F3 regional set. They dominate the outcrop and are parallel to the cut face. Many F3 cleats are in zones of individual cleats that overlap vertically and are spaced 1 mm or less apart. Many of these zones cut the full thickness of the coal layer. The thinnest, most brittle coal layers are only a few millimeters thick and contain cleats of similar height. Most of the end cleats correlate with the F4 regional set and terminate against the F3 face cleats. The end cleats are shorter, layer-confined, and more irregular in shape than the face cleats. Two cleats were found that terminate at the F4 end cleats and correlate with the F5 regional set; only one, however, could be measured before the other was destroyed during the measuring process.

Geologist(s)	MAG, EJM
Data Date	07/26/88

n = 31



♦ 849F2	n =	1
x 849F3	n =	17
■ 849F4	n =	11
♦ 849F5	n =	1
• 849SD	n =	1

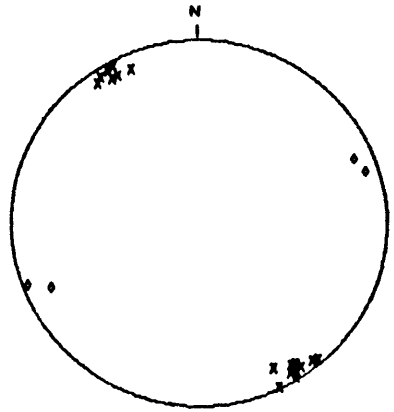
Schmidt net, lower hemisphere projection

849F2	849F3	849F4	849F5	849SD
N70W89SW	N62E88NW	N29W90SW	N80W76SW	N50W05NE
	N60E90NW	N19W68SW		
	N71E89SE	N33W80SW		
	N64E85SE	N19W87NE		
	N72E88SE	N32W82SW		
	N80E87SE	N30W81SW		
	N66E88SE	N31W86SW		
	N72E84SE	N44W80SW		
	N74E90SE	N08W90SW		
	N60E89SE	N37W79SW		
	N70E87SE	N31W86SW		
	N62E89SE			
	N60E88SE			
	N67E87SE			
	N60E90SE			
	N70E84SE			
	N62E85SE			

Station Number	854
Quadrangle	Dry Creek 7.5'
Twp, Range, Section	T13S, R93W, SE 1/4, SW 1/4, SW 1/4, NW 1/4 sec. 8
Exposure Description	Elev. 7110 ft. SE-facing ledge of 3-m thick shaly coal immediately underlying a 3-5-m thick sandstone bed that pinches out to the NE. NW side of Dry Creek, 0.3 km NW of Landreth Mine. Exposed for 1 m. Coal changes laterally toward the NE into carbonaceous shale. Vitrain laminae.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Shaly coal, low-grade subbituminous Carbonaceous shale
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	Horizontal
Bed Thickness	0.3 m; 0.06 m laminations
F3 Orientation	N60E/89NW (n=18)
Spacing	4-10 cm (coal); 12 cm avg (shale)
Height	Exposed for only 8 cm; true heights not known
Length	Exposed for only 25 cm; true lengths not known
Structures	Not determined
Shape	Planar
Termination	Against no other fractures
Mineralization	None seen
F4 Orientation	N22W/90 (n=4)
Spacing	5-25 cm (shale)
Termination	Against F3
Mineralization	None seen
Remarks	The face cleats correlate with the F3 regional joint set. Care had to be taken to measure the cleat orientations away from the weathered face, where spacings of the weathered face cleats are only 1-2 mm. The end cleats in the low-grade coal layers abut the face cleats at nearly right angles. In the very thin, lustrous, interbedded vitrain layers, however, the end cleats strike about N10W and abut the face cleats at a smaller angle. Orientations of the end cleats were not recorded because weathering had destroyed most of the accessible planes; they probably correlate with the F4 regional set. In carbonaceous shale near the Landreth Mine, 0.3 km to the SW, joints correlate with the F3 and F4 regional sets, but are larger and more widely spaced than the cleats. The orientation and spacings data for the F3 joint sets in the shale are presented with the F3 face-cleat data, whereas only the F4 joint data for the shale are presented.
Geologist(s)	MAG, EJM
Data Date	07/28/88

STATION 854 CLEATS

n = 22



x 854F3 n = 18
◊ 854F4 n = 4

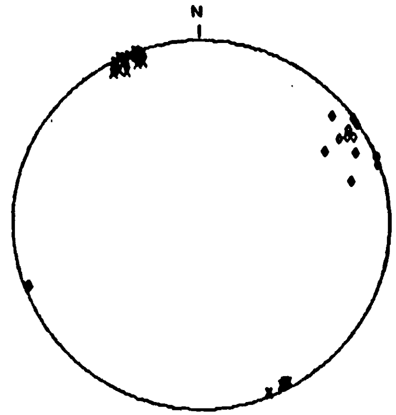
Schmidt net, lower hemisphere projection

854F3	854F4
N52E86NW	N18W83SW
N58E81NW	N24W75SE
N57E82NW	N20W87NE
N56E85NW	N23W79SW
N60E85NW	
N58E86NW	
N64E78NW	
N50E87NW	
N67E81SE	
N60E86SE	
N60E87SE	
N55E83SE	
N62E87SW	
N65E89NW	
N57E85SE	
N59E89NW	
N60E81SW	
N62E81SE	

Station Number	883
Quadrangle	Gray Reservoir 7.5'
Twp, Range, Section	T13S, R92W, SW1/4, SW 1/4, NW/4, NE 1/4 sec. 23
Exposure Description	Elev. 7250 ft. Coal bed, 1 m thick, new roadcut, E side road, on W-facing slope, E side East Roatcap Creek, in saddle between Fry Mesa and unnamed mesa to north. Measured along 8 m of cut. Contains very lustrous, dark vitrain laminae. Coal generally is dull gray.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, subbituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	Subhorizontal
Bed Thickness	1 m
F3 Orientation	N66E/88SE (n=19)
Spacing	0.1-0.6 cm; 0.5-8 cm
Height	0.6 (thin beds); 20 cm (thick beds)
Length	Exposed lengths of 0.5 m; true lengths unknown
Structures	Arrest lines; locally split at layer contacts
Shape	Very planar
Termination	None seen
Mineralization	Many are orange limonite-stained
F4 Orientation	N30W/83SW (n=15)
Spacing	<0.1-16 cm (tr); 0.1-6 cm (cr)
Height	<6-22 cm (tr); 6-15 cm (cr)
Length	0.1-0.6 cm (thin beds); 0.5-8 cm (thick beds)
Structures	Arrest lines and twist hackle on some
Shape	Subplanar; sinuous along strike or broadly curved
Termination	Against F3
Mineralization	None seen
Remarks	The face cleats correlate with the F3 regional set in clastic rocks. The thin lustrous vitain laminas contain face cleats that are no greater than 6 mm high and spaced only 1-6 mm apart. Cleats that cut through the thicker layers are in zones up to 6 mm wide and 66 cm high of individual cleats that overlap vertically and attain heights of 20 cm or less. Many additional cleats are not in zones. An irregularly shaped set of smaller cleats abuts the face cleats and correlates with the F4 regional set in clastic rocks.
Geologist(s)	MAG
Data Date	09/09/88

STATION BB3 CLEATS

n = 34



x BB3F3 n = 19
♦ BB3F4 n = 15

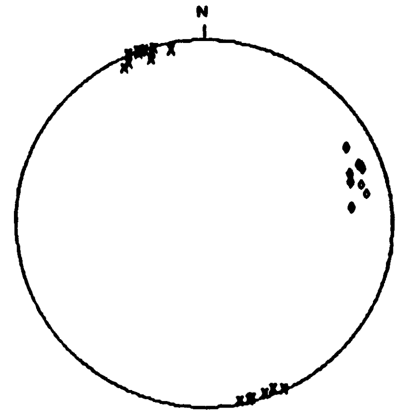
Schmidt net, lower hemisphere projection

BB3F3	BB3F4
N66E87SE	N16W72SW
N65E81SE	N19W89SW
N61E84SE	N33W89SW
N63E89SE	N33W83SW
N63E84SE	N31W80SW
N71E83SE	N25W80SW
N63E86NW	N21W90SW
N62E87NW	N20W87NE
N68E89SE	N31W66SW
N65E90SE	N30W83SW
N64E87NW	N20W88NE
N72E88SE	N32W76SW
N70E87SE	N40W81SW
N65E86SE	N20W87NE
N66E88SE	N35W89SW
N70E90SE	
N69E83SE	
N71E86SE	
N69E88NW	

Station Number	887
Quadrangle	Bowie 7.5'
Twp, Range, Section	T13S, R91W, SE1/4, NW1/4, SW1/4, SW 1/4, sec. 17
Exposure Description	Elev. 7080 ft. Coal layer, 30 cm thick, Farmer's Mine, E side, WSW-facing road cut at first hairpin turn on abandoned road N of mine. Overlain and underlain by very poorly to poorly indurated gray mudstone. Measured along 1.5 m. 3.5 km N of N Fork Gunnison River and 1.2 km W of Terror Creek.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, subbituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	Subhorizontal
Bed Thickness	0.3 m
F3 Orientation	N70E/90 (n=17)
Spacing	0.5-4 cm (tr); 1-2 cm (cr)
Height	8-18 cm; 30 cm (zones)
Length	Exposed for only 6 cm; true lengths unknown
Structures	Delicate arrest lines
Shape	Very planar
Termination	Against no other fractures
Mineralization	None seen
F4 Orientation	N19W/75SW (n=10)
Spacing	<0.1-5 cm (tr); 0.5-1.5 cm (cr)
Height	1-13 cm
Length	0.5-4 cm
Structures	None seen
Shape	Nonplanar; broadly curved and irregular in profile
Termination	Against F3
Mineralization	None seen
Remarks	The face cleats correlate with the F3 regional set in clastic rocks. Although the face cleats appear to cut the entire thickness of the coal bed, they actually are in zones of vertically overlapping fractures; the heights of individual face cleats generally are no more than half the thickness of the coal bed. An irregularly shaped set of smaller cleats abuts the face cleats and correlates with the F4 regional set in clastic rocks.
Geologist(s)	MAG
Data Date	09/28/88

STATION 887 CLEATS

n = 37



x 887F3 n = 17
♦ 887F4 n = 10

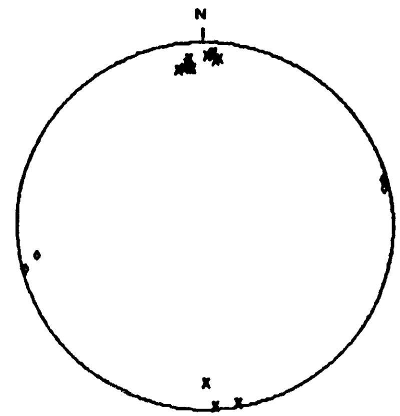
Schmidt net, lower hemisphere projection

887F3	887F4
N66E90SE	N07W68SW
N65E89NW	N22W77SW
N76E89NW	N17W70SW
N69E90SE	N11W77SW
N74E89SE	N20W71SW
N72E83SE	N15W75SW
N70E89SE	N29W75SW
N71E88NW	N16W70SW
N79E86SE	N20W78SW
N65E85SE	N21W78SW
N69E88SE	
N73E86NE	
N75E88NW	
N68E87NW	
N63E84SE	
N79E88NW	
N71E90SE	

Station Number	888
Quadrangle	Paonia Reservoir 7.5'
Twp, Range, Section	T13S, R89W, SE 1/4, NE 1/4, NW 1/4, NE 1/4 sec. 8
Exposure Description	Elev. 6440 ft. ESE-facing roadcut, N of State Hwy 133 and North Fork of Gunnison River, 0.35 km SSW of Paonia Reservoir dam, across from entrance road to campground immediately below dam. Sandstones, 1.5-3 m thick, interbedded with shaly carbonaceous mudstones; local coal lenses.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Sandstone--characterized below Local coal lenses--described in Remarks
Cement	Very well indurated
Color, fresh	Very light gray buff
Color, weathered	Very light gray buff to light orange buff
Grain size	Very fine to fine-grained
Grain sorting	Moderately well sorted
Grain roundness	Subangular to subrounded
Bed Orientation	Subhorizontal
Bed Thickness	1.5-3 m
F3 Orientation	N86E/79SE (n=15)
Spacing	0.25-1 m (tr); 0.4-0.66 m (cr)
Height	1.5-3 m
Length	Exposed for only 3-6 m; true lengths unknown
Structures	Arrest lines common; twist hackle on split planes
Shape	Planar to locally subplanar; locally split planes
Termination	Against no other fractures
Mineralization	Dogtooth calcite, 2mm long; gypsum and siderite?
F4 Orientation	N13W/90 (n=4)
Spacing	0.5-6 m (tr); 2-3 m (cr)
Height	1.5-<3 m
Length	0.25-1 m (tr); 0.4-0.66 m (cr)
Structures	Arrest lines are common
Shape	Subplanar; curved broadly in dip
Termination	Against F3
Mineralization	Locally limonite-stained
Remarks	All descriptions given above pertain to joint sets in the sandstones; the corresponding cleats in a 2-cm high x 20-cm long coal lens could not be reached for measurement. The first-formed joints in the sandstone correlate with the F3 regional joint set. Face cleats in the coal lens parallel the orientation of the F3 set in the sandstone. The second-formed joint set in the sandstone correlates with the F4 regional set. They cut the full thickness of only the thinnest (1.5 m) sandstone layer, unlike the F3 joints that extend a few millimeters above and below the 1.5-3-m thick sandstone layers. The end cleats in the coal lens are at about right angles to the face cleats and appear to corralate with the F4 joint set in the sandstone.
Geologist(s)	MAG
Data Date	09/30/88

STATION 888

n = 19



x 888F3 n = 15
◊ 888F4 n = 4

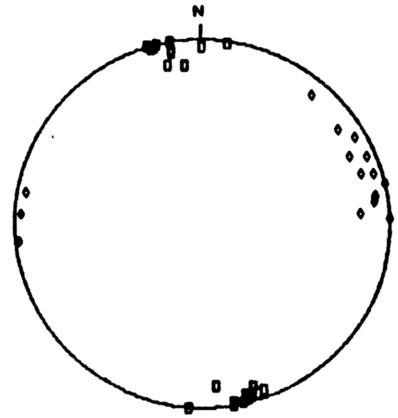
Schmidt net, lower hemisphere projection

888F3	888F4
N86W79SW	N14W88NE
N80E88NW	N10W80NE
N87W83SW	N15W88SW
N87W84SW	N12W87SW
N83E75SE	
N85W80SW	
N89W82SW	
N90W75SW	
N85E75SE	
N87E88NW	
N85E80SE	
N81E75SE	
N86E75SE	
N84E78SE	
N85E75SE	

Station Number	898
Quadrangle	Somerset 7.5'
Twp, Range, Section	T13S, R90W, NE1/4, NW1/4, SE1/4, SW 1/4 sec. 10
Exposure Description	Elev. 5940 ft. Coal seam, 2.4 m thick, road cut, N side frontage road, State Hwy 133, and North Fork Gunnison River, 0.3 km NW of Oliver Mine. Overlain by interbedded siltstone and shale which in turn is overlain by a 12-m-thick sandstone bed. Located 2.75 km E of Somerset.
Stratigraphic Unit	Upper Cretaceous Mesaverde Group
Lithology (General)	Coal, bituminous
Cement	
Color, fresh	
Color, weathered	
Grain size	
Grain sorting	
Grain roundness	
Bed Orientation	Subhorizontal
Bed Thickness	2.4 m
F3 Orientation	N75E/85SE (n=24)
Spacing	0.1-3 cm
Height	2-3 cm (cr); one is 110 cm
Length	2-12 cm (cr); one is 150 cm
Structures	Not determined
Shape	Planar; sinuous dip and local splits along bedding
Termination	Against no other fractures
Mineralization	None seen
F4 Orientation	N13W/84SW (n=15)
Spacing	0.1-1 cm
Height	0.25-8 cm
Length	0.1-3 cm
Structures	None seen
Shape	Subplanar to nonplanar
Termination	Against F3 face cleats
Mineralization	None seen
Remarks	The face cleats correlate with the F3 regional set in clastic rocks. One face cleat strikes due E, is 1.1 m high x 1.5 m long, and extends into the overlying siltstone, shale, and sandstone; none of other face cleats exceed 12 cm in length. The end cleats correlate with the F4 regionsl set in clastic rocks; they are smaller than the face cleats and terminate against them at about right angles.
Geologist(s)	HDN
Data Date	08/09/88

STATION 898 CLEATS

n = 39



• 898F3 n = 24
◊ 898F4 n = 15

Schmidt net, lower hemisphere projection

898F3	898F4
N75E88SE	N10E85SE
N84E75SE	N03E86SE
N80E85SE	N13W90SW
N74E88SE	N02W90SW
N86W90NE	N23W85SW
N80E83SE	N25W76SW
N90E85NE	N18W78SW
N82W88SW	N04W74SW
N73E82NW	N08W82SW
N85E78NW	N17W85SW
N73E90SE	N50W80SW
N75E88NW	N35W78SW
N72E86NW	N10W83SW
N78E77SE	N30W84SW
N80E90SE	N06W88NE
N76E90SE	
N77E89NW	
N80E88NW	
N74E86NW	
N75E88NW	
N80E90NW	
N70E85NW	
N76E85NW	
N75E87NW	