

# **Geologic mapping and fracture studies of the Upper Cretaceous Pictured Cliffs Sandstone and Fruitland Formation in selected parts of La Plata County, Colorado**

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***With Contributions From E.A. Johnson, R.C. Milici, And J.E. Fassett***

## **INTRODUCTION**

In early 1995 a proposal was submitted by the U.S. Geological Survey to the Colorado Oil and Gas Commission to conduct a geologic study addressing the problem of coalbed methane gas seepage in La Plata County. Part of the original proposal was to map the entire outcrop of Fruitland Formation in the county, exclusive of land on the Southern Ute Indian Reservation, and to measure fractures in these same rocks. This proposal did not meet the budget requirements of the funding group, so a scaled-down proposal was submitted, and accepted, to study only selected parts of the county. Beginning in July, 1995, the USGS conducted studies at selected places in La Plata County that had been previously identified in a geochemical survey as having a potential for above-average amounts of methane and/or hydrogen sulfide gas seepage from coal beds in the Upper Cretaceous Fruitland Formation. These areas were at Basin Creek, southwest of Durango; Carbon Junction, at the south edge of Durango; Florida River, where the coal outcrops cross the river; the South Fork of Texas Creek, west of Columbus in northeastern La Plata County; and an extension of that area southeast to the Pine River, north of Bayfield (fig. 2-1).

The objective of this study was to provide detailed geologic maps of the various sites to establish the stratigraphic position of coal beds at the outcrop in the Fruitland Formation. This stratigraphic information could then be tied to subsurface stratigraphic studies on the same stratigraphic interval being conducted by J.E. Fassett (this report). Because methane is being extracted from Fruitland coal beds a short distance south of the outcrop, and because coal beds are known to be good conduits of gas and water (Gayer and Harris, 1996; Law and Rice, 1993; Schwochow, 1991), it is important to know the extent of coal beds in the subsurface and at surface exposures. An additional part of this study was to measure orientations of joints in sandstone and cleats in coal of the Fruitland Formation and Pictured Cliffs Sandstone at surface exposures. These data can be used to show the type of fracturing present and the regional trends of possible migration pathways for methane and/or hydrogen sulfide from the subsurface to surface outcrops.

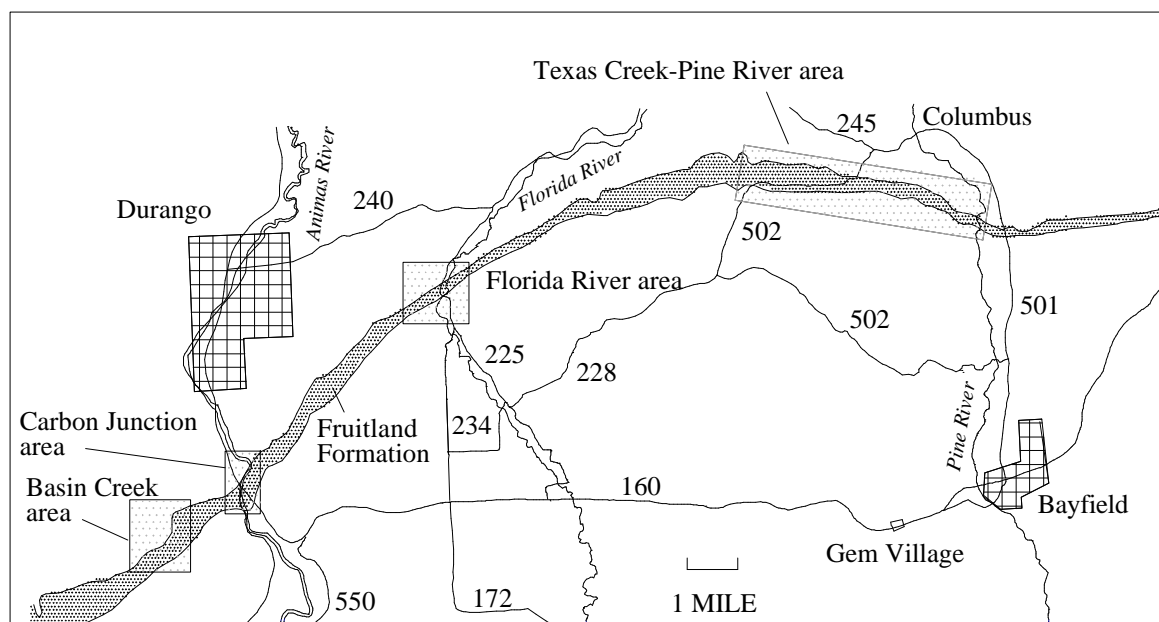
Initial reconnaissance of the area was done in July, 1995 by S.M. Condon and E.A. Johnson; subsequent mapping and fracture studies were conducted by Condon and R.C. Milici in September and October, 1995; by Condon and J.E. Fassett in April, 1996; and by Condon in May, 1996. Techniques used were (1) to

measure sections of the Fruitland to gain an understanding of the rock types and the distribution of rock types in the formation, (2) to use topographic maps and aerial photographs to create geologic maps; and (3) to measure the orientations and characteristics of fractures in sandstone and coal in the Fruitland Formation and Pictured Cliffs Sandstone.

This report is divided into two parts. Part 1 describes the geologic framework of the Fruitland Formation as determined from geologic mapping and from measuring stratigraphic sections through all or part of the Fruitland in various places. Each of the five areas is first discussed separately, and then a synthesis follows that ties together the information gathered in all of the areas. Plates 1, 2, 3, and 5 are geologic maps of the separate areas. Plate 7 shows correlations of measured stratigraphic sections in each of the areas. Part 2 is a discussion of the fractures that were measured and described in each of the sub-areas. Plates 1, 2, 4, and 6 show the locations of

where fractures were measured, plotted on a geologic base map. Note that the maps on plates 1 and 2 are at a scale of 1:6,000 and that the other maps are at a scale of 1:12,000. The small size of the mapped areas at Basin Creek (plate 1) and Carbon Junction (plate 2) allowed the use of the larger scale in those areas.

Thanks are extended to Jeff Olson, Bureau of Land Management in Durango, for his help with this project. Jeff had done preliminary geologic and geochemical studies and had contacted most of the landowners in the study areas prior to the involvement of the USGS in this project. He also provided valuable assistance in the field in collecting some of the data for this report. The manuscript benefited from the comments of Laura N.R. Roberts, Vito Nuccio, Tom Ann Casey, Debbie Baldwin, and Reed Scott.



**Figure 2-1. Map showing the location of the project area and individual sub-areas. Numbers indicate county and state roads and highways. (Modified from digital data provided by the Bureau of Land Management, Durango, Colo.)**

## PART 1—GEOLOGIC FRAMEWORK

### Basin Creek

Mapping in the Basin Creek area was mainly in the southwest and northeast quarters of section 7 and a small part of the SE¼ of section 6, T. 34 N., R. 9 W. (plate 1). This area is characterized by fairly steep topography, with the Fruitland Formation outcrop ranging in elevation from less than 6700 ft along the creek to nearly 7500 ft in the northern part of the study area. The Upper Cretaceous Pictured Cliffs Sandstone and Fruitland Formation strike northeasterly in this area and dip to the southeast, forming part of the northwest side of the San Juan Basin. Dips range from 20 degrees to 42 degrees (Table 2-1), but average about 28 degrees.

A major obstacle to geologic mapping in the part of the area south of the creek is the presence of dense stands of brush that completely obscure much of the hillsides. In that area only scattered outcrops are exposed, mainly along ridge lines. The area north of the creek is covered by a piñon-juniper forest, typical for this area, with

2 and plate 7, was measured along the road. Plate 1 shows the geology of this area. The oldest geologic unit shown on the map is the Upper Cretaceous Lewis Shale, a gray marine shale unit. The contact of the Lewis with the overlying Pictured Cliffs Sandstone is not exposed south of the creek, but is visible high on the west and northwest-facing cliffs north of the creek. This contact was interpreted from aerial photographs, and was placed at the base of the massive sandstone beds of the Pictured Cliffs. The contact is gradational, with sandstone beds in the upper Lewis becoming thicker up-section. The Pictured Cliffs is light brown to light gray, very fine grained, well-sorted sandstone. Some intervals in the Pictured Cliffs are firmly cemented with calcite; other intervals are non-calcareous. Black accessory minerals and reddish-orange oxidized iron minerals are abundant in this area. Also abundant are burrows of the trace fossil *Ophiomorpha*, which can be observed on the large exposed dip slope just north of the road at station BC01<sup>1</sup>. The thickness of the Pictured Cliffs depends on where the contact is placed with the underlying Lewis Shale. Based on nearby drill holes, the thickness in this area is estimated to be between 125 and 200 ft.

**Table 2-1. Strike and dip measurements in the Basin Creek area.**  
[Locations are shown on plate 1.]

| Station No. | Strike and dip | Station No. | Strike and dip |
|-------------|----------------|-------------|----------------|
| BC01        | N45°E/29°SE    | BC14        | N48°E/28°SE    |
| BC03        | N45°E/32°SE    | BC16        | N45°E/25°SE    |
| BC04        | N52°E/24°SE    | BC17        | N45°E/37°SE    |
| BC05        | N44°E/24°SE    | BC18        | N60°E/42°SE    |
| BC07        | N48°E/26°SE    | BC21        | N45°E/26°SE    |
| BC08        | N53°E/20°SE    | BC26        | N62°E/31°SE    |
| BC09        | N50°E/20°SE    | BC28        | N45°E/31°SE    |
| BC13        | N52°E/24°SE    | BC44        | N53°E/23°SE    |

somewhat better exposures of the mapped rocks. A road is present along the north side of the creek, and several road cuts allow for examination of the Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale. The measured section in this area, shown on figure 2-

<sup>1</sup> The numbering system for fracture stations is as follows: Basin Creek = BC\_\_, Carbon Junction = CJ\_\_, Florida River = FR\_\_, Pine River = PR\_\_. In these areas the prefix is not shown on the maps in order to make the maps easier to read. In the Texas Creek area a series of flatirons was lettered A through J and stations are designated TA\_\_ through TJ\_\_.

In the northern part of the area a tongue of Pictured Cliffs overlies the main body. From just north of the road to just west of station BC07 the tongue is separated from the main body by a thin coal bed. This coal bed pinches out to the north, but the tongue can still be differentiated on the basis of weathering characteristics. It forms an upper, more massive-weathering ledge that can be followed updip past the mapped area. The tongue is light gray, very fine grained, well sorted sandstone that has abundant dark accessory minerals that highlight crossbedding laminae in some places. No *Ophiomorpha* burrows were noted in the Pictured Cliffs tongue, but it does appear to be bioturbated in places. A rooted sandstone is at the top of the tongue, which is overlain by a coal bed of the Fruitland Formation. The tongue appears to thin and pinch out southward at about the position of the road through the area; it was not seen in the poor exposures south of the creek. In the northern part of the area, at station BC08, the tongue is about 50 ft thick, with the lower 35 ft being a mixture of sandstone and shale and the upper 15 ft a massive sandstone.

The Fruitland Formation is a heterogeneous unit consisting of interbedded sandstone, mudstone, carbonaceous shale, and coal beds (fig. 2-2). As mentioned above, in the central part of the mapped area a coal bed, which is a tongue of Fruitland, separates the main body and a tongue of the Pictured Cliffs Sandstone. This coal bed is only about 1 ft thick and is poorly exposed over most of its extent, so it was not mapped separately. The Fruitland measured along the road is just less than 400 ft thick (fig. 2-2, plate 7), which is slightly less than the thickness of the Fruitland in nearby wells. This discrepancy may be due to conservatively estimating a thick covered interval in the upper part of the formation along the road.

Sandstone beds of the Fruitland are very fine to fine grained, well sorted, and firmly cemented with calcite. Accessory minerals are abundant and are of a greater variety compared to Pictured Cliffs sandstones. Reddish-orange oxidized iron minerals are especially abundant in Fruitland sandstone beds. Clay rip-up clasts are abundant in one sandstone bed near the base of the formation. Sandstone beds in the Fruitland can generally be grouped into two types: channel sandstones and crevasse splay sandstones. The channel sandstones typically fine upward, have a lenticular geometry, and are crossbedded. Thicknesses of the channel sandstones in this area are as much as 25 ft. Crevasse splay sandstones are commonly thinner, on the order of 1-3 ft thick, and maintain a more constant thickness along strike than the channel sandstones. They are commonly bioturbated and don't display crossbedding. These thinner, more brittle sandstone beds fracture more readily and regularly than the channel sandstones though, and were used more than channels in measuring joints for this study.

Mudrock is a generic term for the clay- and silt-sized fraction of rocks in the Fruitland Formation. Two types of mudrock are recognized: mudstone and carbonaceous shale. Mudstone ranges from light to medium gray to greenish-gray. It commonly has a hackly, or blocky fracture pattern, but is fissile in some exposures. Carbonaceous shale is dark gray to black, moderately to highly carbonaceous, and commonly has a fissile or platy fracture. The two types of mudrock are normally interbedded and gradational into one another. Ironstone concretions are common in Fruitland mudrock of both lithologies. These concretions are a rusty orange color, and are very dense and hard.

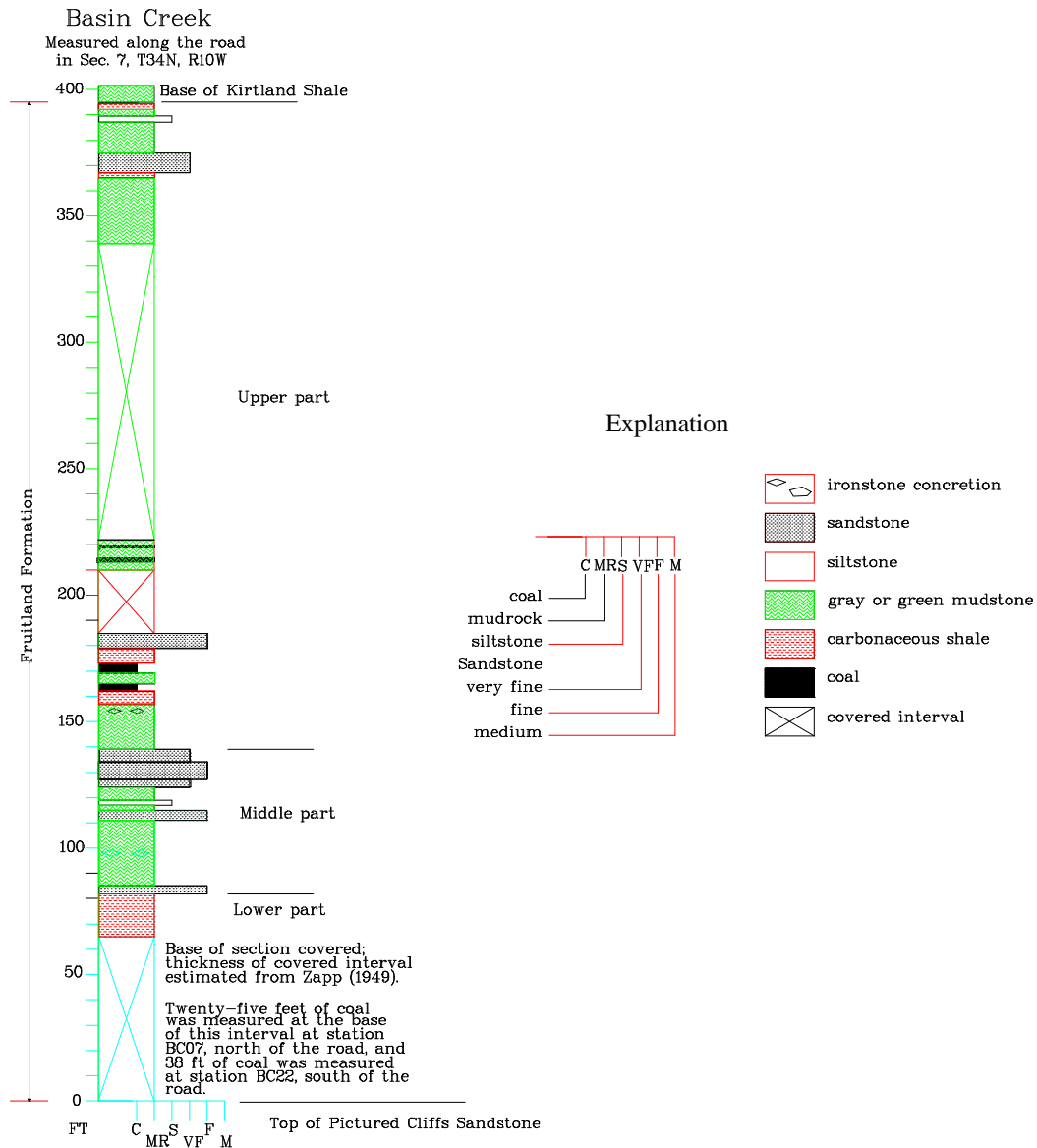


Figure 2-2. Stratigraphic section at Basin Creek. See plate 7 for correlation to other sections.

Coal in the Fruitland Formation in this area generally occurs in thin beds, except at the base of the formation, where thick beds are present. The occurrence of coal determined the division of

the Fruitland into the units shown on the geologic map (plate 1) and the measured section (fig. 2-2, plate 7). Although at any given outcrop in this area several coal beds can be distinguished, these

beds cannot be traced very far laterally because of the poor exposures, especially south of the creek. Instead of tracing individual beds, the Fruitland was divided into lower, middle, and upper parts. The lower part consists of thick coal beds, with or without mudstone or sandstone partings. The middle part consists largely of sandstone and mudstone beds, with relatively minor amounts of carbonaceous shale and coal. The upper part consists of repeating cycles of carbonaceous shale, thin coal beds, and sandstone. South of the creek the lower and middle parts of the Fruitland could not be separated, due to cover, and so are mapped together.

The thickest coal beds in the Fruitland lie at the base of the formation, directly over the tongue of Pictured Cliffs, or over the main body where the tongue is not present. At station BC07 25 ft of coal was measured, overlain by an additional 5-10 ft of ash from burned coal. This basal coal thickens to the south of the creek where 38 ft was measured at station BC22. An additional 21 ft of coal above the basal coal was measured at station BC24. A small adit was dug into the basal coal just west of station BC07, north of the creek, and a collapsed mine entrance is at station BC18 on the south side of the creek. Kaolinite beds are present in the lower coal interval, but outcrops are so discontinuous that the clay beds couldn't be traced from one area to another.

One feature of the Basin Creek area that was not seen in any of the other studied areas is the presence of thick intervals of ash from burned coal beds in the lower part of the Fruitland. As much as 10 ft of ash is present above the coal at station BC07, and ash is common in the narrow gully north of station BC31. An associated feature is the presence of abundant amounts of reddish-orange, burned sandstone that has been shattered into small pieces by heat. This burned sandstone is known by the general term "clinker", and a large area of it was mapped in the north-central part of the area. Although this is the largest area of clinker, the whole area north of

the road has scattered occurrences of it. The thick beds of coal at the base of the Fruitland burned, but the thin beds higher in the section did not.

The middle part of the Fruitland in this area is dominated by channel sandstone beds, but also includes mudrock and coal. In general, the middle part coarsens upward, with mudstone and carbonaceous shale being more abundant low in the middle part and sandstone being more abundant high in the middle part. The top of the middle part is marked by a thick sequence of stacked fluvial channels that can be seen both south and north of the creek. Coal is present in thin beds in the middle part of the Fruitland, but is not abundant.

The upper part of the Fruitland consists of thin coal beds interbedded with mudstone, carbonaceous shale, and sandstone. In this area there are three complete sequences of mudrock, coal, and sandstone and a partial fourth sequence. The sandstone beds are relatively thin, about 10 ft being a maximum thickness, but they can be traced laterally throughout the area north of the road. The sandstone beds serve as marker beds because they always overlie 1-3 ft thick coal beds in this area. Similar sequences of mudrock, coal, and sandstone are also present south of the creek, but the poor exposures make it impossible to trace the units laterally.

The uppermost part of the Fruitland is well-exposed at station BC17. This unit consists of interbedded mudstone, carbonaceous shale, thin streaks of coal, minor sandstone, and green siltstone. Characteristic features are light-orange septarian nodules that formed in siltstone intervals. A 1.5 inch pelecypod was found in gray mudstone in this upper unit. This unit appears to be transitional with the overlying Upper Cretaceous Kirtland Shale; the main difference being the presence of the carbonaceous beds in the Fruitland and their absence in the Kirtland. The lower part of the Kirtland also has relatively more sandstone than the upper part of the Fruitland, in this area and in the other areas studied.

A small fault is well-exposed in the outcrop described above at station BC17. Viewed from the south side of the road, the trace of the fault is U-shaped, with a broad, nearly horizontal trace along most of the outcrop. There is only about 1-2 ft of offset on the fault and it is down to the northwest. Since this fault is only seen in a vertical outcrop face, it couldn't be shown on the geologic map (plate 1). A second possible fault was noted just north of station BC34. This fault appears to cut the top sandstone in the middle part of the Fruitland. It trends N30°W and dips steeply to the northeast. It is down to the southwest and there may be as much as 10 ft of offset. A third area of possible faulting or slumping is near station BC15 in a roadcut.

side of the gravel pit on Ewing Mesa, outside the mapped area (fig. 2-3). Both of these sections are shown on plate 7. The topography of Carbon Junction Canyon is steep, but the elevation is only between about 6500 and 6700 ft. The ridge line above the shooting range extends higher, up to about 6900 ft at the western end of the mapped area. As in the Basin Creek area, the Pictured Cliffs Sandstone and Fruitland Formation strike northeasterly and dip to the southeast. Dips range from 24 to 35 degrees and average 31 degrees (Table 2-2).

**Table 2-2. Strike and dip measurements in the Carbon Junction area.**  
[Locations are shown on plate 2.]

| Station No. | Strike and dip | Station No. | Strike and dip |
|-------------|----------------|-------------|----------------|
| CJ01        | N50°E/33°SE    | CJ11        | N53°E/35°SE    |
| CJ02        | N46°E/24°SE    | CJ12        | N53°E/35°SE    |
| CJ04        | N50°E/33°SE    | CJ13        | N45°E/32°SE    |
| CJ06        | N57°E/31°SE    | CJ18        | N48°E/35°SE    |
| CJ07        | N64°E/29°SE    | CJ20        | N58°E/27°SE    |
| CJ08        | N64°E/29°SE    | CJ23        | N47°E/34°SE    |
| CJ09        | N58°E/34°SE    | CJ24        | N50°E/30°SE    |
| CJ10        | N64°E/24°SE    |             |                |

Although somewhat covered, it appears that there may have been faulting or slumping along bedding planes in carbonaceous shale low in the upper part of the Fruitland.

## Carbon Junction

Mapping in the Carbon Junction area was in sections 4 and 5, T. 34 N., R. 9 W., east of the Animas River (plate 2). Reconnaissance was also done on the west side of the river above the shooting range. Two sections were measured in this area; one at the lower end of Carbon Junction Canyon, extending southward along the highway roadcut, and the other on the northeast

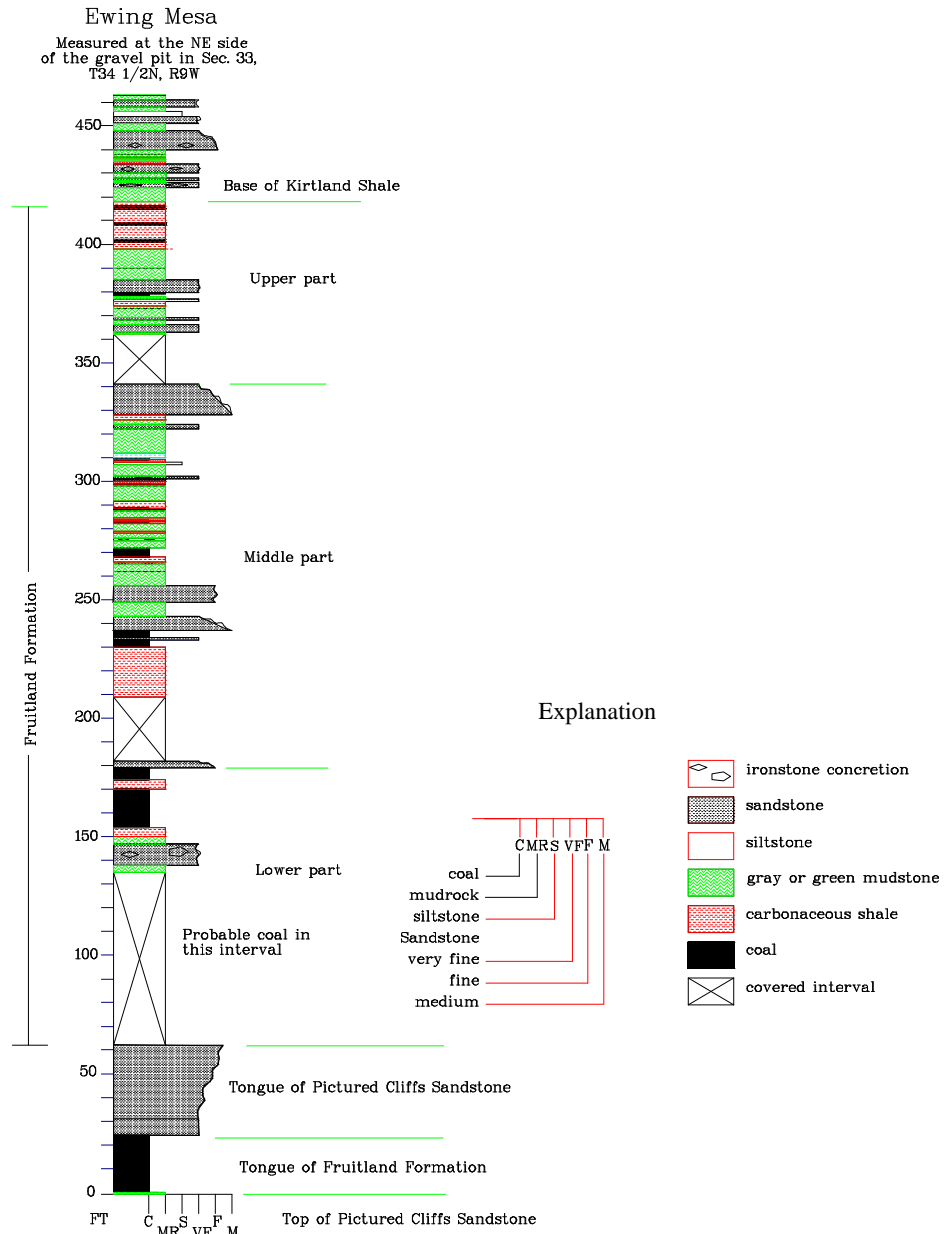


Figure 2-3. Stratigraphic section at Ewing Mesa.  
See plate 7 for correlation to other sections.

The vegetation in the Carbon Junction area is similar to that at Basin Creek—piñon-juniper forest. The underbrush is not quite as dense at Carbon Junction as at Basin Creek, but the steep southeast canyon wall made it somewhat difficult to accurately locate outcrops on the aerial photographs to make the geologic map. The best

exposures of the Fruitland are at two places along the creek, in eroded gullies that cut the southeast canyon wall, and also along the old highway road cuts south of the canyon.

Plate 2 shows the geology of the Carbon Junction area. The oldest unit shown is the Lewis Shale, which underlies the Pictured Cliffs Sandstone. The contact of the Lewis with the



Pictured Cliffs was interpreted from aerial photographs in this area. The lithology of the Pictured Cliffs is the same here as at Basin Creek—light brown to light gray, very fine grained, well sorted sandstone. A dark gray to black sandstone is at the top of the Pictured Cliffs in some exposures. This sandstone is rooted, similar to the one found at the top of the tongue of Pictured Cliffs at Basin Creek. The Pictured Cliffs forms a narrow ridge line held up by massive sandstone beds in the upper part of the formation.

A tongue of Pictured Cliffs is present in Carbon Junction Canyon, but it is only well-exposed at the northeastern end of the mapped area (plate 2). At this outcrop the unit is about 30 ft thick, is light yellowish-gray, fine grained, and well sorted. It displays minor amounts of small-scale crossbedding, but mainly has horizontal, wavy bedding. The upper part of the sandstone contains abundant carbonaceous material. This bed thins abruptly southwestward and is replaced by thick coal at the base of the Fruitland Formation (plate 7).

Lithologies of the Fruitland Formation at Carbon Junction are the same as those in the Basin Creek area, which are sandstone, mudrock, and coal (fig. 2-3). The Fruitland was divided into the same lower, middle, and upper units that were mapped at Basin Creek. The section of Fruitland measured in and near Carbon Junction Canyon is only about 280 ft thick; the upper part of the unit is covered by terrace gravels. A complete section was measured at the Ewing Mesa gravel pit. There, the Fruitland is about 355 ft thick, not including a tongue of coal and mudstone 25 ft thick below the tongue of Pictured Cliffs Sandstone (fig 2-3, plate 7).

The lower part of the Fruitland is composed mainly of coal, with minor mudrock and siltstone partings. There are two good exposures of this unit at stations CJ01 and CJ25, and partial exposures at station CJ02. At station CJ25 a total of 80 ft of coal was measured, consisting of a lower bed 37 ft thick and an upper bed 43 ft thick, separated by 4 ft of mudrock and siltstone. At station CJ01 the lower contact of the coal is not exposed; 20 ft of coal is exposed above the stream bed and is overlain by 3-4 ft of partings

that correlate with the same interval at station CJ25. An upper bed of coal 45 ft thick overlies the partings. At station CJ02 about 12 ft of coal is exposed above the stream and it is overlain by the tongue of Pictured Cliffs Sandstone. A kaolinite bed, 6"-7" thick, that occurs approximately 1 ft below the parting is present at both stations CJ01 and CJ02. The thick coal beds in the lower part of the Fruitland are partially replaced northeastward by the tongue of Pictured Cliffs, and partially overlies the tongue. A strong odor of hydrogen sulfide was noted in several places in Carbon Junction Canyon at the top of the basal coal of the Fruitland.

The middle part of the Fruitland is composed of interbedded carbonaceous shale and sandstone with relatively minor amounts of coal. Northeast of about station CJ15 a channel sandstone bed is at the base of the middle part; southwest of that locality carbonaceous shale is at the base. Otherwise, the amount of sandstone in the middle part increases upward in the section, similar to the middle part at Basin Creek. Sandstone beds are of channel and crevasse splay origin and reach a thickness of as much as 25 ft at the top of the middle part of the Fruitland. One or two 1 ft thick coal beds are present just below this upper sandstone; only carbonaceous shale was noted lower in the middle part.

The best exposures of the upper part of the Fruitland are at stations CJ7-10. As at Basin Creek, the upper part here consists of sequences of carbonaceous shale and coal intervals separated by sandstone beds. The carbonaceous shale beds are as thick as 40 ft; the coal beds are as thick as about 3 ft; the sandstone beds average about 6-10 ft thick. The contact with the Kirtland Shale occurs in the gravel-covered slopes just west of the water tank at the southeast corner of the mapped area (marked WT on the base map, plate 2). The contact was placed at a zone of septarian nodules that weathers out of the gravel-covered slope. I believe that this zone is at the same stratigraphic position as that noted at the top of the Fruitland at Basin Creek.

Exposures of the Fruitland Formation adjacent to the shooting range (plate 2) were examined and found to be essentially the same lithologies as those at Basin Creek and in Carbon

Junction Canyon. There is a thick coal sequence at the base of the Fruitland overlain by a sequence of carbonaceous shale, coal, and sandstone beds. Much of the Fruitland just west of the shooting range is obscured by landslide deposits, shown on the map as the Qls unit. I did climb up the rim of the Pictured Cliffs west of the range to examine what appeared to be a thick coal bed, but what is actually tailings from mining activity. The "coal" bed is a mixture of finely ground carbonaceous shale, mudstone, and coal that has been dumped on top of the Pictured Cliffs Sandstone.

No definite faulting was seen in Carbon Junction Canyon, but an area of disrupted bedding just northeast of station CJ15 was noted. It appears that there is some offset of a channel sandstone at the base of the middle part of the Fruitland Formation at that locality, but poor exposures made it difficult to determine if there was offset on a fault or just slumping of the outcrop.

## Florida River

Mapping in the Florida River area was

mainly in sec. 24, T. 35 N., R. 9 W., but extended southwestward into the SE¼ of section 23 and northeastward into sections 18 and 19, T. 35 N., R. 8 W. The area ranges in elevation from about 7100 ft along the Florida River to over 8100 ft where the Pictured Cliffs Sandstone forms the ridge in the southwest part of the study area. This outcrop area is a continuation of the exposures at Carbon Junction and the strike of the Pictured Cliffs Sandstone and Fruitland Formation remain northeasterly. Dip is southeast into the San Juan Basin. Dips in this area are the highest of any of the areas mapped, ranging from 27 degrees (which seems anomalously low) to 59 degrees, averaging 48 degrees (Table 2-3).

Much of this area is covered by piñon-juniper forest, but the increase in elevation is enough for Ponderosa pine and other larger conifer trees to grow in places. In the lower elevations, especially on the southwest side of the river and on slopes adjacent to the east side of the river, dense underbrush again obscures much of the surface geology. An old road traverses part of the area southwest of the river, providing limited access to some of the area. The best exposures in the area are along the Florida canal,

**Table 2-3. Strike and dip measurements in the Florida River area.**  
[Locations are shown on plate 4.]

| Station No. | Strike and dip | Station No. | Strike and dip |
|-------------|----------------|-------------|----------------|
| FR01        | N63°E/54°SE    | FR23        | N62°E/45°SE    |
| FR02        | N50°E/45°SE    | FR24        | N51°E/55°SE    |
| FR03        | N58°E/53°SE    | FR26        | N64°E/54°SE    |
| FR04        | N58°E/53°SE    | FR27        | N66°E/45°SE    |
| FR05        | N62°E/42°SE    | FR28        | N60°E/45°SE    |
| FR08        | N57°E/27°SE    | FR30        | N74°E/56°SE    |
| FR11        | N65°E/39°SE    | FR31        | N54°E/51°SE    |
| FR12        | N59°E/44°SE    | FR32        | N65°E/52°SE    |
| FR15        | N60°E/38°SE    | FR35        | N65°E/40°SE    |
| FR16        | N64°E/46°SE    | FR36        | N55°E/59°SE    |
| FR17        | N68°E/48°SE    | FR38        | N70°E/50°SE    |
| FR19        | N68°E/58°SE    | FR39        | N66°E/51°SE    |
| FR20        | N64°E55°SE     | FR40        | N61°E/54°SE    |

adjacent to the north-south paved road. A stratigraphic section was measured in the cuts along the canal (fig. 2-4, plate 7).

Plate 3 shows the geology of the Florida River area. The contact of the Lewis Shale with the Pictured Cliffs shown on the maps was interpreted by aerial photo analysis. The Pictured Cliffs Sandstone—Fruitland Formation contact is conformable and intertonging in this area. A tongue of Fruitland Formation is present below a tongue of Pictured Cliffs Sandstone at the Florida River area, but pinches out a short distance northeast of the river. The contact between the Fruitland Formation and Kirtland Shale is also conformable and gradational in this entire area.

In the mapped area the Pictured Cliffs Sandstone occurs as a lower main body and an upper tongue. The main body transitionally overlies the Lewis Shale and is composed of a lower and an upper part. The lower part consists of interbedded very fine-grained, argillaceous, thin, rippled sandstone and gray shale; sandstones in this interval become thicker-bedded higher in the section, and the percentage of gray shale decreases upward. *Ophiomorpha* burrows were noted at one outcrop in this interval. The top of this lower part is composed of massive, yellowish sandstones that form the dip slopes at stations FR02 and FR07 (plate 4). This lower part of the main body is not continuously exposed, but is estimated to be about 150-200 ft thick, depending on the placement of the lower contact with the Lewis Shale. The upper part of the main body is composed of a light-gray, fine-grained sandstone that forms a distinctive ridge along the outcrop. It is much less argillaceous than sandstones of the lower part of the main body of the Pictured Cliffs. This upper part is relatively thin, on the order of 15-25 ft thick. A dark gray to black rooted zone is present at the top of this unit. The main body, mapped as Kpc, is poorly exposed northeast of Florida River, but regional stratigraphic relations suggest that it pinches out depositionally into the Lewis Shale a short distance northeast of the river.

The tongue of Pictured Cliffs Sandstone is light gray to yellowish gray, very fine to fine-

grained, well sorted sandstone. It is well-exposed near the highest point in the mapped area, downslope from station FR08. There it consists of a series of thick sandstone beds that have a combined thickness of at least 100 ft. Along the Florida canal, near County Road 225 (plate 3), the tongue was measured at 123 ft thick. The tongue forms a prominent outcropping ridge along the north side of Horse Gulch Road (County Road 237) and along the irrigation canal, but is poorly exposed northeast of Florida River. Northeast of the river it is hidden in the trees on the north-facing slope of the hogback. It gradually rises topographically northeastward and eventually forms the ridge line northeastward from section 17.

As shown on figure 2-4 and plate 3, the Fruitland Formation is divided into several mapped intervals on the basis of lithology. As measured along the Florida canal, the Fruitland is about 460 ft thick. Where the Fruitland Formation is well exposed it can be broadly divided into as many as three coal-bearing intervals, separated by sandstone and mudstone. Extensive cover in the Florida River area made it difficult to accurately trace out these intervals and some units were combined in some areas. In the Florida River area the tongue of Fruitland Formation (Kft), a lower coal-bearing interval (Kfab), and an upper coal-bearing interval (Kfu) are highlighted on the geologic map. The tongue of Fruitland contains a thin (1-3 ft thick) bed of coal at the base and another about 20 ft above the base, but otherwise is composed of mudstone, carbonaceous shale, and thin sandstone beds. At station FR09 a bed of carbonaceous shale underlies the tongue of Pictured Cliffs Sandstone. It is quite possible that this carbonaceous shale is replaced by coal in other areas nearby. In the Ewing Mesa area, southwest of Florida River (plate 7), a coal bed is present just below the tongue of Pictured Cliffs Sandstone. The tongue of Fruitland Formation was estimated to be approximately 30 ft thick at station FR09; it thins northeastward and pinches out in the alluvium-covered, north-facing slope northeast of Florida River.

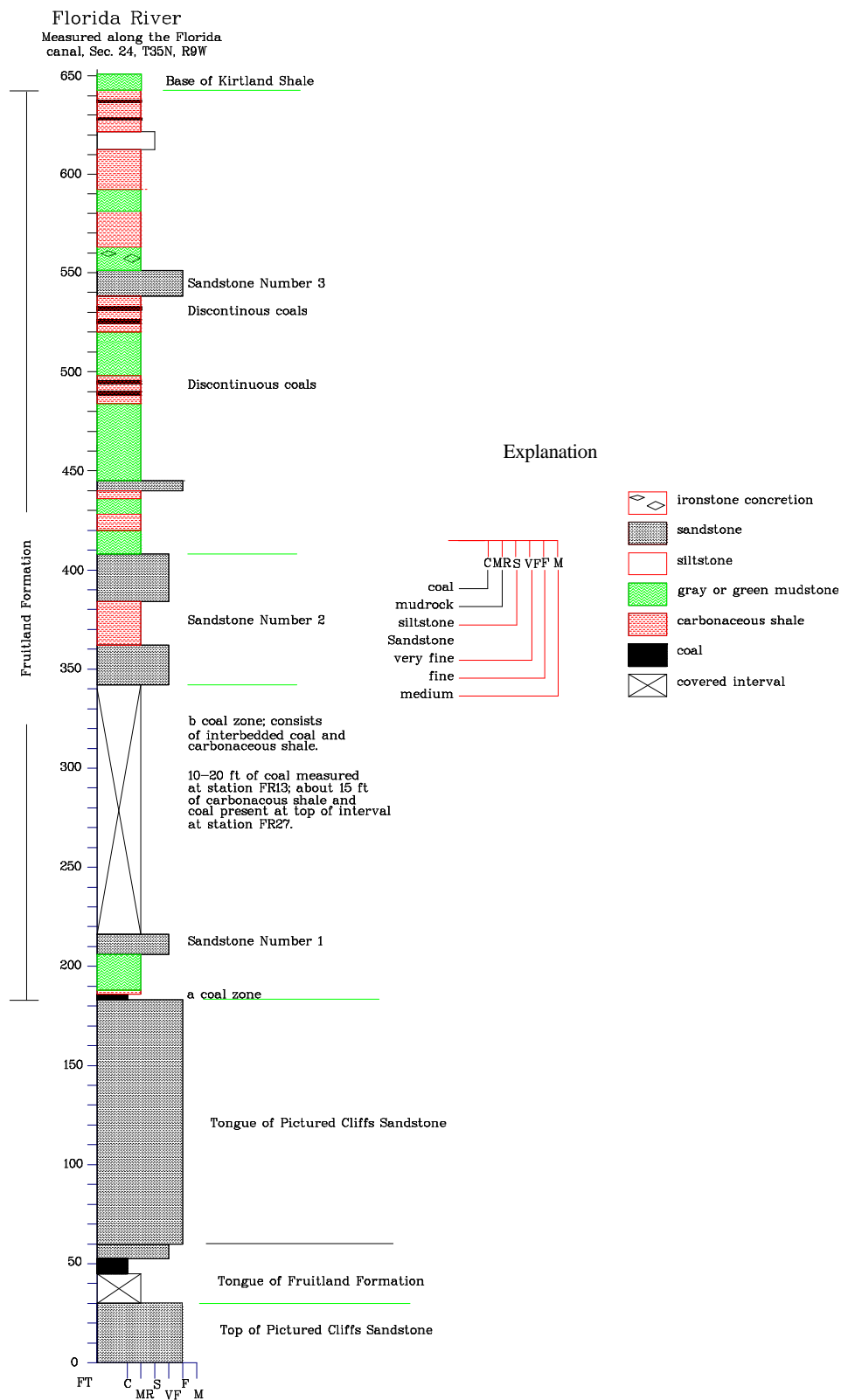


Figure 2-4. Stratigraphic section at Florida River. See plate 7 for correlation to other sections.

The unit labeled Kfab on the geologic map contains the thickest beds of coal in this area. The coal immediately overlying the upper tongue of Pictured Cliffs Sandstone is poorly exposed in most of the area, and is quite thin in comparison with coals in similar stratigraphic positions in the Carbon Junction and Texas Creek areas. The Kfab unit contains a thin sandstone above the lowest coal, and is overlain by another carbonaceous shale and coal interval. The lowest coal is 3 ft thick along the Florida canal (plate 7) and is overlain by about 20 ft of carbonaceous shale and brown mudstone. The first sandstone in the Fruitland, which was not mapped separately due to poor exposures, is a composite of about 3 ft of sandstone interbedded with 7 ft of mudstone along the canal. The interval between the first and second sandstones is about 125 ft thick along the canal (possibly overestimated in this covered interval). Coal just below Kf2 is the thickest in the area; a unit of interbedded coal and carbonaceous shale about 15 ft thick immediately underlies Kf2. A kaolinite bed was noted in this coal sequence at station FR18. An adit was discovered just off the old road in the SW $\frac{1}{4}$  of section 24 within the Kfab interval (see plates 3 or 4 for the location of the adit). Northeast of the river a small area of the upper Kfab unit is covered with reddish-orange chips of sandstone typical of burned coal intervals. Heavy brush in this area made it difficult to trace the clinker very far to the northeast.

Kf2 is a sandstone that forms a steep hogback on the southwestern end of the study area and forms the low ridge that much of the old road in section 24 was built on. The upper part of Kf2 forms the ridgeline northeast of Florida River. Kf2 is very thick (50-75 ft) in the southwest part of the area, where it appears to be a fining-upward stacked channel complex. The unit thins somewhat to the northeast.

At the southwest end of the mapped area another sandstone, Kf3, overlies the Kf2 sandstone. In that part of the area no coal was seen separating the two sandstones; however, at the Florida canal (plate 7) and east of the river, coal is present below this third sandstone interval. Two to three feet of coal is present

along the irrigation canal, and a similar amount is present east of the river.

The upper part of the Fruitland, mapped as Kfu, is a unit transitional with the Kirtland Shale. It consists of thin sandstone beds, greenish-gray mudstone, carbonaceous shale, and thin coal beds. Kfu generally weathers to a poorly exposed slope, but is well-exposed along the Florida canal. The top contact was mapped at the base of a greenish, argillaceous sandstone that forms a low ridge in many places. This upper unit of the Fruitland contains characteristic yellowish-orange septarian concretions that were also seen in the Basin Creek and Carbon Junction areas. A coal bed 1-2 ft thick was measured at stations FR21 and FR22 at the top of the Kfu unit (plate 4). Carbonaceous shale with thin streaks of coal are present lower in Kfu, but no other continuous coal beds were seen.

The Fruitland Formation is gradationally overlain by the Kirtland Shale throughout this area. As noted previously in other areas along the Fruitland outcrop, the basal Kirtland beds are similar to the upper beds of the Fruitland, but lack the carbonaceous shale and coal. One other difference in this area is that sandstone beds of the Kirtland have a greenish color or are iron-rich and are dark brown as opposed to the yellowish-brown sandstone beds characteristic of the Fruitland. The contact between the Fruitland and Kirtland could thus change laterally if coal beds occur higher or lower in the section.

Fairly large areas just southwest and northeast of Horse Gulch (plate 3), are obscured by terrace gravel and were mapped as Qg. These units, and a smaller, similar unit just east of the Florida River are composed of pebbles and cobbles of igneous and metamorphic rocks. Quaternary alluvium (Qal) is present in the valley of Florida River and in a drainage adjacent to the largest terrace gravel deposit. Exposures in Horse Gulch, especially on the south side of the stream, are quite poor. Contacts were drawn as dashes across the drainage to show the inferred distribution of units.

No faulting or other structural complications were noted in this mapped area. The main structural feature is the extreme dip of the beds;

however, the dip moderates abruptly just a short distance basinward from the Fruitland outcrop.

## South Fork of Texas Creek to the Pine River

An extensive area was mapped along part of the South Fork of Texas Creek and southeastward to the Pine River in northeastern

hills. In contrast, in the eastern part of the area the Pictured Cliffs and units of the Fruitland form a long, linear outcrop. The elevations of the area gradually decrease from west to east, from nearly 8900 ft at Vosburg Pike in the west to about 7200 ft in the east at the Pine River. This area of outcrops lies at the northern rim of the San Juan Basin; this particular segment of the rim has a northwestward strike and the rocks dip southwestward. In the Texas Creek part of the

**Table 2-4. Strike and dip measurements in the South Fork of Texas Creek area.**  
[Locations are shown on plate 6.]

| Station No. | Strike and dip | Station No. | Strike and dip |
|-------------|----------------|-------------|----------------|
| TA01        | N85°W/13°SW    | TD03        | N76°W/28°SW    |
| TA03        | N85°W/25°SW    | TD04        | N72°W/25°SW    |
| TA04        | N80°W/19°SW    | TD05        | N85°W/25°SW    |
| TA05        | N85°W/16°SW    | TD06        | N77°W/23°SW    |
| TA08        | N80°E/34°SE    | TD07        | N90°E/28°S     |
| TA10        | N88°E/19°SE    | TE02        | N81°W/31°SW    |
| TA11        | N90°E/20°S     | TE03        | N85°W/23°SW    |
| TB01        | N80°E/35°SE    | TE04        | N52°W/15°SE    |
| TB02        | N88°W/17°SW    | TE05        | N79°W/31°SW    |
| TB03        | N80°E/21°SE    | TE06        | N40°W/20°SW    |
| TB04        | N90°E/17°S     | TE07        | N75°W/25°SE    |
| TB07        | N89°E/26°SE    | TF01        | N80°W/24°SW    |
| TC02        | N80°E/20°SW    | TF03        | N80°E/21°SW    |
| TC04        | N84°W/22°SE    | TF04        | N44°W/25°SW    |
| TC05        | N84°W/12°SW    | TG01        | N70°W/12°SW    |
| TC06        | N77°W/25°SW    | TG02        | N67°W/25°SW    |
| TC08        | N85°W/18°SW    | TH01        | N44°W/15°SW    |
| TD01        | N79°E/24°SW    | TI01        | N50°W/15°SW    |
| TD02        | N73°W/22°SW    | TJ01        | N50°W/24°SW    |

La Plata County. This area includes parts of sections 6, 7, 8, 9, 10, 14, and 15, T. 35 N., R. 7 W. and a small bit of sec. 12, T. 35 N., R. 8 W. (plate 5). The character of this area changes significantly from west to east. In the west the Pictured Cliffs Sandstone and Fruitland Formation form a series of isolated peaks (flatirons) separated by deep drainages. This topography produces a zig-zag pattern of units in the Fruitland as the units cross the gullies and

area dips range from 12 to 35 degrees and average 22 degrees (table 2-4). In the Pine River part of the area the dips range from 23 to 52 degrees and average 35 degrees (table 2-5).

While mapping from Texas Creek to the Pine River it became apparent that significant errors exist on the topographic map in some places, especially at the boundary between the Rules Hill and Ludwig Mountain quadrangles along the Fruitland—Kirtland contact (plates 5 and 6).

For example, the wide, flat-topped hill just to the west of the Hoier property is not really as flat as the map shows. Also, the hills shown north and east of the unit shown as Qal, just east of Hoier's property, do not agree with the aerial photographs. The geologic contacts were adjusted to the topographic map, but be advised

appendix 2-1 for a composite stratigraphic section that was compiled for the western section along Texas Creek.

Plate 5 shows the geology from Texas Creek to the Pine River. The oldest unit shown is the Lewis Shale, which is overlain by the Pictured Cliffs Sandstone. In this area there is one main

**Table 2-5. Strike and dip measurements in the Pine River area.**  
[Locations are shown on plate 6.]

| Station No. | Strike and dip | Station No. | Strike and dip |
|-------------|----------------|-------------|----------------|
| PR01        | N43°E/23°SE    | PR20        | N57°W/35°SW    |
| PR02        | N80°W/36°SW    | PR22        | N61°W/28°SW    |
| PR04        | N70°W/30°SW    | PR23        | N85°W/35°SW    |
| PR05        | N44°W/32°SW    | PR27        | N84°W/39°SW    |
| PR08        | N52°W/31°SW    | PR28        | N84°W/39°SW    |
| PR10        | N66°W/39°SW    | PR29        | N70°W/45°SW    |
| PR11        | N69°W/35°SW    | PR31        | N70°W/40°SW    |
| PR12        | N70°W/31°SW    | PR33        | N65°W/52°SW    |
| PR13        | N85°W/31°SW    | PR36        | N68°W/25°SW    |
| PR16        | N85°W/32°SW    | PR38        | N80°W/34°SW    |

of the problems with the base map.

A wide range in vegetation corresponds to the change in elevation across the area. In the west, vegetation consists of Ponderosa pine forest with other mixed conifers. There is some brush in the western area, but in general the forest is open. The eastern part of the area has mixed vegetation of both tall conifer and piñon-juniper forest mixed with some stands of dense underbrush. The most covered area is in the central part of the eastern half of the area, just west of the Hoier property. A critical area in the NW¼ of sec. 14 is also very poorly exposed, which makes interpretation of faulting in that area difficult. A completely exposed section of Fruitland was not found anywhere in the mapped area, so the measured section for this area, shown in fig. 2-5 and on plate 7, is a composite of observations made at several places. Most of the descriptions were made in the western half of the mapped area; however, stratigraphic units can be traced through most of the mapped area. See

body of Pictured Cliffs overlain by one interval of Fruitland. The Pictured Cliffs Sandstone in this area is the same lithologic unit as the tongue of Pictured Cliffs Sandstone in the Florida River area (plate 7). A northeastward stratigraphic rise resulted in the lower part of the Pictured Cliffs at the Florida River pinching out depositionally into the Lewis Shale in a northeastward direction while the stratigraphically higher tongue extends into this area. The Pictured Cliffs here can also be generally divided into a lower, yellowish, argillaceous part that is transitional with the Lewis Shale and an upper part that is composed of clean, well sorted sandstone. A thin coal is present within the Pictured Cliffs in part of the northern San Juan Basin, such as in the AMOCO Gurr Federal Gas Unit No. 1 well. Although the coal was not seen at the outcrop in this study, the break between the lower and upper Pictured Cliffs would be a likely place for the coal to occur. The difference in lithology causes the two parts of the Pictured Cliffs to weather differently

and to form a double outcrop in places. On lobe H (plate 6), north of the Ragsdale property, it appears that the upper part of the Pictured Cliffs has been eroded, producing a stripped surface that is at a lower elevation than the top of the Pictured Cliffs on lobe G. This difference in elevation of the two outcrops could be mistaken for offset on a fault, but we checked this area for evidence of a fault and didn't see one.

The Fruitland in this area was again divided into several units of sandstone and coal-bearing intervals. The basal interval (Kfab) consists of mudstone, carbonaceous shale, and coal, with one, thin sandstone near the middle of the unit. This coal interval has the best exposure of any in this mapped area, particularly at the crests of the flatirons where the coal is being eroded. Reddish-orange burned sandstone chips, or clinker, are found in some areas in the basal interval, but are not abundant in this area. Altered volcanic ash beds (kaolinite) were also seen in some of the better-exposed outcrops, but are not abundant in the lower coal. The coal immediately on top of the Pictured Cliffs Sandstone thins irregularly to the southeast along this outcrop. The thickest coal was found at the base of the Fruitland at the western end of the mapped area (station TA04, plate 6). The section described below is of that outcrop.

Several small mines, with collapsed entrances, were found in the lower coal interval, at stations TB06, TJ02, and PR20 (plate 6). Poor exposures made it difficult to measure a thickness of the coal at TJ02, but about 3 to 5 ft is estimated. In contrast, the lowest coal thins to 1 foot or less in some areas toward the Pine River and thickens to 2-4 ft at the southeast end of the outcrop. A thicker interval of coal is present near the top of the Kfab unit, but it is also poorly exposed. The whole Kfab unit maintains a thickness of 40-50 ft from west to east across the whole area. I believe that this Kfab unit corresponds with the Ignacio coal seams as identified by AMOCO (1994) in the subsurface nearby.

An odor of hydrogen sulfide (H<sub>2</sub>S) was noted in three places in the lower coal interval. A moderate odor was noted at station TI01, just east of the Ragsdale property on one occasion in May. Another was just down-slope to the west of station PR01, the third was on the crest of the hill east of station PR20. An extensive area of dead vegetation is associated with the H<sub>2</sub>S area at PR20. A fourth area with H<sub>2</sub>S is just downslope from station PR35, in the Kfcd coal interval.

Overlying Kfab is sandstone mapped as Kf2. This sandstone forms many of the long dip slopes at Texas Creek and toward the Pine River. It is a

| FT  | Description  |
|-----|--|
| ~1  | Soil; top of exposure  |
| 2.3 | Coal, black, dull, poorly developed cleat and bedding. Breaks into blocky to irregular fragments up to 1" across; fractured                              |
| 2.6 | Claystone, weathered, yellowish orange to moderate yellowish brown with carbonaceous laminae in upper part   |
| 6.0 | Coal, dark gray to black, generally dull, cleat poorly developed, poorly bedded. Includes 6" of impure (silty?) coal about 1.9' from top of bed          |
| 0.3 | Claystone, yellowish gray to pale yellowish brown; kaolinitic(?)   |
| 1.0 | Coal, black, dull, blocky, well cleated  |
| 0.3 | Claystone, brownish gray   |
| 1.4 | Coal, bright, black, weathered, well bedded, good cleat  |
| 0.9 | Seat-earth, sandstone, medium gray, carbonaceous; very thin, irregular beds; rooted. Base of coal  |
| --  | Pictured Cliffs Sandstone. Sandstone, quartzose, very fine grained, very light gray, thickly bedded, wavy bedded with finely disseminated dark minerals. |



composite channel sandstone that thickens to as much as 100 ft or more in some places. The lower part of this sandstone is silica-cemented in some areas and has a distinctive rose color.

A unit mapped as Kfcd overlies the second sandstone of the Fruitland Formation in this area. This unit consists of a coal bed at the base, a concretionary limestone interval in the middle, and another coal bed at the top. The coal beds are fairly thin, averaging about 2-4 ft thick. The zone of concretions between the coals is the informally named "skeleton bed" (appendix 2-1). This bed served as a marker in the west part of the study area because of the resistant nature of the concretions and their distinctive color. This coal zone was mined at the east end of the outcrop at the Pine River. According to Barnes

(1953) this was the Schutz Mine. Based on thickness and stratigraphic position, I believe that this coal interval corresponds to that identified as the Lemon coal seams by AMOCO (1994). Two sandstone intervals overlie Kfcd, the Kf3 and Kf4 units. The Kf3 sandstone is continuous across the whole mapped area, but the Kf4 sandstone could not be traced all the way to the Pine River. Kf3 is as thick as 50 ft on the west end of the study area, but thins to about 15 ft near the Pine River. Kf4 appears to thin southeastward from about 35 ft and disappeared near the area just west of section 14 that is obscured by vegetation. Kf4 was not found in the better exposures of this part of the section just west of the Pine River.

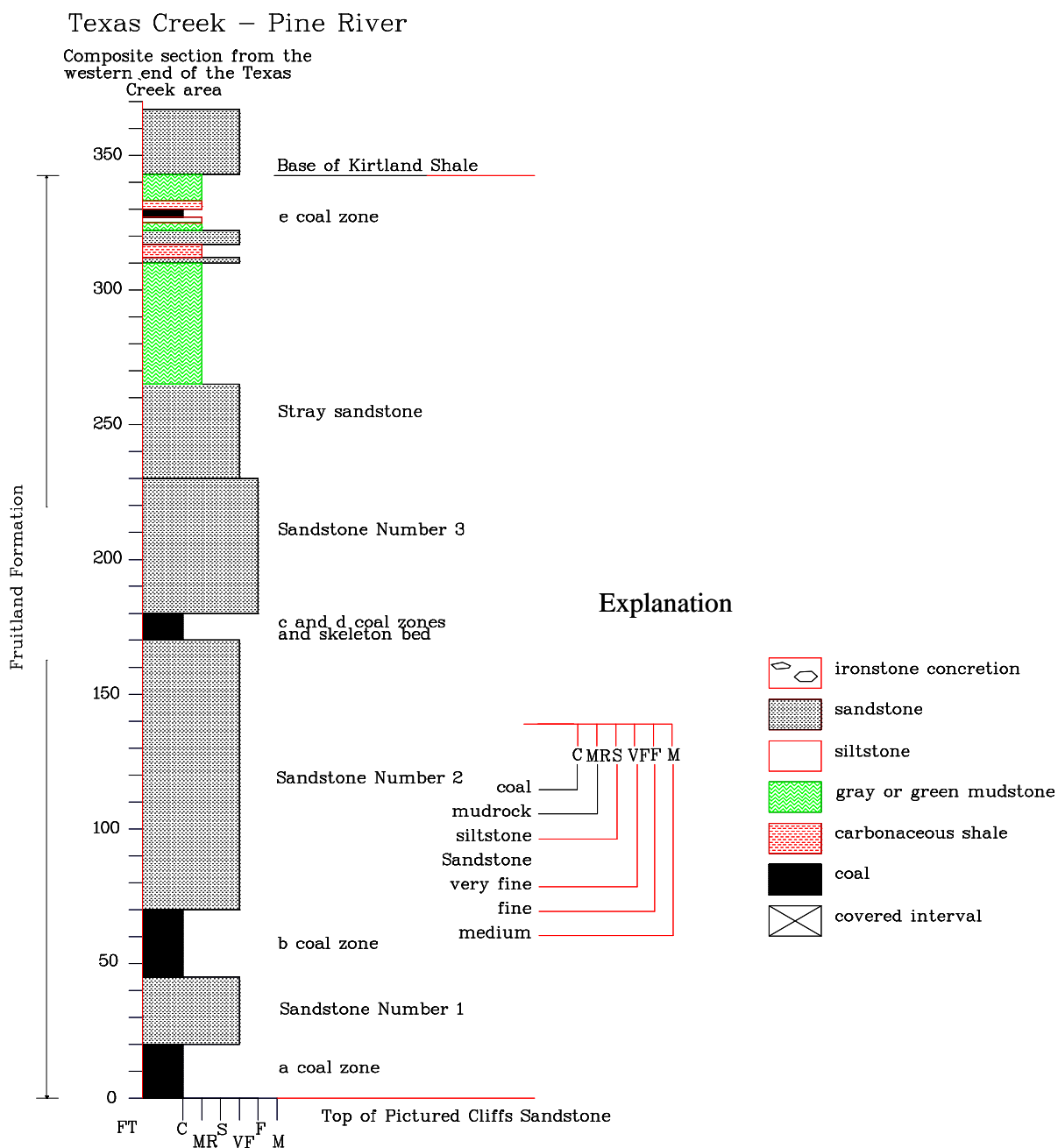


Figure 2-5. Stratigraphic section at Texas Creek-Pine River. See plate 7 for correlation to other areas.

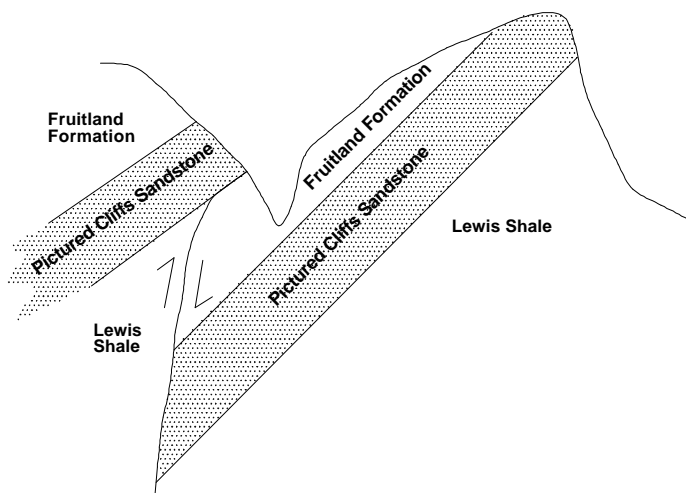
As in the other areas discussed in this report, the top unit of the Fruitland Formation was mapped as Kfu. The lithology is similar to that at Basin Creek and at Florida River and consists of greenish mudstone, thin sandstone,

carbonaceous shale, and thin coal beds. The thickness of this unit is approximately 80 ft. Here too, it has a lithology similar to the Kirtland Shale, except that the Kirtland lacks the coals. Fairly good exposures are present at stations

PR15, PR18, and PR36 (plate 6). There is not a good marker bed that can be used to separate the Fruitland Formation from the Kirtland Shale; the presence or absence of coal beds and carbonaceous shale was used to place the contact in an interval that was otherwise very similar lithologically. Based on stratigraphic position, this upper interval of the Fruitland most likely corresponds with the Pargin coal zone of AMOCO (1994).

Quaternary alluvium (Qal) is present primarily in the valley of Pine River, but was also mapped east of the Hoier property. An attempt was made to show the inferred position of Fruitland units under the alluvium in the valley of the South Fork of Texas Creek (plate 5).

One of the more interesting features of the Pictured Cliffs—Fruitland outcrop in this area is a fault at the extreme east end of the outcrop, just west of the Pine River (fig. 2-6). This fault was previously mapped by Barnes (1953) as a normal fault, down to the north. Some features lead me to speculate that it could be a moderate- to high-angle thrust fault, with thrusting directed



**Figure 2-6. Schematic diagram of reverse fault just west of the Pine River.**

northward. The fault trace is along a steep-walled gully that cuts the outcrop just behind the Field property adjacent to the outcrop. On the north side of the gully Pictured Cliffs Sandstone and the Kfab and Kf2 units of the Fruitland roll steeply into the gully at about 45 degrees. Boulders of Pictured Cliffs that were used to

construct a retaining wall on the north side of the gully display slickenside striations, which is clear evidence that the Pictured Cliffs is faulted at this locality.

On the south side of the gully it appears that there is a complete repeated section of Pictured Cliffs Sandstone that is between 100 and 130 ft thick. Below the lowest identified Pictured Cliffs are a few feet of fissile, fossiliferous, gray shale, underlain by Fruitland coal, probably from the Kfab unit. Initially I speculated that the gray shale might be a sliver of Lewis Shale, but D. Baldwin (written commun., 1996) indicated that there is a similar gray shale associated with the basal coal in several monitoring wells in the Pine River Ranches area adjacent to the outcrop. It still appears that a repeated section of Pictured Cliffs overlies the Kfab unit of the Fruitland in the gully, however, suggesting that the Pictured Cliffs was pushed northward over the coal, causing the abrupt increase in dip of the underlying wedge of Pictured Cliffs—Fruitland on the north side of the fault. D. Baldwin (written commun., 1996) noted that no fault was encountered in the James No. 1 monitor well, which was drilled approximately .2 mi east of the gully in which the fault occurs. Unfortunately the well was not drilled all the way through the Pictured Cliffs Sandstone to test whether there is a repeated section of Pictured Cliffs in that area. The only way to know if there is a fault there would be to drill completely through the Pictured Cliffs into underlying rocks to see if there is either Lewis Shale or a repeated section of Pictured Cliffs. The fault in the gully could not be traced confidently very far west due to cover by vegetation, but perhaps the poor exposures can be explained, in part, by disruption of bedding due to the faulting. No other significant faulting was noted in this mapped area, although a few inches of offset was seen on sandstone beds at station TI02.

## Synthesis

Following is a description of regional changes and correlations of stratigraphic units from Basin Creek to the Pine River, based on my outcrop studies. Fassett and Hinds (1971), Fassett (1988), Ambrose and Ayers (1991), Ayers and others (1991), and Roberts and McCabe (1992) have previously summarized the Pictured Cliffs, Fruitland, Kirtland, and associated strata, and their depositional environments.

The study area is located on what was the western shore of the Upper Cretaceous seaway that bisected North America (Fassett and Hinds, 1971; Fassett, 1988). Sedimentation rate and sea level rise and fall had marked effects on deposition of sediments that comprise the Pictured Cliffs Sandstone and Fruitland Formation in the study area. Seaward progradations and landward transgressions of the shoreline are part of a complex interplay between sea level, sediment influx, tectonic events, and other variables.

The effects of sea level changes are clearly expressed in the Pictured Cliffs Sandstone in La Plata County. The stratigraphic intertonguing of nearshore marine and coastal plain deposits indicates that there were a series of seaward progradations of the shoreline followed by shoreline buildups and transgressions back to the southwest across nearshore peat swamps. In the far southwestern end of the study area, on the south side of Basin Creek, there is only one main body of Pictured Cliffs, overlain by Fruitland coal. However, in the northern part of the Basin Creek area a tongue of Pictured Cliffs overlies the main body and is separated from the main body by a thin coal in places. This represents a progradation of the Pictured Cliffs shoreline sandstone to the northeast in a seaward direction, followed by a transgression back to the southwest over the swamp deposits of the Fruitland Formation. This was a relatively short-lived transgression, and the tongue merges with the main body of the Pictured Cliffs northeastward into the Carbon Junction area about 2 mi to the northeast.

At Carbon Junction there is another doublet of a main body of Pictured Cliffs and an overlying tongue. Near the landward extent of the tongue is a thick buildup of coal in the basal Fruitland Formation, indicating a period of shoreline stability just seaward of the coal. The doublet of Pictured Cliffs sandstones continues to the northeast slightly past the Florida River (Zapp, 1949), at which point the lower Pictured Cliffs sandstone grades out into the Lewis Shale and the tongue becomes the only Pictured Cliffs unit present. This represents a stratigraphic rise of the prograding shoreline sandstone to the northeast. In the Texas Creek to Pine River area there is only the one Pictured Cliffs sandstone unit.

The thickness of coal in the basal part of the Fruitland Formation is closely tied to the rate at which the shoreline changed. In the Basin Creek area there is a combined thickness of 50-60 ft of coal at the base of the formation; at Carbon Junction there is approximately 80 ft of coal at the base. This indicates a relatively long period of stability in which coal swamps developed. In contrast, in the Florida River area the coal at the base of the main body of Fruitland is only a few feet thick and much of the rest of the lower part of the Fruitland is carbonaceous shale or mudstone. This indicates a relatively quick seaward progradation of the shoreline; an environment in which the peat in swamps did not have time to accumulate. At the west end of the Texas Creek area the basal coal is fairly thick, but it thins toward the Pine River, indicating another period of stability, followed by more rapid progradation. This sequence of progradation and aggradation of the shoreline was shown diagrammatically by Fassett and Hinds (1971, p. 11) and is documented in the subsurface by Ayers and others (1991, p. 11) and Roberts and McCabe (1992, p. 121).

In the Basin Creek and Carbon Junction areas the rock interval just above the basal coals consists of mudstone and carbonaceous shale that gradually becomes more sandstone-dominated upward in the section and culminates in a stacked-channel complex that is approximately 25 ft thick. This sandstone complex is very well developed at the southwest end of the Florida

River area, where it approaches 75 ft of nearly all sandstone (mapped as the number 2 sandstone [Kf2]) and comprises most of the middle part of the Fruitland. The sandstone complex is also present in the Texas Creek to Pine River area, where it and associated mudrocks are as thick as 100 ft. This interval in the Fruitland is interpreted to represent a major influx of sediment from the source area to the southwest of the La Plata County area.

Strata in the upper part of the Fruitland in the Basin Creek and Carbon Junction areas consist of a series of interbedded mudrock, coal, and sandstone beds that repeat in several cycles. A similar series of rocks is present in the Florida River and Texas Creek—Pine River areas in the upper part of the Fruitland. Coal beds in this interval are relatively thin, usually only 3-4 ft thick maximum, and the sandstone channels are also relatively thin, commonly about 10 ft, but as much as 30 ft thick in places. Where coal beds are present they are commonly directly overlain by sandstone beds. This upper part of the Fruitland section is interpreted as representing meandering streams on a surface of low relief, such as a delta plain. Some of the sandstone beds are thin and tabular, and probably are of crevasse splay origin. The coal developed in swampy areas adjacent to the fluvial channels and this accounts for their relative thinness and lenticularity. Coal-bearing horizons do appear to be fairly persistent laterally, but the coal beds pinch and swell within those intervals.

The uppermost unit of the Fruitland is transitional with the overlying Kirtland Shale and is present in all the mapped areas. This unit has certain features characteristic of the Fruitland, such as carbonaceous shale and thin coal beds, but has other features characteristic of the Kirtland, such as dense, green siltstone and abundant yellowish-orange concretions. As a whole, the unit has very little sandstone and is commonly weathered and poorly exposed. The transitional unit is recognizable in all of the areas, however, and makes a good marker bed for the contact between the Fruitland and Kirtland. It was deposited farther up the depositional slope than the lower and middle parts of the Fruitland,

and thus does not have a good development of coal beds.

## PART 2--FRACTURE STUDIES

Joints in sandstone and cleats in coal were measured at 209 localities in the project area. By area, the totals are 47 localities, or stations, at Basin Creek, 27 stations at Carbon Junction, 40 stations at the Florida River, 57 stations along the south fork of Texas Creek, and 38 stations between Texas Creek and the Pine River. Each of the areas is summarized separately below; rose diagrams of the individual stations are shown in appendix 2-2. Tables 2-6 through 2-10 show in which geologic unit the stations were recorded;

used to construct the diagram. The R magnitude is the magnitude of the vector mean. Data sets that exhibit large dispersion about the mean will have small resultants, and those sets that are tightly grouped have large resultants. R is standardized to range between 0 and 1; tightly clustered data sets have R values near 1. The confidence angle is another test of the reliability of the vector mean. The confidence angle forms an arc plus or minus either side of the calculated vector mean. A small confidence angle indicates tightly clustered data, a large angle indicates dispersed data. There is a 95% probability that

**Table 2-6. Average orientations of joints in sandstone and cleats in coal in the project area**

|                 | <b>Kpc-J1</b>    | <b>Kpc-J2</b>    | <b>Face</b>      | <b>Butt</b>      | <b>Kf-J1</b>    | <b>Kf-J2</b>     |
|-----------------|------------------|------------------|------------------|------------------|-----------------|------------------|
| Basin Creek     | N. 28° W.        | N. 59° E.        | N. 2° W.         | N. 88° E.        | N. 2° W.        | East-West        |
| Carbon Junction | N. 77° E.        | N. 50° W.        | N. 20° W.        | N. 69° E.        | N. 9° W.        | N. 85° E.        |
| Florida River   | N. 23° W.        | N. 64° E.        | N. 31° W.        | N. 58° E.        | N. 20° W.       | N. 67° E.        |
| Texas Creek     | N. 9° W.         | N. 79° E.        | N. 22° W.        | N. 68° E.        | N. 1° E.        | N. 89° W.        |
| Pine River      | N. 5° E.         | N. 75° W.        | N. 35° W.        | N. 54° E.        | N. 7° E.        | N. 81° W.        |
| <b>Totals</b>   | <b>N. 14° W.</b> | <b>N. 74° E.</b> | <b>N. 21° W.</b> | <b>N. 69° E.</b> | <b>N. 3° W.</b> | <b>East-West</b> |

Kpc - Pictured Cliffs Sandstone; Kf - Fruitland Formation

plates 1, 2, 4, and 6 show the locations of each station. The rose diagrams were constructed using a Macintosh program called Rosy. Rose diagrams in figures 2-8 through 2-12 and in appendix 2-2 show statistics for each area or station.

In each of the rose diagrams, N is the number of readings in each data set used to construct the diagram. The class interval indicates the number of degrees each wedge of the diagram shows. A class interval of 10 degrees was used for all the diagrams. The size of the wedge is a relative measure of the number of readings within each wedge. The statistics are intended to provide measures of central values and dispersion of the data. All the tests, such as maximum percentage, mean percentage, and standard deviation, are made on cells having values greater than 0. Other calculations are as follows. The vector mean is the combined azimuth of all the readings

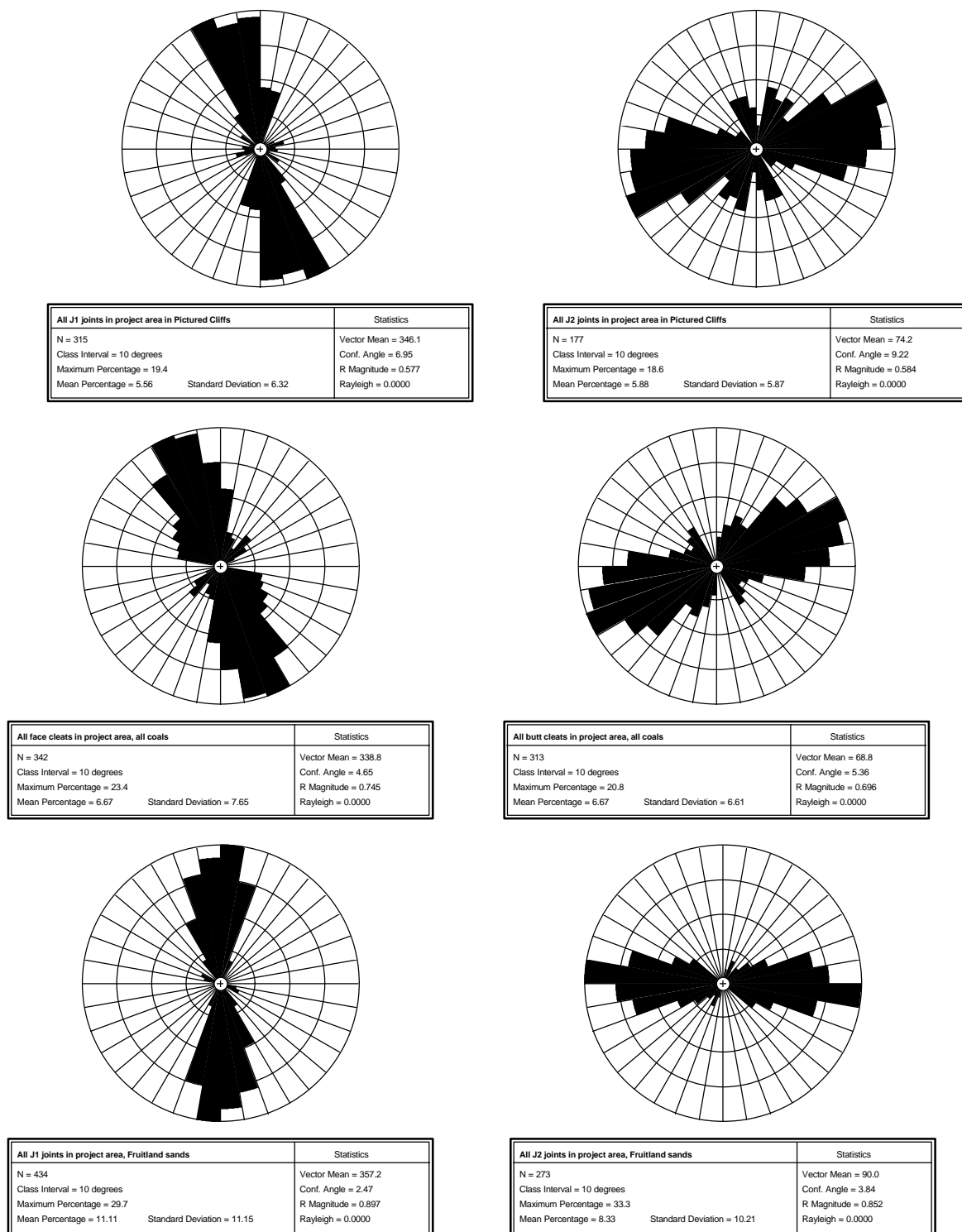
the arc formed by the confidence angle contains the true population mean direction. The Rayleigh number is a test for uniformity in a data set. Values less than 0.05 (95% confidence level) indicate that the data are non-uniform and show a preferential orientation. These tests of uniformity only apply to figures 2-7 through 2-12 in this report, because these figures show single sets of joints or cleats.

In general, in each area there is one main joint set in each geologic unit, and a second set that is oriented at about right angles to the first. These joint sets were named the J1 and J2 sets. In some areas a third set, and even a fourth set, are also present. This discussion focuses on the J1 and J2 sets because they are the most common and pervasive in all the areas; individual localities where the other sets are important are pointed out below. All the joint sets are oriented perpendicular to bedding, even in areas of steep

dip. In coal beds, fractures are known as 'cleats', and in coal too, there are two main sets, a face cleat and a butt cleat. The face cleat is the main fracture set in coal beds; butt cleats are oriented at about 90° to the face cleats.

For this study, four main characteristics of joints and cleats were emphasized—length, spacing, sinuosity, and mineral fillings. In addition, basic parameters of joints, such as terminations of one joint set against another (to determine relative age) and surface features (to determine mode of origin) were also noted. In general, joint surfaces in this area are weathered, obscuring surface ornamentation. Some joints of each set do display features such as plumose structures, arrest lines, and twist hackle, features characteristic of opening mode (mode I) fractures (Kulander and others, 1979). No evidence of shear movement, such as slickenside striations, was noted on any of the joint sets.

Figure 2-7 shows rose diagrams that summarize over 1850 readings taken of all J1 and J2 joints and of all face and butt cleats in coal in the entire study area. Figure 2-7 also shows that in a regional sense there is a good clustering of joint and cleat directions. For the Pictured Cliffs Sandstone the regional average of J1 joints is 346°, or N. 14° W., and the average of J2 joints is 74°, or N. 74° E. The regional average of all face cleats in all coal beds is 339°, or N. 21° W., and the average of all butt cleats is 69°, or N. 69° E. The average J1 orientation for all sandstone beds in the Fruitland Formation is 357°, or N. 3° W., and for J2 joints is 90°, or East-West. Table 2-6 tabulates the average orientations of each of the mapped areas in addition to the totals for the whole area.



**Figure 2-7. Summary rose diagrams of all J1 and J2 joints in Pictured Cliffs and Fruitland sandstones and all face and butt cleats of coal in the project area.**



## Basin Creek

Figure 2-8 shows summary rose diagrams of joint and cleat orientations in the Pictured Cliffs Sandstone, Fruitland Formation coals, and Fruitland sandstone beds. In the Pictured Cliffs (including both the main body and tongue) the average orientation of the J1 joint set is 332°, or N. 28° W. The average orientation of the J2 set is 59°, or N. 59° E. There were only scattered occurrences of J3 or J4 sets in the Pictured Cliffs in this area. In general, the main body of the Pictured Cliffs has few joints at Basin Creek. However, the outcrop just north of the road, at station BC01, has some of the largest J1 joints in the area. The J1 joints there exceed 100 ft in length and are irregularly spaced, from as close as 6 inches to as wide as about 20 ft. The length of the J2 set also varies from 6 inches to 20 ft, depending on the spacing of the J1 set. J2 joints are spaced 6-10 ft apart here. The joints are somewhat sinuous, but extend across the entire outcrop. No mineralization of either set was noted. This locality is good for examining joints because it is a large, stripped dip slope at the top of the Pictured Cliffs.

In the entire Basin Creek area, the exposed lengths of J1 joints in the Pictured Cliffs vary from 1 ft to over 100 ft; spacing between joints is from 6 inches to 20 ft, and there is a wide range of sinuous to linear traces of joints across the outcrops. No calcite fillings were seen in the Pictured Cliffs, but iron-rich bands, or halos, are present along some joints. Exposed lengths of J2 joints range from 6 inches to 20 ft, spacing varies

from 2-10 ft, and the joints are fairly planar. No mineralization was noted in the J2 set either.

Face cleat orientations in all coal beds at Basin Creek average 358°, or N. 2° W. and butt cleats average 89°, or N. 88° E (fig. 2-8). Lengths of cleats could not be readily seen in this area because most of the coal beds are weathered and have to be dug out to see the cleat pattern. Spacing of face cleats ranges from about ¼ inch to 6 inches, spacing of butt cleats is from ¼ inch to a maximum of about 2 inches. Most outcrops of coal have no mineral fillings in the cleats, but traces of iron were seen at several locations, and there is abundant iron mineralization of cleats at station BC33.

For all sandstone beds of the Fruitland Formation at Basin Creek the average orientation of the J1 set is 358°, or N. 2° W. The average orientation of the J2 set is 270° (fig. 2-8). Exposed lengths of J1 joints in Fruitland sandstone beds are 1-20 ft, although the top surfaces of these sandstone beds are rarely exposed. Spacing is from 2 inches to about 24 inches, and many joints in these sandstones are planar and well-formed. Calcite fillings are common in joints in Fruitland sandstone beds, as are coatings of iron oxide. In general, well-cemented, relatively thin sandstones display a greater abundance and better-formed joints than thick, poorly cemented sandstone beds. J2 joints in these sandstones have exposed lengths of 1-6 ft, are spaced 1-8 ft apart, and are also fairly linear and planar. The J2 joints also display fillings of calcite.

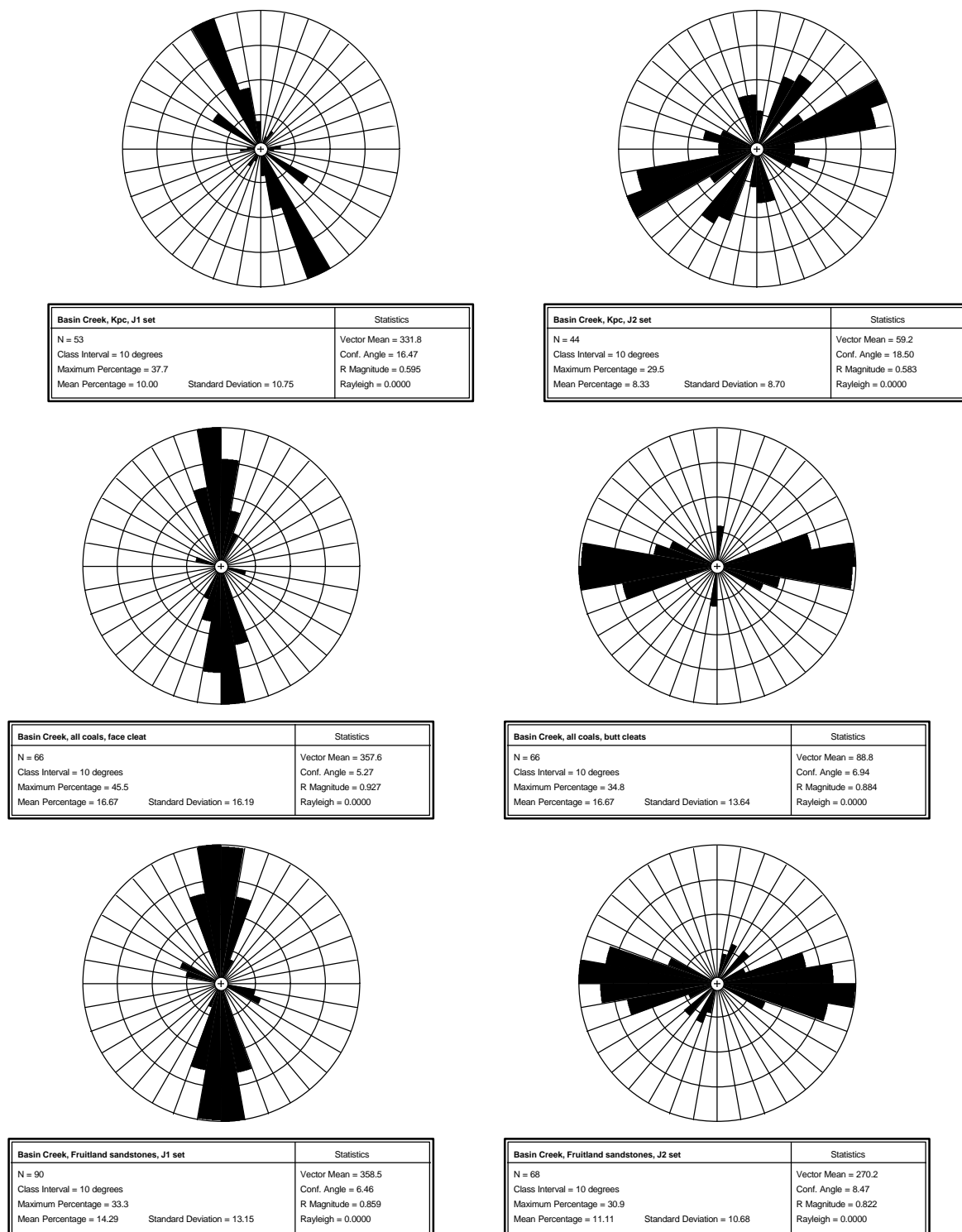


Figure 2-8. Summary rose diagrams of joints and cleats in the Basin Creek area.

## Carbon Junction

Figure 2-9 shows summary rose diagrams of joint and cleat orientations in the Pictured Cliffs Sandstone, Fruitland Formation coal beds, and Fruitland sandstone beds.

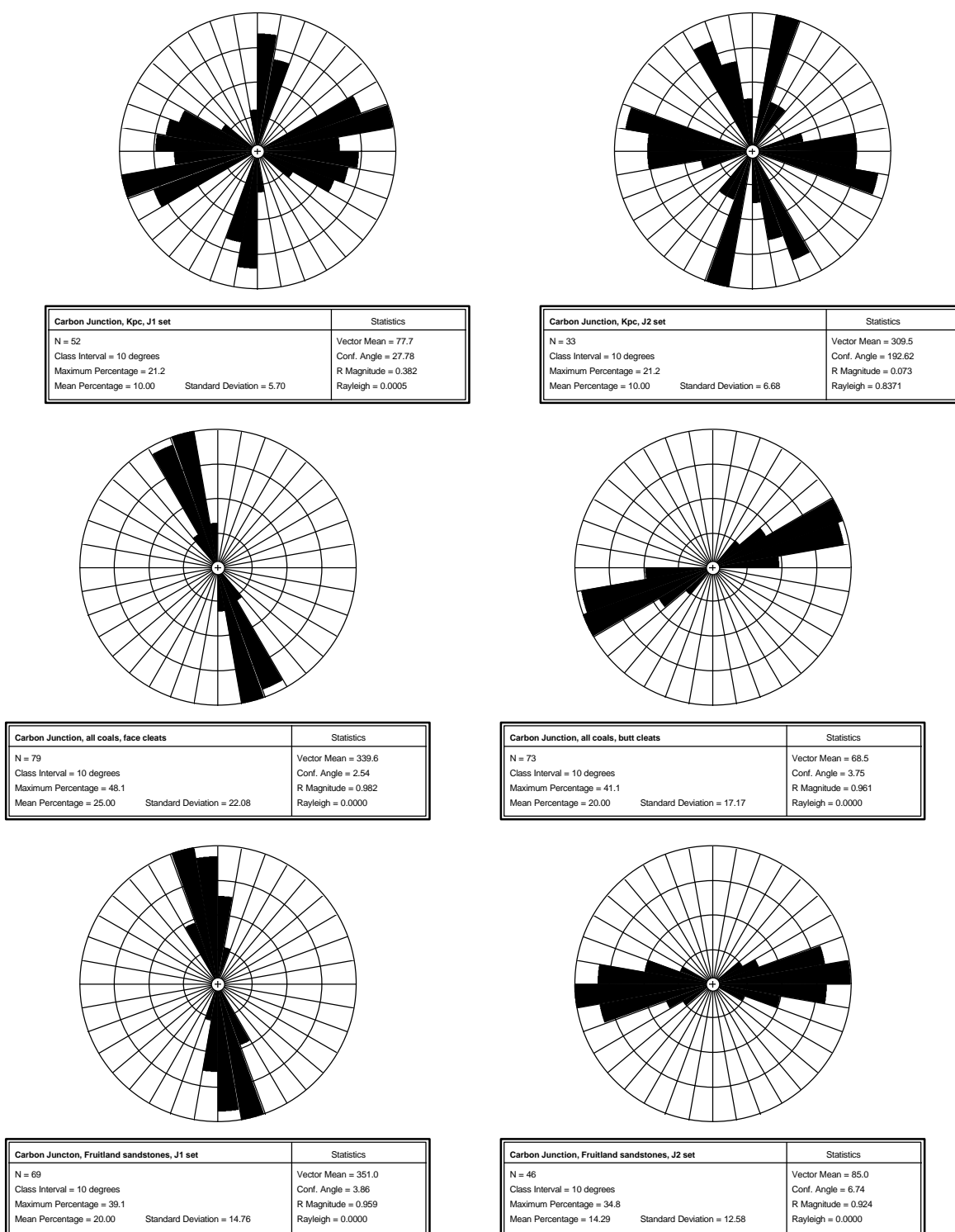
In the Pictured Cliffs (including readings from the tongue of Pictured Cliffs) the average orientation of the J1 set is 77°, or N. 77° E. The average orientation of the J2 set is 310°, or N. 50° W, although there is quite a bit of scatter in the readings obtained from the Pictured Cliffs in this area. The scatter in these diagrams is a result of combining the orientations measured at the individual stations (CJ11, CJ13, CJ 24, CJ27, CJ03, and CJ19, appendix 2-2). Joints of the J1 set in the main body of the Pictured Cliffs, measured in Carbon Junction Canyon, are clustered between N. 70°-80° E., whereas those measured southwest of the canyon are oriented strongly northwest, and those northeast of the canyon are just a little east of north. J1 joints in the tongue of Pictured Cliffs are also oriented strongly northwest to east-west. These divergent directions all are displayed on the summary rose plot (fig. 2-9). J2 joints are oriented nearly at right angles to those of the J1 set, and their divergent directions also are apparent in figure 2-9.

In this area the Pictured Cliffs main body and tongue generally lack good jointing, resulting in a small number of readings. Laubach and others (1991) noted that the outcrop at Carbon Junction Canyon has few fractures, and that many of those are surficial. Station CJ11 is at a locality described by Laubach and others (1991) as a fracture “swarm”, where the joints are tightly clustered. Station CJ27 is another area where the joints are tightly clustered. Elsewhere, joints may be more a result of stress release or of weathering.

The J1 joints range in length from 2 to about 30 ft, except at station CJ27, where they are as long as 60 ft or more. Spacing is from less than 1 inch in the “swarms” to as much as 10 ft. Most of the J1 joints in this area in the Pictured Cliffs are somewhat sinuous, not linear. Most joints had either no mineralization or slight amounts of iron coatings, except at station CJ24, where there are abundant iron coatings on joint surfaces. The J2 joints are somewhat poorly developed and range in length from 6 inches to about 30 inches. They are spaced from 6 inches to 15 ft apart. Most of them are also relatively sinuous and unmineralized.

More consistent results were obtained from measurements of coal cleats in the Carbon Junction area. The face cleats are tightly clustered at an orientation of 340°, or N. 20° W., and the butt cleats are oriented at 69°, or N. 69° E. (fig. 2-9). In this area, as at the other areas, the total length of the cleats could not be observed, due to cover. The spacing of face cleats ranges from ¼ inch to 3 inches; the spacing of butt cleats ranges from ¼ inch to about 2½ inches. Many of the outcrops have films of iron oxide coating the cleat surfaces.

Joint orientations of sandstone beds in the Fruitland Formation are also fairly tightly clustered in this area. The average orientation of J1 joints is 351°, or N. 9° W.; that of the J2 set is 85°, or N. 85° E. (fig. 2-9). A J3 set was observed at station CJ20, and the orientation of this set is about 296°, or N. 64° W. The J1 set ranges from an exposed length of about 1 ft to 8 ft and has spacing of from 2 to 36 inches. They are relatively well-formed and are planar and linear in many outcrops. Mineral fillings of iron and calcite are present in many J1 joints in Fruitland sandstone beds. The J2 set length is from 2 inches to 4 ft, spacing is from 6 inches to 4 ft, and they are relatively abundant and well-formed in several outcrops. They also displayed fillings of iron and calcite.



**Figure 2-9. Summary rose diagrams of joints and cleats in the Carbon Junction area.**

## Florida River

Summary rose diagrams of Pictured Cliffs Sandstone, Fruitland Formation coal, and Fruitland sandstone beds in the Florida River area are shown in figure 2-10. Joint and cleat orientations are fairly tightly clustered for all units in this area. The average orientation for the J1 set for the Pictured Cliffs is 337°, or N. 23° W.; that for the J2 set is 64°, or N. 64° E. The observed lengths of J1 joints ranges from 1 to 10 ft; spacing ranges from 2 inches to 15 ft. The J1 joint set is linear and planar in many outcrops, but somewhat sinuous in others. Except for one outcrop at station FR38, which displays calcite coatings, none of the J1 joint stations were observed to have mineral fillings.

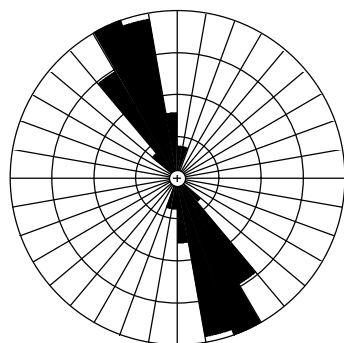
The J2 joint set in the Pictured Cliffs is poorly developed in this area; many of the stations had no J2 joint set. Of those observed, the length varies from about 2 ft to over 5 ft; spacing ranges from 2 inches to 3 ft. Bands of iron, in a halo effect, are present adjacent to J2 joints at station FR03, but no other associated mineralization was noted.

Face cleats in coal in the Florida River area have an average orientation of 329°, or N. 31°

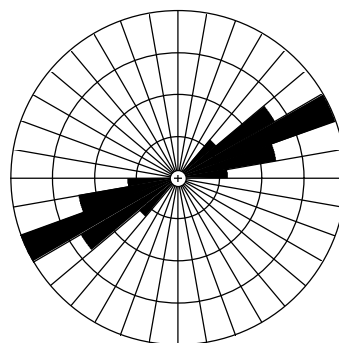
W.; butt cleats have an average orientation of 58°, or N. 58° E. Spacing of face cleats ranges from one-eighth inch to one inch; that of butt cleats ranges from one-eighth inch to one-half inch. No mineral coatings are present on cleats in most of the area; iron oxide is present at stations FR37 and FR40, near the Florida canal.

The average orientation of J1 joints in Fruitland sandstone beds is 340°, or N. 20° W.; that of J2 joints is 67°, or N. 67° E. J1 joints are from 18 inches to in excess of 10 ft long; spacing ranges from 2 inches to 10 ft. Most of the J1 joints in Fruitland sandstone beds are well-developed, linear and planar. Many of the joints cut multiple beds of Fruitland sands. Iron coatings were noted at a few stations, and calcite at one station, but many J1 joints do not have mineral coatings.

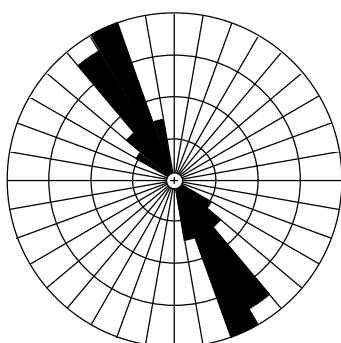
In contrast, the J2 joint set is poorly developed in Fruitland sands in this area, similar to the situation with the Pictured Cliffs Sandstone. Where they do occur the J2 set is from 1 to 4 ft long, but are so scattered that a reliable range of spacing could not be determined. Mineral fillings or coatings are also rare, consisting of minor iron oxide or calcite.



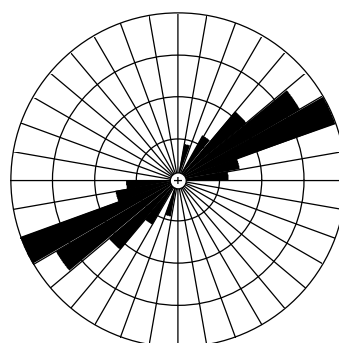
| Florida River, Kpc, J1 set  | Statistics                 |
|-----------------------------|----------------------------|
| N = 71                      | Vector Mean = 337.4        |
| Class Interval = 10 degrees | Conf. Angle = 5.06         |
| Maximum Percentage = 36.6   | R Magnitude = 0.934        |
| Mean Percentage = 14.29     | Standard Deviation = 15.10 |
|                             | Rayleigh = 0.0000          |



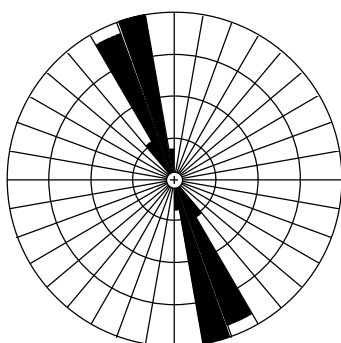
| Florida River, Kpc, J2 set  | Statistics                 |
|-----------------------------|----------------------------|
| N = 22                      | Vector Mean = 63.6         |
| Class Interval = 10 degrees | Conf. Angle = 7.68         |
| Maximum Percentage = 50.0   | R Magnitude = 0.947        |
| Mean Percentage = 20.00     | Standard Deviation = 17.57 |
|                             | Rayleigh = 0.0000          |



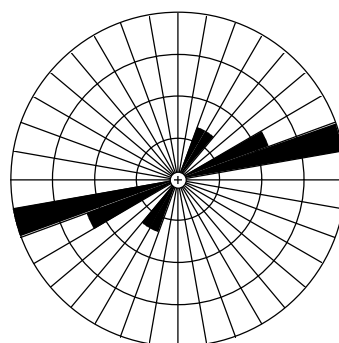
| Florida River, all coals, face cleats | Statistics                 |
|---------------------------------------|----------------------------|
| N = 62                                | Vector Mean = 329.3        |
| Class Interval = 10 degrees           | Conf. Angle = 4.08         |
| Maximum Percentage = 46.8             | R Magnitude = 0.957        |
| Mean Percentage = 20.00               | Standard Deviation = 19.19 |
|                                       | Rayleigh = 0.0000          |



| Florida River, all coals, butt cleats | Statistics                 |
|---------------------------------------|----------------------------|
| N = 50                                | Vector Mean = 58.2         |
| Class Interval = 10 degrees           | Conf. Angle = 6.87         |
| Maximum Percentage = 42.0             | R Magnitude = 0.914        |
| Mean Percentage = 14.29               | Standard Deviation = 14.94 |
|                                       | Rayleigh = 0.0000          |



| Florida River, Fruitland sandstones, J1 set | Statistics                 |
|---|----------------------------|
| N = 55                                      | Vector Mean = 339.9        |
| Class Interval = 10 degrees                 | Conf. Angle = 3.04         |
| Maximum Percentage = 50.9                   | R Magnitude = 0.984        |
| Mean Percentage = 25.00                     | Standard Deviation = 23.98 |
|   | Rayleigh = 0.0000          |



| Florida River, Fruitland sandstones, J2 set | Statistics                 |
|---|----------------------------|
| N = 14                                      | Vector Mean = 66.6         |
| Class Interval = 10 degrees                 | Conf. Angle = 16.37        |
| Maximum Percentage = 64.3                   | R Magnitude = 0.860        |
| Mean Percentage = 25.00                     | Standard Deviation = 25.04 |
|   | Rayleigh = 0.0000          |

**Figure 2-10. Summary rose diagrams of joints and cleats in the Florida River area.**

## South Fork of Texas Creek

Figure 2-11 shows summary rose diagrams of joint and cleat orientations of the mapped units at the South Fork of Texas Creek. In that area the average orientation of J1 joints in the Pictured Cliffs is 351°, or N. 9° W.; the average orientation of J2 joints is 79°, or N. 79° E. Several areas exist at Texas Creek where a stripped dip slope exposes large areas of the top of the Pictured Cliffs, allowing for a more accurate assessment of the lengths of joints. Observed lengths of J1 joints range from 20 ft to over 100 ft. J1 joints occur in closely spaced zones in some areas, but are more evenly spaced in other areas. Where tightly clustered, the spacing is less than 2 inches to 1 ft. Otherwise, spacing ranges up to 8 ft. In the good exposures in this area the pattern of J1 joints is somewhat anastomosing, where one joint will die out into rock or hook into an adjacent joint. A cluster of joints will form a long, linear zone that consists of curvilinear joints. In this area only iron oxide coatings were seen on the J1 joints.

In this area, too, J2 joints are relatively poorly expressed in the Pictured Cliffs Sandstone. Their length depends on the spacing of J1 joints, and is therefore quite variable. Spacing of J2 joints is 6 inches to over 5 ft, but averages about 3-4 ft. In a few places J2 joints are relatively well-formed, but in general they are difficult to find. The only mineralization noted on J2 joints is iron oxide.

An interesting feature of the Texas Creek area is the presence of a third joint set in the Pictured Cliffs at some of the stations. Stations where this set was observed are TC04, TD01, TD02, TE01, AND TF01 (appendix 2-2).

Except for TF01, the stations are concentrated in the central part of the mapped area. The orientation of the J3 set is about 325°, or N. 35° W. These joints terminate against the J1 and J2 sets, and are therefore believed to be younger than either of those sets. A fourth set is also rarely present that is at about right angles to the J3 set. All four sets are well-expressed at station TF01, just upslope from the Hobbs property, toward the eastern end of the mapped area. This site has an old road leading to it and is easily accessible.

Coal cleats in the Texas Creek area have mixed orientations, possibly due to slumping at some outcrops. The face cleats average 338°, or N. 22° W., and the butt cleats average 68°, or N. 68° E., with quite a bit of scatter. The majority of face cleats are sub-parallel with J1 joints in the Pictured Cliffs, and the butt cleats are sub-parallel to J2 joints of the Pictured Cliffs. Spacing of both face and butt cleats is one-eighth inch to one inch. No significant mineralization was noted on cleats in this area.

In sandstone beds of the Fruitland Formation, the average orientation of J1 joints is 1°, or N. 1° E.; the average orientation of J2 joints is 271°, or N. 89° W. Length of J1 joints is from 1 ft to 15 ft; spacing is about 2 inches to 2 ft. As with other mapped areas, the joints in Fruitland sandstone beds are well-formed, linear, and planar. Only minor iron oxide mineralization was noted on these joints. The J2 joint set varies from poorly expressed to common at different localities at Texas Creek. They are commonly short, less than 2 ft, and have a spacing of about 1-3 ft. Only minor iron oxide coatings were noted on this set.

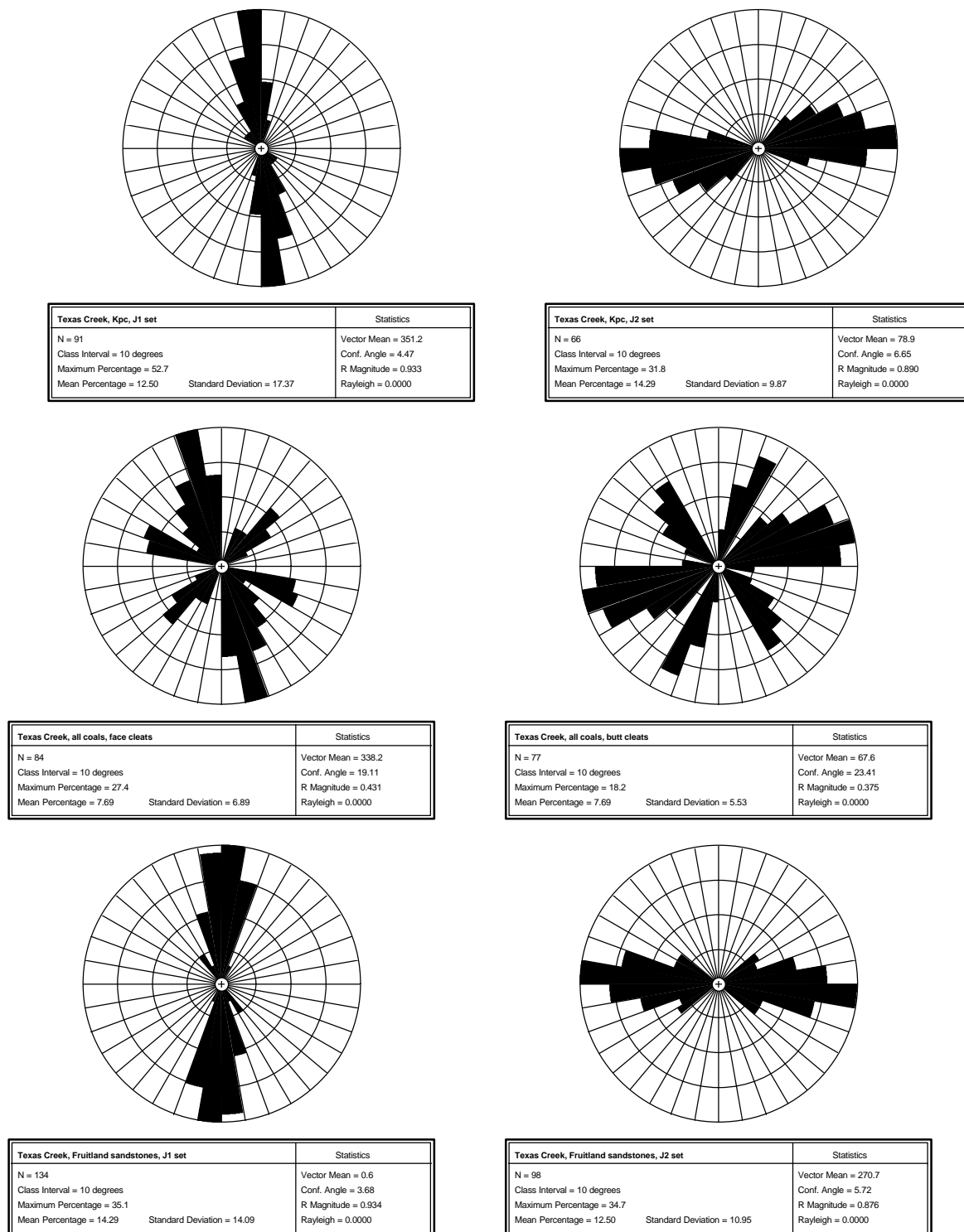


Figure 2-11. Summary rose diagrams of joints and cleats in the Texas Creek area.



## Pine River

Figure 2-12 shows the average orientations of joints and cleats in the area between the South Fork of Texas Creek and the Pine River. There is a bit of scatter in average orientations of the Pictured Cliffs Sandstone, but J1 joints average 5°, or N. 5° E.; J2 joints average 285°, or N. 75° W. In this area the Pictured Cliffs is characterized by relatively few systematic joints. In many outcrops there is abundant surficial jointing, or spalling of blocks of sandstone. J1 joints range in length from 10 to 20 ft. Spacing averages from 6 inches to 10 ft, although there is clustering of joints in some areas where spacing is as close as 2 inches. The J1 set consists of long, linear, and planar joints. Minor calcite and iron oxide was noted on some joint surfaces.

J2 joints in the Pictured Cliffs are poorly developed. They range in length from 8 inches to 5 ft and have spacing of 1-4 ft. Like the J1 joints, mineralization is not a significant feature.

The average orientation of face cleats in coal here is 325°, or N. 35° W.; butt cleat orientations are 54°, or N. 54° E. Face cleats are spaced one-

eighth inch to 2 inches; butt cleats are spaced one-eighth inch to one inch. Iron oxide was noted at several localities coating both sets of cleats.

There is a good development of J1 joints in Fruitland Formation sandstone beds in this area. The average orientation is 7°, or N. 7° E.; the average orientation of J2 joints is 279°, or N. 81° W. The length of J1 joints ranges from less than 1 ft to greater than 60 ft. An especially well-exposed dip slope of the number 2 sandstone is present at station PR12, where the longest joints are present. This outcrop is probably typical of surface jointing in the Fruitland sandstone beds in this and other areas. In most places these sandstones are poorly exposed, making it likely to underestimate the extent of jointing. Spacing of J1 joints in this area ranges from 1 to 18 inches; iron oxide was noted at several localities coating the joint surfaces.

J2 joints are also fairly abundant in this area and range from less than 1 ft to about 3 ft in length. Spacing is 1 to 3 ft in most localities. Only minor iron oxide was noted on some J2 joints; no calcite was seen on this or the J1 set.

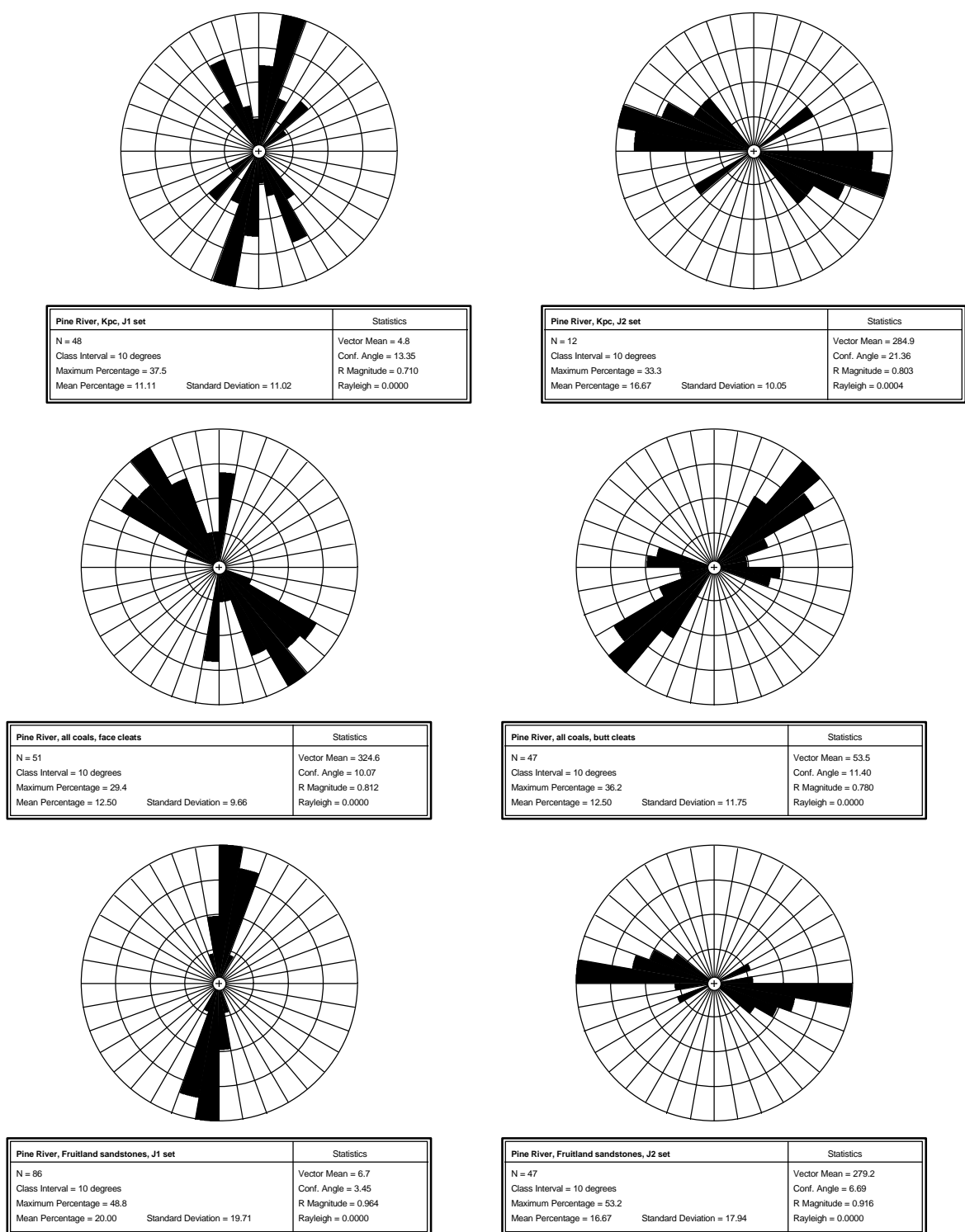


Figure 2-12. Summary rose diagrams of joints and cleats in the Pine River area.

## Discussion of fractures

Orientations of joints and cleats vary somewhat over the entire study area, but these variations are less evident when the area as a whole is considered. Figure 2-7 shows that there are regional similarities of joint orientations in the various geologic units studied. However, each individual mapped area has its own identity, as shown in figures 2-8 through 2-12. More specific information about individual localities is shown in appendix 2-2.

In each area one main joint or cleat set can be identified in each geologic unit. This set is composed of relatively long, commonly linear joints, and in some instances joints of this set occur in narrowly clustered zones. Joint fillings or coatings consist of iron oxide or calcite, with iron and calcite being abundant at Basin Creek, moderately abundant at Carbon Junction, rare at the Florida River, and relatively rare at Texas Creek and at the Pine River. No slickenside striations were noted on any of the J1 or other joint sets in the study area. The joints are oriented perpendicular to bedding surfaces in most instances, which may indicate that the jointing occurred prior to the rocks being uplifted into their present configuration.

The lithology of the rock unit has an important impact on the degree of fracturing that occurs. Coal is relatively brittle and breaks easily, resulting in the closely spaced face and butt cleats. Sandstone beds of the Fruitland Formation are relatively thin and firmly cemented, which also promotes the development of joints. Thick, weakly cemented rocks, characteristic of the upper part of the Pictured Cliffs Sandstone, are the least prone to develop good, systematic joint sets.

In some outcrops, a second joint set is also present. This joint set is commonly at nearly right angles to and terminates against the main joint set. This set is clearly secondary to the main set. This secondary set is also oriented perpendicular to bedding surfaces.

In a few outcrops a third or a fourth joint set were also observed. These joints terminate against both the J1 and J2 joints, indicating that

they are younger than the other two sets.

Although a cluster of these joints was found in the Texas Creek area, they are generally rare in the entire project area.

The joints and cleats in the study area share characteristics of those in this and nearby areas previously described by myself (Condon, 1988, 1989, 1995) and by others (Close (1993), Close and Mavor (1991), Laubach and others (1991), Tremain and Whitehead (1990), Tremain and others (1991a, b).

Fundamental questions in fracture studies involve the cause of fracturing, time of fracturing, and predictions of fracture trends in the subsurface. These topics are briefly discussed below.

**Joints.** Based on surface features and the lack of shear displacement, the joints along the northern rim of the basin were interpreted as mode I fractures (Laubach and others, 1991), otherwise known as opening mode or extension fractures. In sandstones, this type of fracture is thought to initiate at inhomogeneities in the rock, such as fossils, clasts, voids, microcracks, or other features, which concentrate local tensile stresses in an overall compressive stress field (Pollard and Aydin, 1988). Opening mode fractures form parallel to the maximum compressive stress direction and perpendicular to the least compressive stress direction (Lorenz and others, 1991). Pore pressure also has been recognized as an important component in the formation of natural fractures by decreasing the effective confining pressure of rocks in the subsurface (Secor, 1965; Lorenz and others, 1991).

The timing of fracture development in sandstones of the Fruitland and Pictured Cliffs is not very well constrained. Before fracturing can occur the sediments must have been lithified to some degree. The Pictured Cliffs and Fruitland Formation are Campanian to Maastrichtian in age (roughly 75 to 72 Ma) (Molenaar and Baird, 1991). Lorenz (1995) suggested that the Frontier Formation in the Green River basin was lithified at a depth of approximately 3,000 ft. In the San Juan Basin the Pictured Cliffs and Fruitland first reached that depth of burial at about 60 million years ago in the Paleocene and reached a depth of

nearly 7,000 ft in the Miocene (Law, 1992). A complicating factor in the San Juan Basin is elevated thermal maturity caused by a thermal event 40 to 20 m.y. ago, extending from the late Eocene to the early Miocene (Law, 1992).

Law and others (1989) suggested an endogenetic mechanism whereby thermogenic gas generation causes overpressuring that eventually leads to the creation of fractures in the enclosing rocks. Lorenz and others (1991), however, maintained that pore pressure cannot exceed the least compressive stress and therefore cannot alone cause tensile fracturing. Differential stress is needed for the development of systematic joint sets.

The tectonic fabric of this part of the southwestern USA was established at about 1,790 to 1,700 Ma in the Proterozoic during accretion of a series of crustal provinces (Condie, 1992). Baars and Stevenson (1982) attributed the orientation of major northwest- and northeast-oriented basement faults and lineaments to north-south compression that formed conjugate shear zones. Given that opening mode fractures form parallel to the maximum compressive stress direction (Lorenz and others, 1991), it is not unreasonable to expect north-south-oriented fractures in basement rocks of the San Juan Basin. The northwest-northeast pattern of basement faults has also been interpreted from seismic lines (Huffman and Taylor, 1989), and the pattern of faulting was shown in Huffman and Condon (1993). Although probably not propagated upward through the geologic section as distinct features, the north-south-oriented fractures may have formed zones of weakness or anisotropy that affected fracture orientations in rocks deposited at later times.

The main compressional tectonic events that occurred during and after deposition of the Pictured Cliffs Sandstone and Fruitland Formation were the Sevier and Laramide orogenies (Armstrong, 1968; Dickinson, 1978; Hamilton, 1987; Heller and others, 1986; Tweto, 1975). Lorenz (1985) provided a concise history of tectonic events in the nearby Piceance Creek basin, on the other side of the Uncompahgre uplift, north of the San Juan Basin.

The Sevier thrust belt developed in response to general east-west compression and crustal shortening along an Andean-type continental margin (Coney, 1978). Although much of the compression was east-west, the configuration of the orogenic belt and adjacent foreland basin suggests a significant southeastward component to the compressive stress (Heller and others, 1986). The effects of the Sevier orogeny are thought to have largely dissipated by about 72 Ma, however (Lorenz, 1985), so the sandy sediments of the Pictured Cliffs and Fruitland would not have been buried deeply enough to lithify and form fractures as a result of Sevier-related stress.

There has been much discussion regarding the cause of the change in tectonic style between the Sevier and Laramide orogenies and the mechanisms for Laramide deformation, topics which are beyond the scope of this report. Whatever the causes, Laramide tectonism is characterized by basement-cored anticlinal uplifts that are bounded by deep structural basins. East-west crustal shortening occurred from Montana to New Mexico in Late Cretaceous to late Eocene time (roughly 75 to 40 Ma) (Coney, 1978; Hamilton, 1987; Lorenz, 1985). This structural event would seem to be the most likely to have caused fracturing in the Pictured Cliffs and Fruitland because (1) the units would have been buried deep enough to have lithified and (2) initial gas generation could have increased the pore pressure to a point favorable for initiation of fracturing. The problem with this scenario is that the orientations of the main joints in the units are not parallel to the east-west-oriented stress, and are in fact, nearly perpendicular to it.

The generally north-south orientation of the main joints may be explained by the stress generated by the clockwise rotation of the Colorado Plateau at this time (Hamilton, 1987) or by late Laramide north-south-oriented compression (Gries, 1983). The rotation or compression of the San Juan Basin resulted in convergence of the basin with the Uncompahgre uplift to the north. The uplift may have acted as a buttress and the stress would have been roughly north-south, parallel to the fractures generated in Proterozoic time (these directions refer to current

orientations). This collision of the basin with the Uncompahgre uplift may also have led to the development of the reverse fault just west of the Pine River (plate 5) and to thrust faults discussed by Huffman and Taylor (this report).

The time between the Laramide and the present has been characterized by extension, along with one period of intense volcanism in the Oligocene and several periods of regional uplift and erosion (Coney, 1978; Lorenz, 1985). Transform movement along the western continental boundary led to the relaxation of the east-west Laramide stress, allowing for the present extensional mode of the Basin and Range province (Hamilton, 1987). This time period seems to lack the necessary compression event or events that could have caused initial fracturing in the Pictured Cliffs and Fruitland Formation. The J2 and younger sets could possibly have formed during this time as a result of unloading of the overburden.

**Cleats.** Tremain and Whitehead (1990), Tremain and others (1991a, b), and Laubach and others (1991) summarized the characteristics and origin of coal cleats in the northern San Juan Basin, and my studies generally support their conclusions. Important facts to note are that coal cleats are also mode I fractures that formed parallel to the principle compressive stress and perpendicular to the least compressive stress. Close (1993) emphasized that two mechanisms, or a combination of the two, have been proposed for the formation of cleats. Endogenetic processes include dewatering and compaction, while exogenetic processes include paleotectonic or neotectonic responses to stress.

Law and others (1983) noted that peat contains 80 to 90% water by volume, which decreases to about 7% in high-volatile B bituminous and higher-rank coals. Much of the water is expelled early in coalification, decreasing to about 20% by volume at the subbituminous B rank. The mechanisms for dewatering are mainly physical compaction and thermal destruction of functional groups (Law and others, 1983). Many coal beds in the Fruitland are immediately overlain by channel sandstones which contributed to compaction.

The coals of the Fruitland were subjected to the same stresses that produced joints in sandstones, but cleat formation may have occurred earlier than the development of joints. Close and Mavor (1993) thought that lithification of Fruitland coals may have occurred in as little as 3.4 million years after deposition. Early formation of cleats has also been reported in Pennsylvanian-age strata in Wales (Gayer and others, 1996), where coal clasts were eroded from coals belonging to the same stage as sediments in which the clasts were redeposited. Some of these clasts had already developed cleat as a result of extensional fracturing of overpressured coal in response to compression. Another example of early formation of cleats was reported by Pattison and others (1996). Based on age dates from mineral fillings in cleats, Pattison and others (1996) interpreted the cleats to have formed less than 10 Ma after peat accumulation. Cleats were interpreted to have formed parallel to the maximum horizontal stress.

On the basis of these other studies, it seems likely that cleats in the Fruitland formed relatively soon after deposition, possibly as a result of southeastward-directed compression from the Sevier thrust belt to the west. As with the joints in sandstone, the possibility exists that basement fractures or faults had some influence on the orientation of stress in the coals of the Fruitland.

#### **Fracture trends in the subsurface.**

Determining joint and cleat trends in the subsurface is complex and involves many uncertainties (Grout and Verbeek, 1985; Lorenz, 1995; Verbeek and Grout, 1984). Techniques such as drilling oriented core and pressure tests between nearby wells are of use in limited areas, but cannot usually be extended over a large area. Well log analysis (Johnston and Scholes, 1991; Mullen, 1991) may also be of use in some areas.

Advances in understanding the origin of joints and cleats (Lorenz and others, 1991), however, suggest that joint orientations may be consistent over fairly large areas, so surface studies of joints can be of use in predicting subsurface orientations (Lorenz and Finley, 1991). Cleat domain studies (Kulander and

Dean, 1993; Tremain and others, 1991b) indicated that large areas having similar cleat orientations exist, but that there may be overlap of domains and that domains can change abruptly, depending on local structure.

Even given the uncertainties, it seems likely to me that the largest, oldest joints in sandstones of the Pictured Cliffs and Fruitland in the subsurface of the northern San Juan Basin are oriented north-south and north-northwest to south-southeast. I would expect that face cleats in coal would have a dominantly north-northwest to south-southeast orientation in the subsurface. Within that context, there seem to be a slight clockwise rotation of the joints in sandstone in the Texas Creek and Pine River areas (figs. 2-6 and 2-7).

## Summary

1. Joints and cleats in the Pictured Cliffs Sandstone and Fruitland Formation are opening mode fractures.
2. The main joints in the Pictured Cliffs Sandstone are oriented N. 14° W. over the whole project area, and an orthogonal set trends N. 74° E. There appears to be clockwise rotation of the sets from west to east across the study area.
3. The main joints in sandstones of the Fruitland Formation are oriented N. 3° W. on average, and an orthogonal set trends East-West. There is also clockwise rotation of these sets from west to east across the area.
4. Face cleats in all coals of the Fruitland Formation are at an average orientation of N. 21° W.; butt cleats are oriented N. 69° E.
5. The most likely time of jointing of Pictured Cliffs and Fruitland sandstones was during north-south-oriented Laramide deformation when the San Juan Basin rotated clockwise into the Uncompahgre uplift. Joint trends may have been influenced by previously formed zones of weakness in basement rocks.

6. The most likely time of cleat formation was in the Late Cretaceous, probably during or shortly after coalification, and in response to deformation in the Sevier thrust belt.

7. Joint and cleat orientations measured at the outcrop probably extend some distance south into the subsurface. Differences do exist between different studied areas of the outcrop, however, so each area must be considered individually.

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## APPENDIX 2-1.

### Composite Stratigraphic Section of the Fruitland Formation in the Texas Creek Area (Described by S.M. Condon and R.C. Milici)

|                            |            |  |                        |
|----------------------------|------------|--|------------------------|
| <b>Kirtland Shale</b>      | <b>Kk</b>  | <b>Sandstone and mudstone</b>  | thickness not measured |
| <b>Leaf beds</b>           |            | <b>Mudstone</b> , some slightly silty, carbonaceous, light olive gray to olive gray; with abundant impressions of leaves and other plant fossils, slightly rooted, with muscovite flakes; some beds massive, jointed; with interbeds of silty, yellowish gray to dusky yellow sandstone; irregularly bedded, hackly weathering, with abundant muscovite flakes and finely disseminated carbonaceous material, rooted; 10 feet exposed  |                        |
| <b>Sandstone</b>           |            | <b>Sandstone</b> , very fine grained, clay rich, with interstitial kaolinite(?), limonite, grayish orange to yellowish gray, with rip-up clasts of olive-gray mudstone, impressions of plants; bedding is massive to tabular; three feet measured; minimum thickness estimated to be about 25 feet   |                        |
| <b>Fruitland Formation</b> |            | total thickness about 350 feet   |                        |
| <b>Upper part</b>          | <b>Kfu</b> | <b>Mudstone</b> , slightly silty, pale yellowish brown, with finely disseminated carbonaceous material; 8-10 feet thick<br><b>Shale</b> , carbonaceous, medium-dark gray; 2-3 feet thick<br><b>Coal</b> , weathered; 2-3 feet thick<br><b>Shale</b> , carbonaceous, medium dark to dark gray; 1-2 feet thick<br><b>Mudstone</b> , olive gray; 3 feet thick<br><b>Sandstone</b> , very fine grained, and very slightly calcareous siltstone, with finely disseminated carbonaceous material and muscovite flakes; irregularly bedded, beds 6 to 8 inches thick; with septaria of dolomitic limestone up to 2 feet across in upper part; with plant fossils; 5 feet thick<br><b>Mudstone</b> , olive gray, and dark-gray carbonaceous shale, with leaf impressions; 5 feet thick<br><b>Sandstone</b> , very fine grained, argillaceous, very slightly calcareous, with muscovite flakes, finely disseminated carbonaceous material; irregularly bedded, weathers grayish orange; 2 feet thick<br><b>Mudstone</b> , light gray to olive gray; 45 feet thick |                        |
| <b>No. 4 sandstone</b>     | <b>Kf4</b> | <b>Sandstone</b> , very fine to fine grained, well sorted, with white interstitial minerals, black accessory minerals, carbonaceous material on bedding surfaces; weathers yellowish gray, grayish yellow; beds generally range from 1 to 10 inches thick; basal bed is about 5 feet thick; some beds with abundant leaf impressions, twigs, sticks; few beds with abundant invertebrate fossils, including gastropods and pelecypods; estimated thickness about 35 feet   |                        |

|   |             |   |
|---|-------------|---|
| <b>No. 3 sandstone</b>                    | <b>Kf3</b>  | <b>Sandstone</b> , fine grained, light olive gray, weathers grayish red to dark reddish brown; well sorted, subangular to subrounded; moderately calcareous, argillaceous, with black accessory minerals, feldspathic, with abundant interstitial limonite; contains yellowish-orange septarian concretions; bedding up to 18 inches thick, massive and cross-bedded near base, ripple bedded at top, with some slumped, contorted bedding; minimum thickness about 50 feet                                       |
| <b>d coal zone</b><br><b>Skeleton bed</b> | <b>Kcd</b>  | Occurs at top of No. 2 sandstone; 2-4 feet thick<br>Not mapped separately; occurs between c and d coal zones; outcrops consist of lenticular masses of septarian limestone up to 10 feet long, 2 to 3 feet across, and one or two feet thick; exhibits radial and concentric fracture patterns; septae are filled with white calcite crystals and another dark brown carbonate minerals; limestone consists of light-olive gray dolomitic micrite; weathers dark yellowish orange                                 |
| <b>c coal zone</b>                        | <b>Kcd</b>  | Overlies No. 2 sandstone; 3-4 feet thick  |
| <b>No. 2 sandstone</b>                    | <b>Kf2</b>  | <b>Sandstone</b> , very fine grained, well sorted, grayish red, with finely disseminated hematite, very slightly calcareous; basal unit cross bedded, with scour base; tightly cemented, with quartz overgrowths; overlain by fine-grained, light-to medium-gray, irregularly bedded sandstone, rippled at base, horizontally laminated at top; bedding up to one foot thick; with woody debris, plant fragments, fossil pelecypods; thickness estimated to be up to 100 feet                                     |
| <b>ab coal zone</b>                       | <b>Kfab</b> | <b>Coal</b> ; occurs where No. 1 sandstone thins to a parting and the two coal zones combine into one; thickness, including partings, about 50 feet   |
| <b>b coal zone</b>                        | <b>b</b>    | <b>Coal</b> ; thickness about 20-25 feet  |
| <b>No. 1 sandstone</b>                    | <b>Kf1</b>  | <b>Sandstone</b> , upper beds are very fine grained, very well sorted, slightly calcareous, well cemented with quartz overgrowths; light brownish gray to light olive gray; bedding about 1 inch to 1 foot thick, some rippled, some burrowed, with clay chips; basal unit consists of 6 inches of irregularly bedded, carbonaceous, argillaceous to silty, fine- to medium-grained sandstone that is overlain by 3 feet of medium-gray mudrock; No. 1 sandstone thins to east; estimated thickness up to 25 feet |
| <b>a coal zone</b>                        | <b>a</b>    | <b>Coal</b> ; estimated thickness 15-20 feet, including partings  |
| <b>Pictured Cliffs Sandstone</b>          | <b>Kpc</b>  | <b>Sandstone</b> , fine grained, very light to light gray, medium to thick bedded, irregularly bedded, with abundant <i>Ophiomorpha</i> in upper part; divided into two main units; the lower is massively bedded, the upper is thinner bedded; in general, bedding is uneven and wavy, some is massive or cross bedded; top is marked by grayish-black rooted sandstone; sandstone dikes that are locally several inches thick occur in places in the upper beds of the unit; thickness not measured.            |

## APPENDIX 2-2. ROSE DIAGRAMS AT INDIVIDUAL FRACTURE STATIONS.

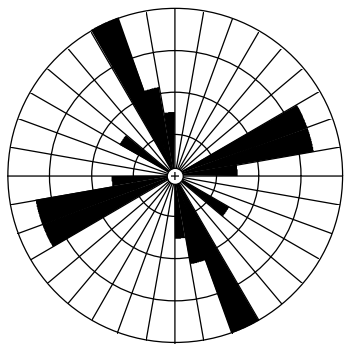
Tables 2-7 through 2-11 show a breakdown of which geologic unit each joint or cleat station was recorded in. Rose diagrams of the individual stations are also grouped by geologic unit.

**Table 2-7. Joint and cleat stations established in the Basin Creek study area, grouped by geologic unit. Station locations are shown on plate 1.**

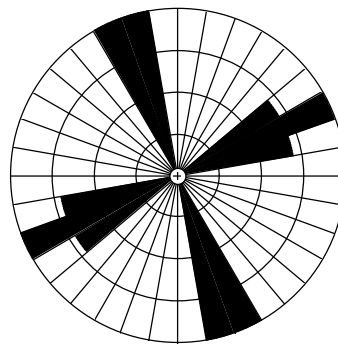
| Kpc  | Kft  | Kpct | Kflc | Kfls | Kfmc | Kfms | Kfuc | Kfus |
|------|------|------|------|------|------|------|------|------|
| BC01 | BC03 | BC05 | BC02 | BC11 | BC33 | BC10 | BC15 | BC16 |
| BC04 |      | BC08 | BC06 | BC18 |      | BC12 | BC17 | BC25 |
| BC21 |      | BC09 | BC07 | BC23 |      | BC14 | BC28 | BC26 |
|      |      | BC31 | BC13 | BC45 |      | BC27 | BC30 | BC29 |
|      |      | BC46 | BC19 |      |      | BC32 | BC35 | BC36 |
|      |      |      | BC20 |      |      | BC34 | BC37 | BC38 |
|      |      |      | BC22 |      |      | BC44 | BC39 | BC40 |
|      |      |      | BC24 |      |      |      | BC42 | BC41 |
|      |      |      |      |      |      |      | BC47 | BC43 |

Kpc - Pictured Cliffs Sandstone, main body; Kft - coal below tongue of Pictured Cliffs; Kpct - tongue of Pictured Cliffs Sandstone; Kflc - coal in lower part of Fruitland Formation; Kfls - sandstone in lower part of Fruitland; Kfmc - coal in middle part of Fruitland Formation; Kfms - sandstone in middle part of Fruitland; Kfuc - coal in upper part of Fruitland; Kfus - sandstone in upper part of Fruitland.

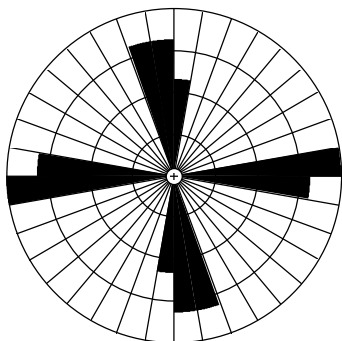
Pictured Cliffs Sandstone, main body:



| BC01                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 22                      | Vector Mean = 284.4        |
| Class Interval = 10 degrees | Conf. Angle = 209.12       |
| Maximum Percentage = 31.8   | R Magnitude = 0.082        |
| Mean Percentage = 14.29     | Standard Deviation = 10.82 |
|                             | Rayleigh = 0.8635          |

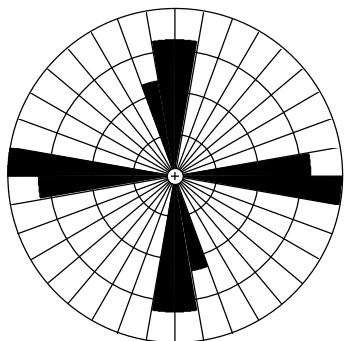


| BC04                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 20.1        |
| Class Interval = 10 degrees | Conf. Angle = 467.20      |
| Maximum Percentage = 25.0   | R Magnitude = 0.060       |
| Mean Percentage = 20.00     | Standard Deviation = 6.45 |
|                             | Rayleigh = 0.9715         |



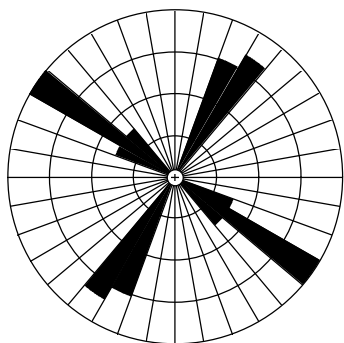
| BC21                        | Statistics                |
|-----------------------------|---------------------------|
| N = 10                      | Vector Mean = 305.9       |
| Class Interval = 10 degrees | Conf. Angle = 204.93      |
| Maximum Percentage = 30.0   | R Magnitude = 0.124       |
| Mean Percentage = 20.00     | Standard Deviation = 6.67 |
|                             | Rayleigh = 0.8570         |

Coal below tongue of Pictured Cliffs Sandstone:

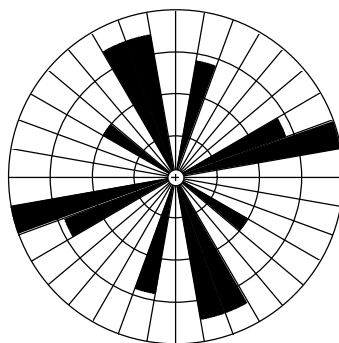


| BC03                        | Statistics                |
|-----------------------------|---------------------------|
| N = 10                      | Vector Mean = 310.8       |
| Class Interval = 10 degrees | Conf. Angle = 245.84      |
| Maximum Percentage = 30.0   | R Magnitude = 0.104       |
| Mean Percentage = 20.00     | Standard Deviation = 6.67 |
|                             | Rayleigh = 0.8978         |

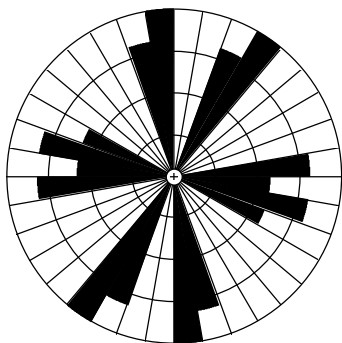
Pictured Cliffs Sandstone, tongue:



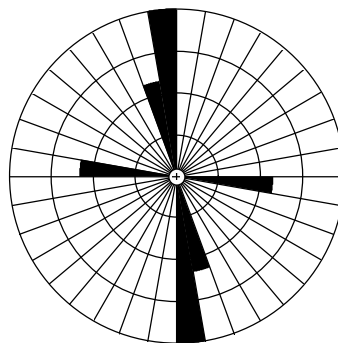
| BC05                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 18                      | Vector Mean = 347.7        |
| Class Interval = 10 degrees | Conf. Angle = 190.38       |
| Maximum Percentage = 38.9   | R Magnitude = 0.096        |
| Mean Percentage = 20.00     | Standard Deviation = 13.66 |
|                             | Rayleigh = 0.8467          |



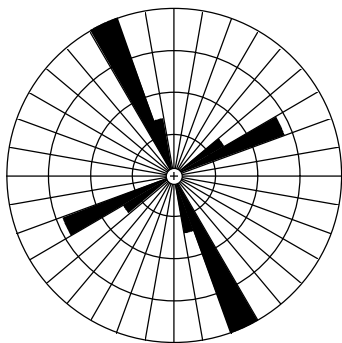
| BC08                        | Statistics                |
|-----------------------------|---------------------------|
| N = 15                      | Vector Mean = 356.8       |
| Class Interval = 10 degrees | Conf. Angle = 249.31      |
| Maximum Percentage = 26.7   | R Magnitude = 0.084       |
| Mean Percentage = 16.67     | Standard Deviation = 6.67 |
|                             | Rayleigh = 0.8990         |



| BC09                        | Statistics                |
|-----------------------------|---------------------------|
| N = 16                      | Vector Mean = 17.6        |
| Class Interval = 10 degrees | Conf. Angle = 163.84      |
| Maximum Percentage = 18.8   | R Magnitude = 0.121       |
| Mean Percentage = 12.50     | Standard Deviation = 4.56 |
|                             | Rayleigh = 0.7898         |

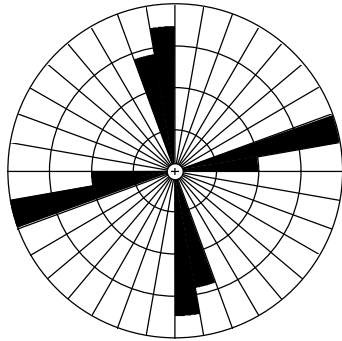


| BC31                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 5                       | Vector Mean = 350.4        |
| Class Interval = 10 degrees | Conf. Angle = 52.68        |
| Maximum Percentage = 60.0   | R Magnitude = 0.600        |
| Mean Percentage = 33.33     | Standard Deviation = 20.66 |
|                             | Rayleigh = 0.1657          |

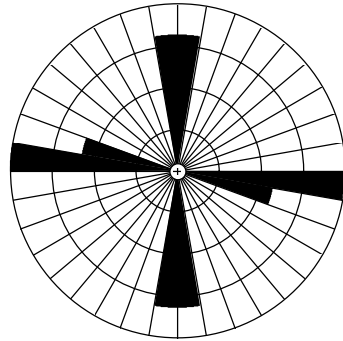


| BC46                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 14                      | Vector Mean = 337.2        |
| Class Interval = 10 degrees | Conf. Angle = 71.98        |
| Maximum Percentage = 57.1   | R Magnitude = 0.287        |
| Mean Percentage = 25.00     | Standard Deviation = 21.93 |
|                             | Rayleigh = 0.3162          |

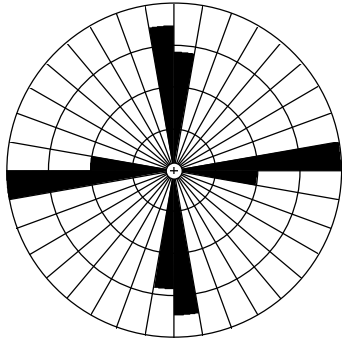
Fruitland Formation, coal in lower part:



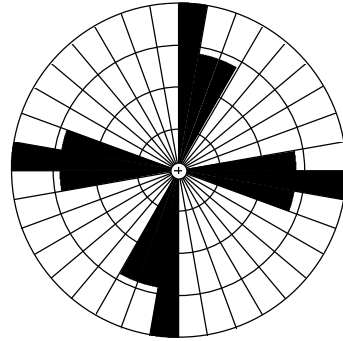
| BC02                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 29.3         |
| Class Interval = 10 degrees | Conf. Angle = 408.19       |
| Maximum Percentage = 40.0   | R Magnitude = 0.063        |
| Mean Percentage = 25.00     | Standard Deviation = 11.95 |
|                             | Rayleigh = 0.9611          |



| BC06                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 318.7       |
| Class Interval = 10 degrees | Conf. Angle = 274.82      |
| Maximum Percentage = 37.5   | R Magnitude = 0.104       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.9174         |

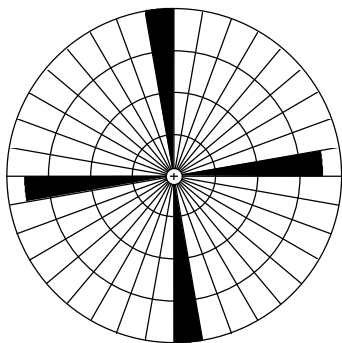


| BC07                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 320.8        |
| Class Interval = 10 degrees | Conf. Angle = INF          |
| Maximum Percentage = 40.0   | R Magnitude = 0.004        |
| Mean Percentage = 25.00     | Standard Deviation = 11.95 |
|                             | Rayleigh = 0.9999          |

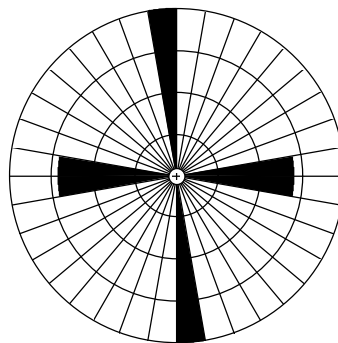


| BC13                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 55.5        |
| Class Interval = 10 degrees | Conf. Angle = 238.12      |
| Maximum Percentage = 25.0   | R Magnitude = 0.115       |
| Mean Percentage = 16.67     | Standard Deviation = 6.15 |
|                             | Rayleigh = 0.8996         |

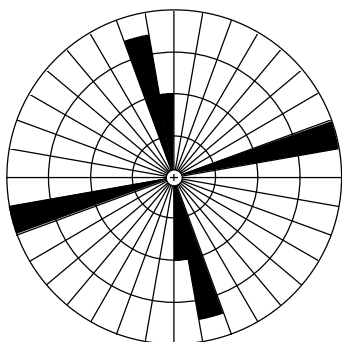




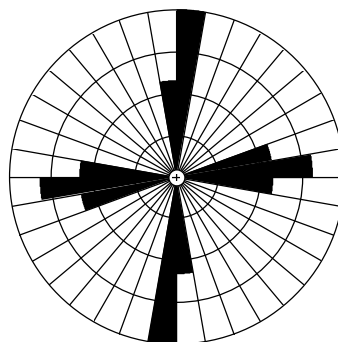
| BC19                        | Statistics                |
|-----------------------------|---------------------------|
| N = 9                       | Vector Mean = 348.3       |
| Class Interval = 10 degrees | Conf. Angle = 223.28      |
| Maximum Percentage = 55.6   | R Magnitude = 0.116       |
| Mean Percentage = 50.00     | Standard Deviation = 6.42 |
|                             | Rayleigh = 0.8855         |



| BC20                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 311.9        |
| Class Interval = 10 degrees | Conf. Angle = 164.73       |
| Maximum Percentage = 50.0   | R Magnitude = 0.168        |
| Mean Percentage = 33.33     | Standard Deviation = 12.91 |
|                             | Rayleigh = 0.7971          |

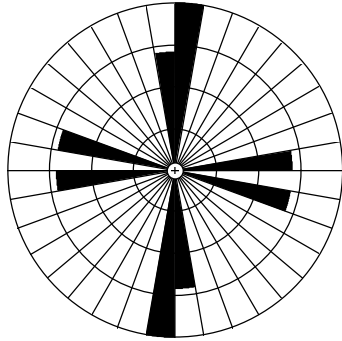


| BC22                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 31.9         |
| Class Interval = 10 degrees | Conf. Angle = 869.10       |
| Maximum Percentage = 50.0   | R Magnitude = 0.035        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9904          |

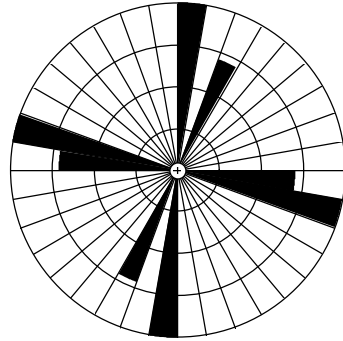


| BC24                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 40.4         |
| Class Interval = 10 degrees | Conf. Angle = 211.97       |
| Maximum Percentage = 37.5   | R Magnitude = 0.134        |
| Mean Percentage = 20.00     | Standard Deviation = 10.54 |
|                             | Rayleigh = 0.8666          |

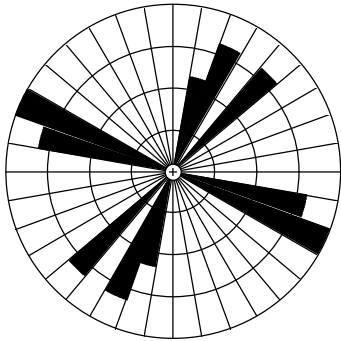
Fruitland Formation, sandstone in lower part:



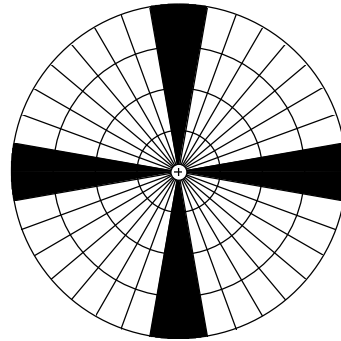
| BC11                        | Statistics                |
|-----------------------------|---------------------------|
| N = 5                       | Vector Mean = 1.1         |
| Class Interval = 10 degrees | Conf. Angle = 152.70      |
| Maximum Percentage = 40.0   | R Magnitude = 0.229       |
| Mean Percentage = 25.00     | Standard Deviation = 9.26 |
|                             | Rayleigh = 0.7697         |



| BC18                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 324.6       |
| Class Interval = 10 degrees | Conf. Angle = 1704.76     |
| Maximum Percentage = 33.3   | R Magnitude = 0.018       |
| Mean Percentage = 25.00     | Standard Deviation = 8.91 |
|                             | Rayleigh = 0.9980         |

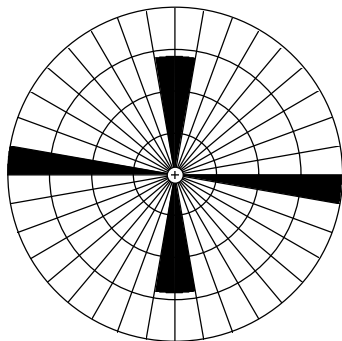


| BC23                        | Statistics                |
|-----------------------------|---------------------------|
| N = 10                      | Vector Mean = 75.3        |
| Class Interval = 10 degrees | Conf. Angle = 176.46      |
| Maximum Percentage = 30.0   | R Magnitude = 0.143       |
| Mean Percentage = 20.00     | Standard Deviation = 6.67 |
|                             | Rayleigh = 0.8145         |



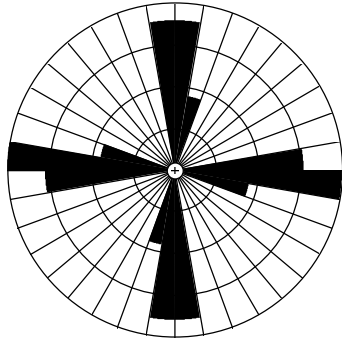
| BC45                        | Statistics                |
|-----------------------------|---------------------------|
| N = 4                       | Vector Mean = 46.5        |
| Class Interval = 10 degrees | Conf. Angle = 2135.33     |
| Maximum Percentage = 25.0   | R Magnitude = 0.017       |
| Mean Percentage = 25.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9988         |

Fruitland Formation, coal in middle part:

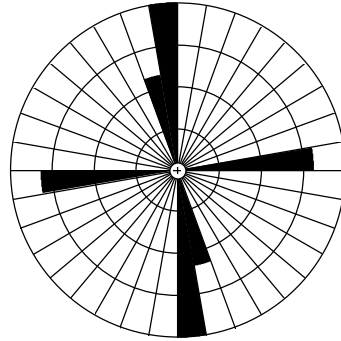


| BC33                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 4                       | Vector Mean = 316.5        |
| Class Interval = 10 degrees | Conf. Angle = 656.04       |
| Maximum Percentage = 50.0   | R Magnitude = 0.061        |
| Mean Percentage = 33.33     | Standard Deviation = 12.91 |
|                             | Rayleigh = 0.9853          |

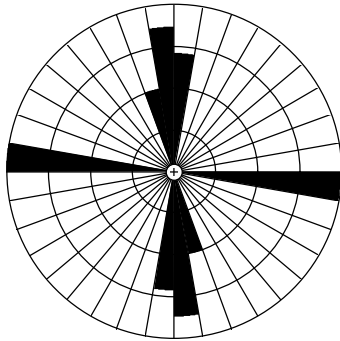
Fruitland Formation , sandstone in middle part:



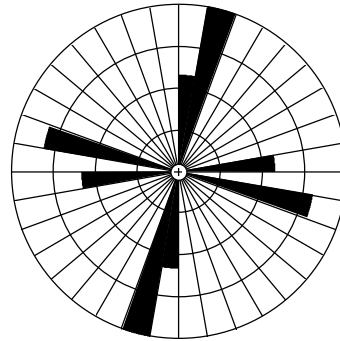
| BC10                        | Statistics                |
|-----------------------------|---------------------------|
| N = 18                      | Vector Mean = 322.9       |
| Class Interval = 10 degrees | Conf. Angle = 677.61      |
| Maximum Percentage = 27.8   | R Magnitude = 0.025       |
| Mean Percentage = 16.67     | Standard Deviation = 8.86 |
|                             | Rayleigh = 0.9884         |



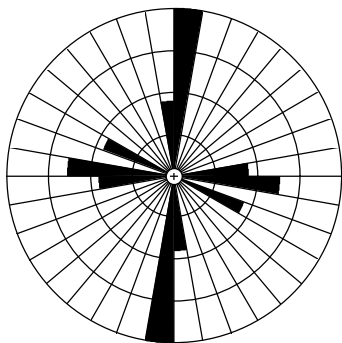
| BC12                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 353.0        |
| Class Interval = 10 degrees | Conf. Angle = 95.99        |
| Maximum Percentage = 50.0   | R Magnitude = 0.326        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.5284          |



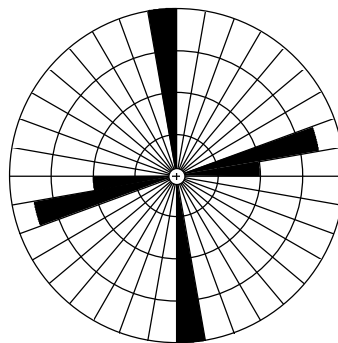
| BC14                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 341.5        |
| Class Interval = 10 degrees | Conf. Angle = 106.76       |
| Maximum Percentage = 40.0   | R Magnitude = 0.234        |
| Mean Percentage = 25.00     | Standard Deviation = 11.95 |
|                             | Rayleigh = 0.5782          |



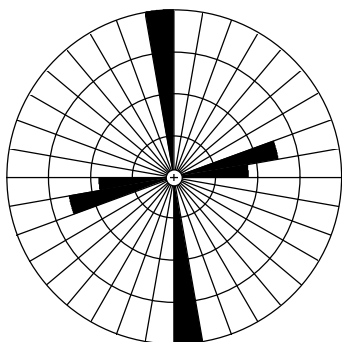
| BC27                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 13.9         |
| Class Interval = 10 degrees | Conf. Angle = 183.79       |
| Maximum Percentage = 42.9   | R Magnitude = 0.165        |
| Mean Percentage = 25.00     | Standard Deviation = 12.66 |
|                             | Rayleigh = 0.8274          |



| BC32                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 357.1        |
| Class Interval = 10 degrees | Conf. Angle = 112.90       |
| Maximum Percentage = 50.0   | R Magnitude = 0.219        |
| Mean Percentage = 20.00     | Standard Deviation = 16.33 |
|                             | Rayleigh = 0.6181          |

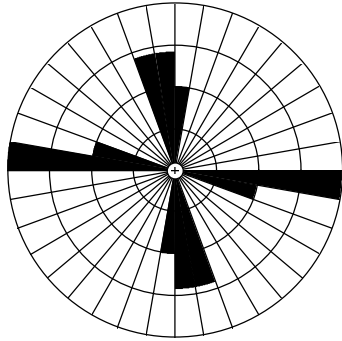


| BC34                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 34.7         |
| Class Interval = 10 degrees | Conf. Angle = 133.24       |
| Maximum Percentage = 50.0   | R Magnitude = 0.207        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.7105          |

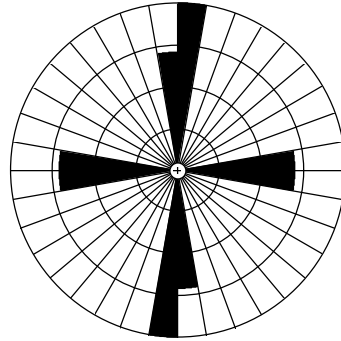


| BC44                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 358.9        |
| Class Interval = 10 degrees | Conf. Angle = 106.78       |
| Maximum Percentage = 62.5   | R Magnitude = 0.257        |
| Mean Percentage = 33.33     | Standard Deviation = 23.27 |
|                             | Rayleigh = 0.5903          |

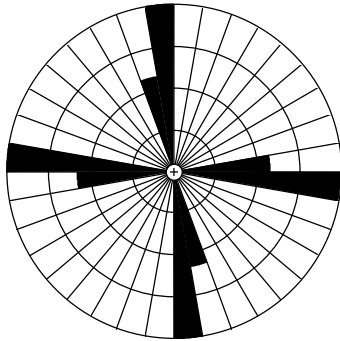
Fruitland Formation, coal in upper part:



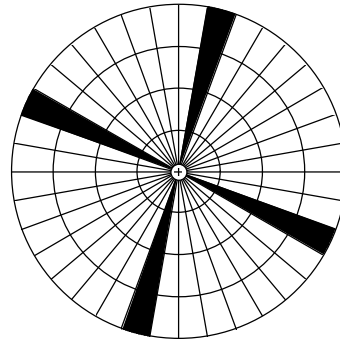
| BC15                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 314.0        |
| Class Interval = 10 degrees | Conf. Angle = 116.93       |
| Maximum Percentage = 40.0   | R Magnitude = 0.215        |
| Mean Percentage = 20.00     | Standard Deviation = 11.55 |
|                             | Rayleigh = 0.6307          |



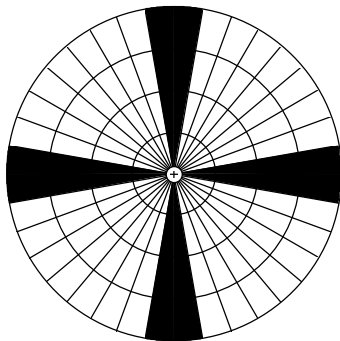
| BC17                        | Statistics                |
|-----------------------------|---------------------------|
| N = 5                       | Vector Mean = 11.0        |
| Class Interval = 10 degrees | Conf. Angle = 174.47      |
| Maximum Percentage = 40.0   | R Magnitude = 0.203       |
| Mean Percentage = 25.00     | Standard Deviation = 9.26 |
|                             | Rayleigh = 0.8139         |



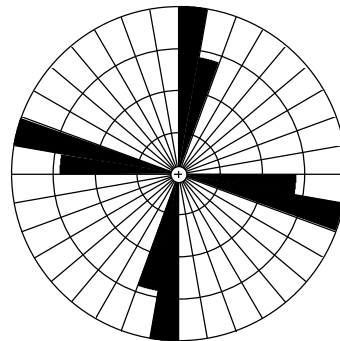
| BC28                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 312.6        |
| Class Interval = 10 degrees | Conf. Angle = 156.24       |
| Maximum Percentage = 37.5   | R Magnitude = 0.176        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.7795          |



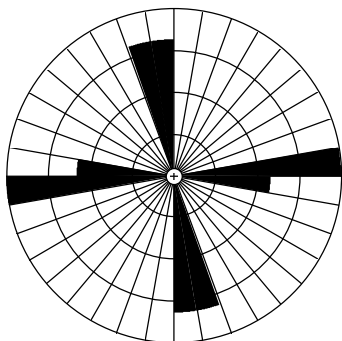
| BC30                        | Statistics                |
|-----------------------------|---------------------------|
| N = 4                       | Vector Mean = 333.0       |
| Class Interval = 10 degrees | Conf. Angle = 197.02      |
| Maximum Percentage = 50.0   | R Magnitude = 0.199       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.8536         |



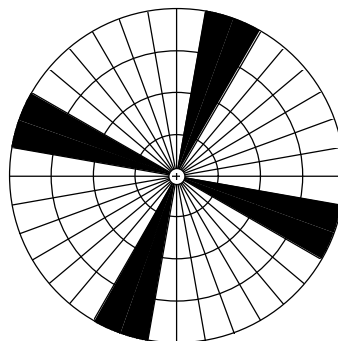
| BC35                        | Statistics                |
|-----------------------------|---------------------------|
| N = 4                       | Vector Mean = 45.3        |
| Class Interval = 10 degrees | Conf. Angle = 777.03      |
| Maximum Percentage = 25.0   | R Magnitude = 0.052       |
| Mean Percentage = 25.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9892         |



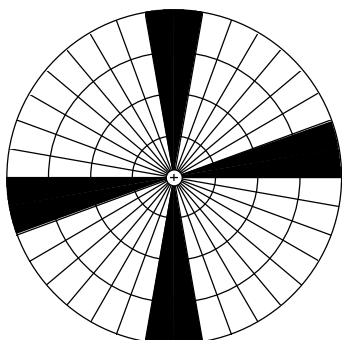
| BC37                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 328.5       |
| Class Interval = 10 degrees | Conf. Angle = 1724.95     |
| Maximum Percentage = 33.3   | R Magnitude = 0.018       |
| Mean Percentage = 25.00     | Standard Deviation = 8.91 |
|                             | Rayleigh = 0.9981         |



| BC39                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 308.8       |
| Class Interval = 10 degrees | Conf. Angle = 449.98      |
| Maximum Percentage = 37.5   | R Magnitude = 0.065       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.9670         |

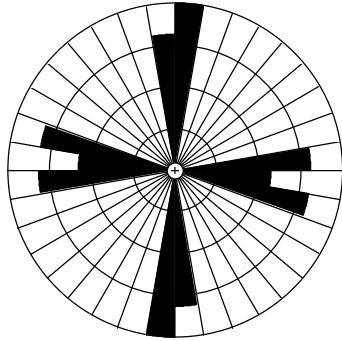


| BC42                        | Statistics                |
|-----------------------------|---------------------------|
| N = 4                       | Vector Mean = 65.5        |
| Class Interval = 10 degrees | Conf. Angle = 4250.26     |
| Maximum Percentage = 25.0   | R Magnitude = 0.009       |
| Mean Percentage = 25.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9997         |

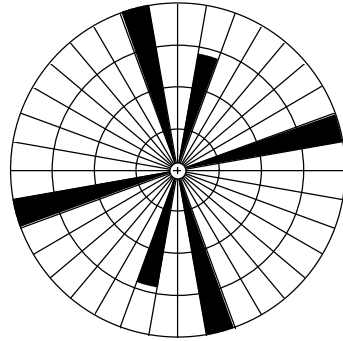


| BC47                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 38.2        |
| Class Interval = 10 degrees | Conf. Angle = 172.30      |
| Maximum Percentage = 25.0   | R Magnitude = 0.164       |
| Mean Percentage = 25.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.8068         |

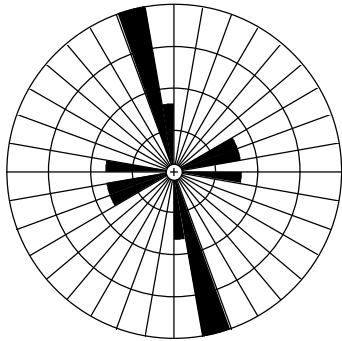
Fruitland Formation, sandstone in upper part:



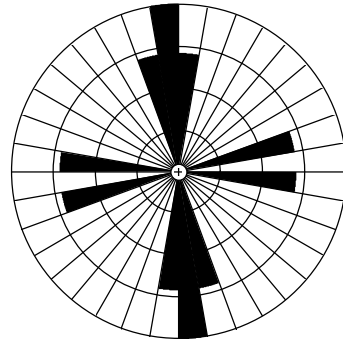
| BC16                        | Statistics                |
|-----------------------------|---------------------------|
| N = 10                      | Vector Mean = 324.3       |
| Class Interval = 10 degrees | Conf. Angle = 282.51      |
| Maximum Percentage = 30.0   | R Magnitude = 0.087       |
| Mean Percentage = 20.00     | Standard Deviation = 6.67 |
|                             | Rayleigh = 0.9264         |



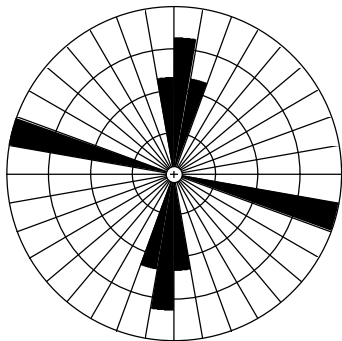
| BC25                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 5                       | Vector Mean = 11.2         |
| Class Interval = 10 degrees | Conf. Angle = 177.79       |
| Maximum Percentage = 40.0   | R Magnitude = 0.195        |
| Mean Percentage = 33.33     | Standard Deviation = 10.33 |
|                             | Rayleigh = 0.8261          |



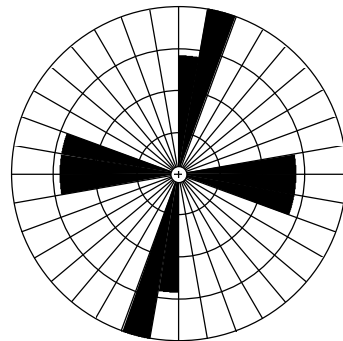
| BC26                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 345.6        |
| Class Interval = 10 degrees | Conf. Angle = 56.95        |
| Maximum Percentage = 60.0   | R Magnitude = 0.419        |
| Mean Percentage = 20.00     | Standard Deviation = 21.08 |
|                             | Rayleigh = 0.1722          |



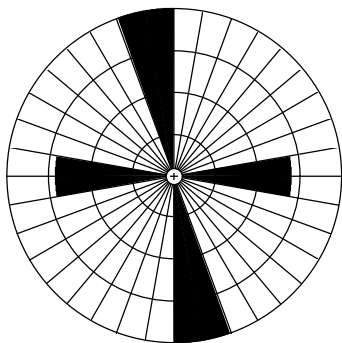
| BC29                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 354.0       |
| Class Interval = 10 degrees | Conf. Angle = 97.85       |
| Maximum Percentage = 33.3   | R Magnitude = 0.325       |
| Mean Percentage = 20.00     | Standard Deviation = 7.03 |
|                             | Rayleigh = 0.5310         |



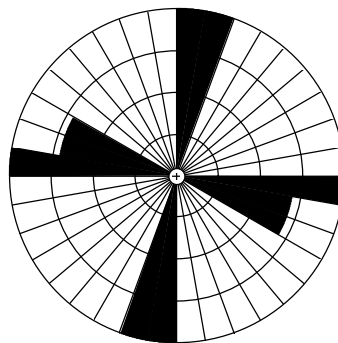
| BC36                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 340.8        |
| Class Interval = 10 degrees | Conf. Angle = 136.03       |
| Maximum Percentage = 42.9   | R Magnitude = 0.216        |
| Mean Percentage = 25.00     | Standard Deviation = 12.66 |
|                             | Rayleigh = 0.7217          |



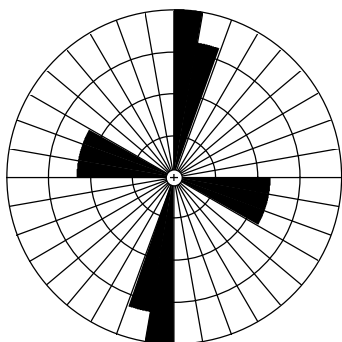
| BC38                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 51.6        |
| Class Interval = 10 degrees | Conf. Angle = 247.96      |
| Maximum Percentage = 33.3   | R Magnitude = 0.130       |
| Mean Percentage = 20.00     | Standard Deviation = 7.03 |
|                             | Rayleigh = 0.9031         |



| BC40                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 338.5       |
| Class Interval = 10 degrees | Conf. Angle = 83.97       |
| Maximum Percentage = 33.3   | R Magnitude = 0.374       |
| Mean Percentage = 25.00     | Standard Deviation = 8.91 |
|                             | Rayleigh = 0.4323         |



| BC41                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 348.6       |
| Class Interval = 10 degrees | Conf. Angle = 3555.69     |
| Maximum Percentage = 25.0   | R Magnitude = 0.006       |
| Mean Percentage = 20.00     | Standard Deviation = 6.45 |
|                             | Rayleigh = 0.9997         |



| BC43                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 1.1          |
| Class Interval = 10 degrees | Conf. Angle = 98.55        |
| Maximum Percentage = 37.5   | R Magnitude = 0.278        |
| Mean Percentage = 20.00     | Standard Deviation = 10.54 |
|                             | Rayleigh = 0.5385          |

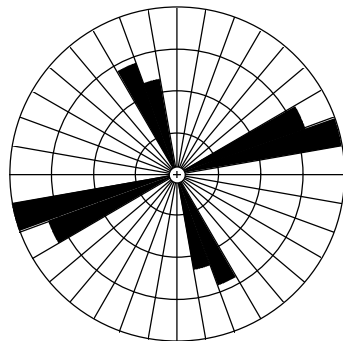


**Table 2-8. Joint and cleat stations established in the Carbon Junction study area, grouped by geologic unit. Station locations are shown on plate 2.**

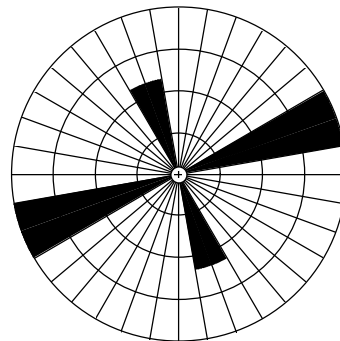
| Kpc  | Kft  | Kpct | Kflc | Kfls | Kfmc | Kfms | Kfuc | Kfus |
|------|------|------|------|------|------|------|------|------|
| CJ11 | CJ02 | CJ03 | CJ01 | CJ14 | CJ06 | CJ05 | CJ07 | CJ08 |
| CJ13 | CJ26 | CJ19 | CJ04 | CJ20 | CJ22 | CJ15 | CJ09 | CJ10 |
| CJ24 |      |      | CJ12 |      |      | CJ16 | CJ17 | CJ23 |
| CJ27 |      |      | CJ25 |      |      | CJ18 |      |      |
|      |      |      |      |      |      | CJ21 |      |      |

Kpc - Pictured Cliffs Sandstone, main body; Kft - coal below tongue of Pictured Cliffs; Kpct - tongue of Pictured Cliffs Sandstone; Kflc - coal in lower part of Fruitland Formation; Kfls - sandstone in lower part of Fruitland; Kfmc - coal in middle part of Fruitland Formation; Kfms - sandstone in middle part of Fruitland; Kfuc - coal in upper part of Fruitland; Kfus - sandstone in upper part of Fruitland. Note that stations CJ26 and CJ27 are not shown on the map because they are located in or near the Ewing Mesa gravel pit, outside the map boundary.

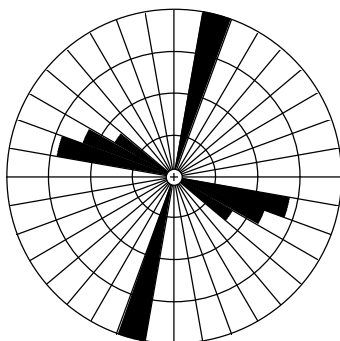
Pictured Cliffs Sandstone, main body:



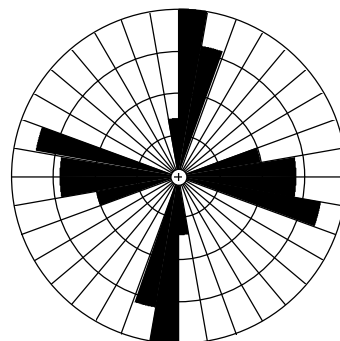
| CJ11                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 15                      | Vector Mean = 72.8         |
| Class Interval = 10 degrees | Conf. Angle = 58.82        |
| Maximum Percentage = 40.0   | R Magnitude = 0.336        |
| Mean Percentage = 25.00     | Standard Deviation = 10.54 |
|                             | Rayleigh = 0.1842          |



| CJ13                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 72.5         |
| Class Interval = 10 degrees | Conf. Angle = 53.14        |
| Maximum Percentage = 37.5   | R Magnitude = 0.495        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.1411          |



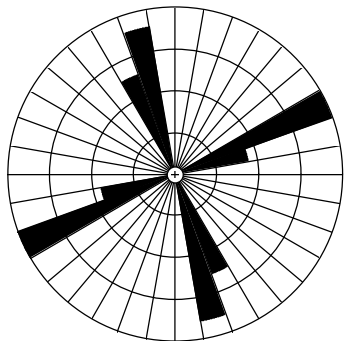
| CJ24                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 12                      | Vector Mean = 337.0        |
| Class Interval = 10 degrees | Conf. Angle = 289.57       |
| Maximum Percentage = 50.0   | R Magnitude = 0.078        |
| Mean Percentage = 25.00     | Standard Deviation = 16.67 |
|                             | Rayleigh = 0.9294          |



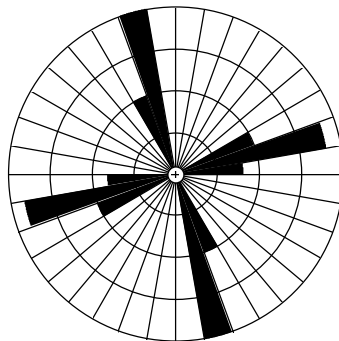
| AF11                        | Statistics                |
|-----------------------------|---------------------------|
| N = 30                      | Vector Mean = 65.9        |
| Class Interval = 10 degrees | Conf. Angle = 163.20      |
| Maximum Percentage = 26.7   | R Magnitude = 0.087       |
| Mean Percentage = 14.29     | Standard Deviation = 7.56 |
|                             | Rayleigh = 0.7955         |

Note: Station AF11 renamed CJ27.

Coal below tongue of Pictured Cliffs Sandstone:



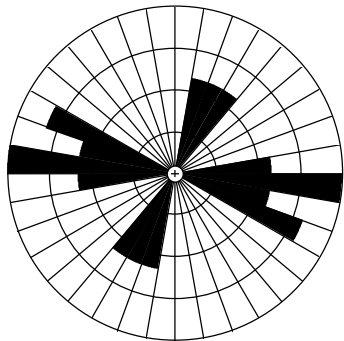
| CJ02                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 12                      | Vector Mean = 24.6         |
| Class Interval = 10 degrees | Conf. Angle = 568.50       |
| Maximum Percentage = 41.7   | R Magnitude = 0.041        |
| Mean Percentage = 25.00     | Standard Deviation = 14.09 |
|                             | Rayleigh = 0.9804          |



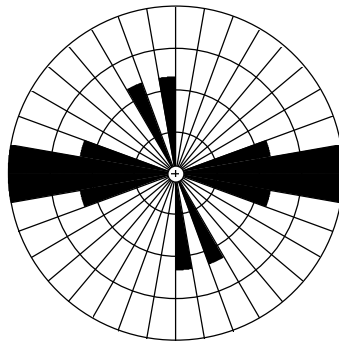
| AF09                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 30                      | Vector Mean = 304.4        |
| Class Interval = 10 degrees | Conf. Angle = 361.60       |
| Maximum Percentage = 40.0   | R Magnitude = 0.040        |
| Mean Percentage = 20.00     | Standard Deviation = 14.57 |
|                             | Rayleigh = 0.9528          |

Note: Station AF09 renamed CJ26.

Pictured Cliffs Sandstone, tongue:

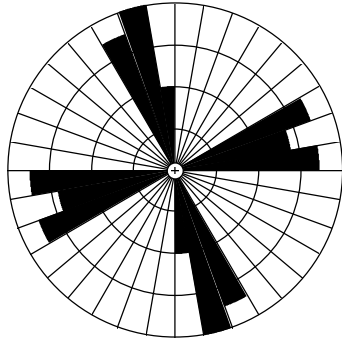


| CJ03                        | Statistics                |
|-----------------------------|---------------------------|
| N = 10                      | Vector Mean = 89.3        |
| Class Interval = 10 degrees | Conf. Angle = 59.76       |
| Maximum Percentage = 30.0   | R Magnitude = 0.404       |
| Mean Percentage = 14.29     | Standard Deviation = 7.56 |
|                             | Rayleigh = 0.1955         |

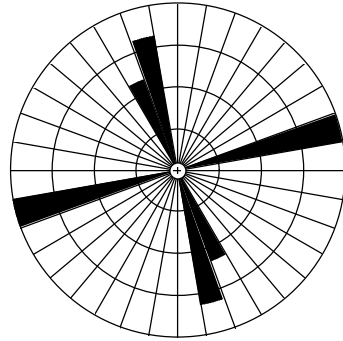


| CJ19                        | Statistics                |
|-----------------------------|---------------------------|
| N = 10                      | Vector Mean = 272.9       |
| Class Interval = 10 degrees | Conf. Angle = 37.13       |
| Maximum Percentage = 30.0   | R Magnitude = 0.604       |
| Mean Percentage = 16.67     | Standard Deviation = 9.85 |
|                             | Rayleigh = 0.0261         |

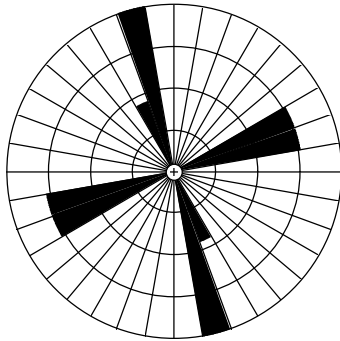
Fruitland Formation, coal in lower part:



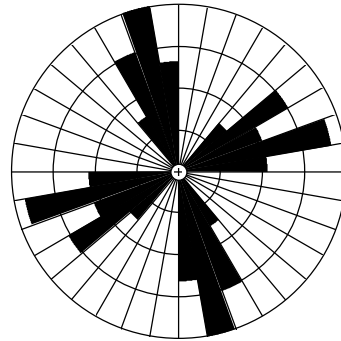
| CJ01                        | Statistics                |
|-----------------------------|---------------------------|
| N = 16                      | Vector Mean = 316.5       |
| Class Interval = 10 degrees | Conf. Angle = 640.77      |
| Maximum Percentage = 25.0   | R Magnitude = 0.032       |
| Mean Percentage = 16.67     | Standard Deviation = 6.15 |
|                             | Rayleigh = 0.9838         |



| CJ04                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 284.6        |
| Class Interval = 10 degrees | Conf. Angle = 4013.76      |
| Maximum Percentage = 50.0   | R Magnitude = 0.007        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.9997          |



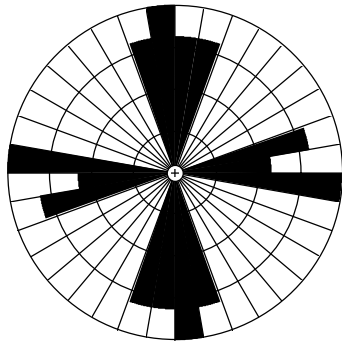
| CJ12                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 12                      | Vector Mean = 23.7         |
| Class Interval = 10 degrees | Conf. Angle = 549.39       |
| Maximum Percentage = 41.7   | R Magnitude = 0.043        |
| Mean Percentage = 25.00     | Standard Deviation = 12.60 |
|                             | Rayleigh = 0.9776          |



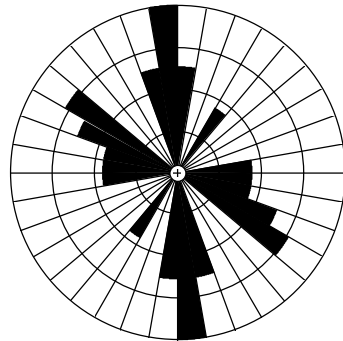
| AF07                        | Statistics                |
|-----------------------------|---------------------------|
| N = 30                      | Vector Mean = 19.8        |
| Class Interval = 10 degrees | Conf. Angle = 145.95      |
| Maximum Percentage = 23.3   | R Magnitude = 0.098       |
| Mean Percentage = 11.11     | Standard Deviation = 6.86 |
|                             | Rayleigh = 0.7489         |

Note: Station AF07 renamed CJ25.

Fruitland Formation, sandstone in lower part:

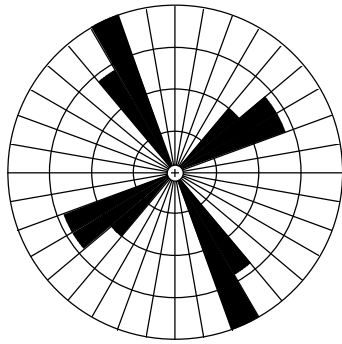


| CJ14                        | Statistics                |
|-----------------------------|---------------------------|
| N = 15                      | Vector Mean = 3.5         |
| Class Interval = 10 degrees | Conf. Angle = 100.53      |
| Maximum Percentage = 20.0   | R Magnitude = 0.204       |
| Mean Percentage = 14.29     | Standard Deviation = 4.42 |
|                             | Rayleigh = 0.5365         |

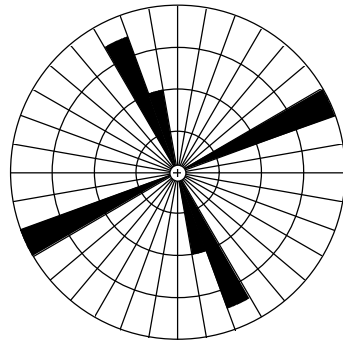


| CJ20                        | Statistics                |
|-----------------------------|---------------------------|
| N = 18                      | Vector Mean = 332.2       |
| Class Interval = 10 degrees | Conf. Angle = 48.99       |
| Maximum Percentage = 27.8   | R Magnitude = 0.366       |
| Mean Percentage = 11.11     | Standard Deviation = 7.13 |
|                             | Rayleigh = 0.0895         |

Fruitland Formation, coal in middle part:

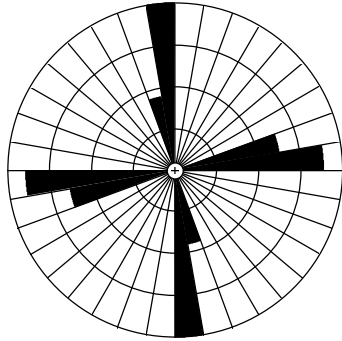


| CJ06   | Statistics           |
|--|----------------------|
| N = 11   | Vector Mean = 341.8  |
| Class Interval = 10 degrees                            | Conf. Angle = 218.30 |
| Maximum Percentage = 36.4                              | R Magnitude = 0.109  |
| Mean Percentage = 20.00      Standard Deviation = 9.39 | Rayleigh = 0.8781    |

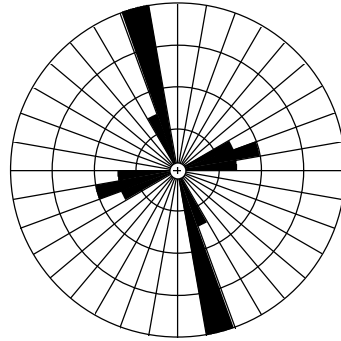


| CJ22  | Statistics           |
|---|----------------------|
| N = 8   | Vector Mean = 21.9   |
| Class Interval = 10 degrees                             | Conf. Angle = 708.52 |
| Maximum Percentage = 50.0                               | R Magnitude = 0.039  |
| Mean Percentage = 33.33      Standard Deviation = 17.08 | Rayleigh = 0.9878    |

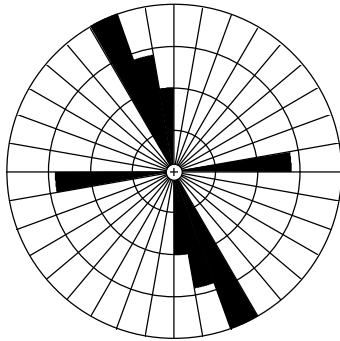
Fruitland Formation, sandstone in middle part:



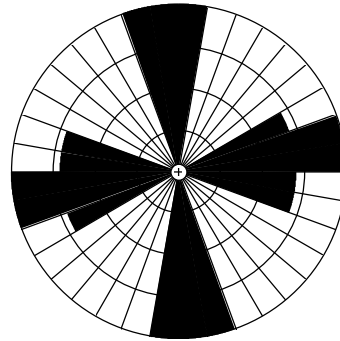
| CJ05                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 12                      | Vector Mean = 29.8         |
| Class Interval = 10 degrees | Conf. Angle = 708.24       |
| Maximum Percentage = 41.7   | R Magnitude = 0.035        |
| Mean Percentage = 25.00     | Standard Deviation = 14.09 |
|                             | Rayleigh = 0.9855          |



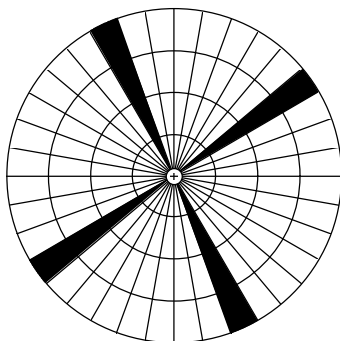
| CJ15                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 13                      | Vector Mean = 343.6        |
| Class Interval = 10 degrees | Conf. Angle = 54.46        |
| Maximum Percentage = 61.5   | R Magnitude = 0.386        |
| Mean Percentage = 20.00     | Standard Deviation = 22.12 |
|                             | Rayleigh = 0.1446          |



| CJ16                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 9                       | Vector Mean = 335.8        |
| Class Interval = 10 degrees | Conf. Angle = 40.19        |
| Maximum Percentage = 44.4   | R Magnitude = 0.588        |
| Mean Percentage = 25.00     | Standard Deviation = 12.94 |
|                             | Rayleigh = 0.0445          |

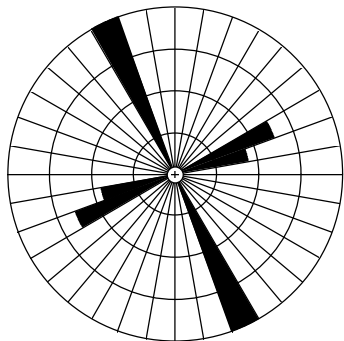


| CJ18                        | Statistics                |
|-----------------------------|---------------------------|
| N = 13                      | Vector Mean = 77.1        |
| Class Interval = 10 degrees | Conf. Angle = 423.86      |
| Maximum Percentage = 15.4   | R Magnitude = 0.054       |
| Mean Percentage = 12.50     | Standard Deviation = 3.85 |
|                             | Rayleigh = 0.9629         |

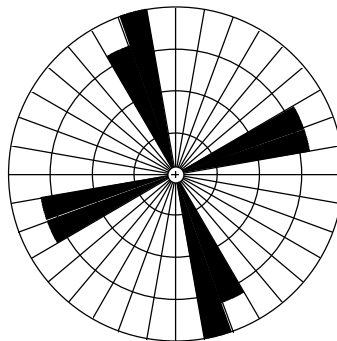


| CJ21                        | Statistics                |
|-----------------------------|---------------------------|
| N = 2                       | Vector Mean = 16.0        |
| Class Interval = 10 degrees | Conf. Angle = 265.69      |
| Maximum Percentage = 50.0   | R Magnitude = 0.208       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9172         |

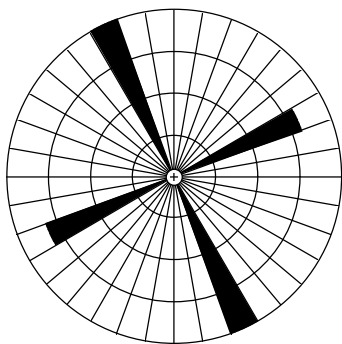
Fruitland Formation, coal in upper part:



| CJ07  | Statistics           |
|---|----------------------|
| N = 8   | Vector Mean = 333.5  |
| Class Interval = 10 degrees                             | Conf. Angle = 110.17 |
| Maximum Percentage = 62.5                               | R Magnitude = 0.251  |
| Mean Percentage = 33.33      Standard Deviation = 23.27 | Rayleigh = 0.6030    |

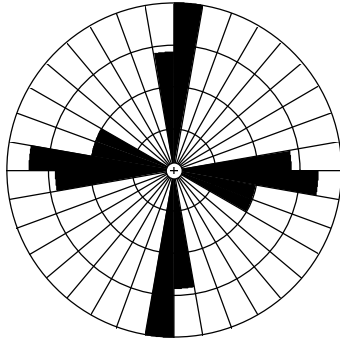


| CJ09   | Statistics           |
|--|----------------------|
| N = 9  | Vector Mean = 343.0  |
| Class Interval = 10 degrees                            | Conf. Angle = 238.99 |
| Maximum Percentage = 33.3                              | R Magnitude = 0.111  |
| Mean Percentage = 25.00      Standard Deviation = 5.14 | Rayleigh = 0.8953    |

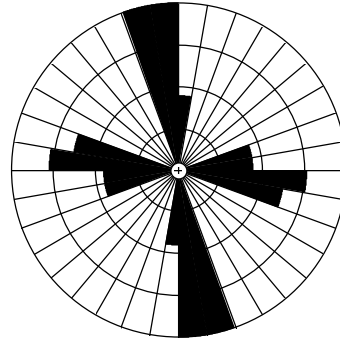


| CJ17  | Statistics           |
|---|----------------------|
| N = 10  | Vector Mean = 342.7  |
| Class Interval = 10 degrees                             | Conf. Angle = 118.71 |
| Maximum Percentage = 60.0                               | R Magnitude = 0.208  |
| Mean Percentage = 50.00      Standard Deviation = 11.55 | Rayleigh = 0.6480    |

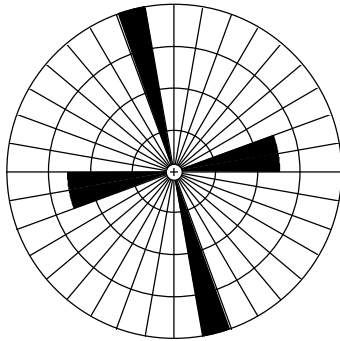
Fruitland Formation, sandstone in upper part:



| C.J08                       | Statistics                |
|-----------------------------|---------------------------|
| N = 13                      | Vector Mean = 295.4       |
| Class Interval = 10 degrees | Conf. Angle = 244.26      |
| Maximum Percentage = 30.8   | R Magnitude = 0.090       |
| Mean Percentage = 16.67     | Standard Deviation = 8.57 |
|                             | Rayleigh = 0.9001         |



| C.J10                       | Statistics                |
|-----------------------------|---------------------------|
| N = 18                      | Vector Mean = 335.5       |
| Class Interval = 10 degrees | Conf. Angle = 60.58       |
| Maximum Percentage = 27.8   | R Magnitude = 0.303       |
| Mean Percentage = 14.29     | Standard Deviation = 9.68 |
|                             | Rayleigh = 0.1907         |



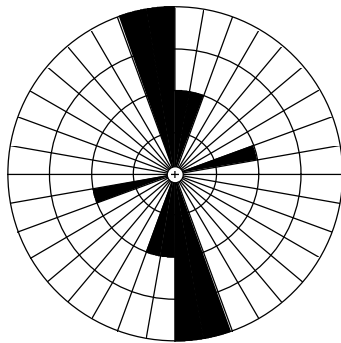
| C.J23                       | Statistics                 |
|-----------------------------|----------------------------|
| N = 9                       | Vector Mean = 334.6        |
| Class Interval = 10 degrees | Conf. Angle = 190.68       |
| Maximum Percentage = 55.6   | R Magnitude = 0.136        |
| Mean Percentage = 33.33     | Standard Deviation = 17.21 |
|                             | Rayleigh = 0.8467          |

**Table 2-9. Joint and cleat stations established in the Florida River area, grouped by geologic unit. Station locations are shown on plate 4.**

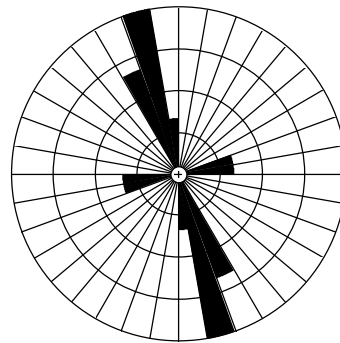
| Kpc  | Kftc | Kfts | Kpct | Kfab | Kf1  | Kf2  | Kf3c | Kf3s | Kfuc |
|------|------|------|------|------|------|------|------|------|------|
| FR01 | FR04 | FR30 | FR11 | FR12 | FR10 | FR19 | FR37 | FR20 | FR21 |
| FR02 | FR06 |      | FR14 | FR13 | FR17 | FR31 | FR40 | FR23 | FR22 |
| FR03 | FR09 |      | FR15 | FR16 |      | FR35 |      | FR24 |      |
| FR05 | FR25 |      | FR26 | FR18 |      | FR36 |      | FR32 |      |
| FR07 | FR29 |      | FR33 | FR27 |      |      |      |      |      |
| FR08 |      |      | FR39 | FR34 |      |      |      |      |      |
| FR28 |      |      |      |      |      |      |      |      |      |
| FR38 |      |      |      |      |      |      |      |      |      |

Kpc - Pictured Cliffs Sandstone, main body; Kftc - Fruitland Formation, tongue, coal; Kfts - Fruitland Formation, tongue, sandstone; Kpct - Pictured Cliffs Sandstone, tongue; Kfab - Fruitland Formation, lower coal interval; Kf1 - Fruitland Formation sandstone number 1; Kf2 - Fruitland Formation sandstone number 2; Kf3c - Fruitland Formation, coal below sandstone number 3; Kf3s - Fruitland Formation sandstone number 3; Kfuc - Fruitland Formation, upper interval coal.

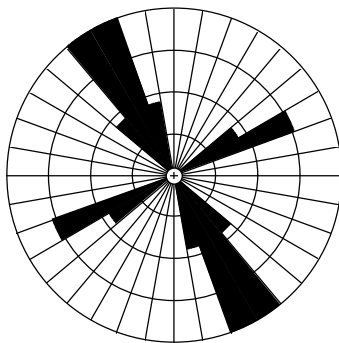
Pictured Cliffs Sandstone, main body:



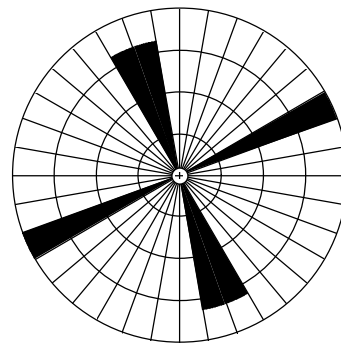
| FR01                        | Statistics                |
|-----------------------------|---------------------------|
| N = 7                       | Vector Mean = 358.6       |
| Class Interval = 10 degrees | Conf. Angle = 38.29       |
| Maximum Percentage = 28.6   | R Magnitude = 0.667       |
| Mean Percentage = 20.00     | Standard Deviation = 7.38 |
|                             | Rayleigh = 0.0443         |



| FR02                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 339.5        |
| Class Interval = 10 degrees | Conf. Angle = 52.12        |
| Maximum Percentage = 37.5   | R Magnitude = 0.501        |
| Mean Percentage = 20.00     | Standard Deviation = 10.54 |
|                             | Rayleigh = 0.1347          |

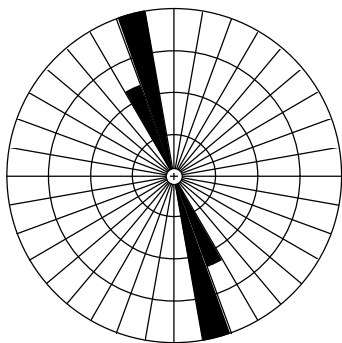


| FR03                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 16                      | Vector Mean = 327.1        |
| Class Interval = 10 degrees | Conf. Angle = 37.92        |
| Maximum Percentage = 31.2   | R Magnitude = 0.486        |
| Mean Percentage = 16.67     | Standard Deviation = 11.72 |
|                             | Rayleigh = 0.0229          |

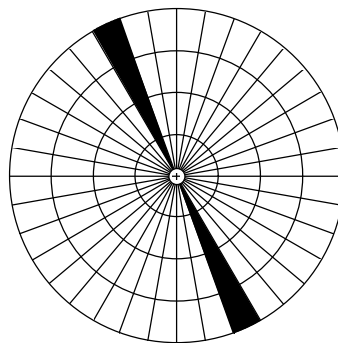


| FR05                        | Statistics                |
|-----------------------------|---------------------------|
| N = 7                       | Vector Mean = 356.0       |
| Class Interval = 10 degrees | Conf. Angle = 176.14      |
| Maximum Percentage = 42.9   | R Magnitude = 0.168       |
| Mean Percentage = 33.33     | Standard Deviation = 7.38 |
|                             | Rayleigh = 0.8201         |

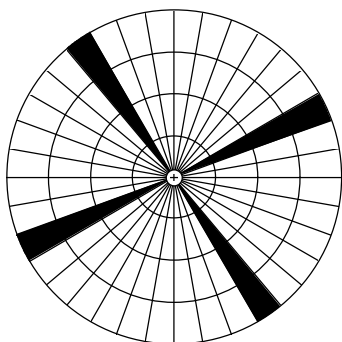




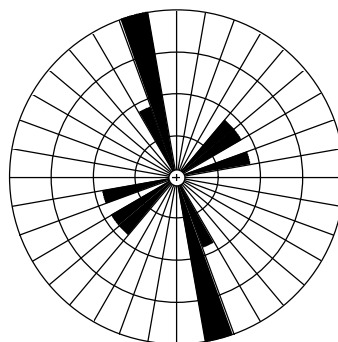
| FR07                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 4                       | Vector Mean = 342.3        |
| Class Interval = 10 degrees | Conf. Angle = 7.97         |
| Maximum Percentage = 75.0   | R Magnitude = 0.989        |
| Mean Percentage = 50.00     | Standard Deviation = 28.87 |
|                             | Rayleigh = 0.0200          |



| FR08                        | Statistics                |
|-----------------------------|---------------------------|
| N = 7                       | Vector Mean = 334.6       |
| Class Interval = 10 degrees | Conf. Angle = 6.00        |
| Maximum Percentage = 100.0  | R Magnitude = 0.995       |
| Mean Percentage = 100.00    | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.0010         |

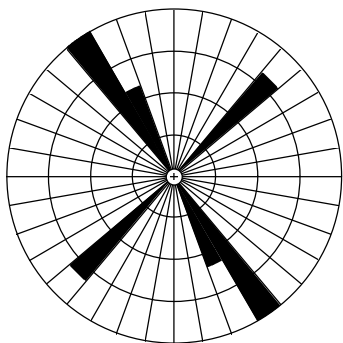


| FR28                        | Statistics                |
|-----------------------------|---------------------------|
| N = 4                       | Vector Mean = 283.1       |
| Class Interval = 10 degrees | Conf. Angle = 250.28      |
| Maximum Percentage = 50.0   | R Magnitude = 0.155       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9081         |

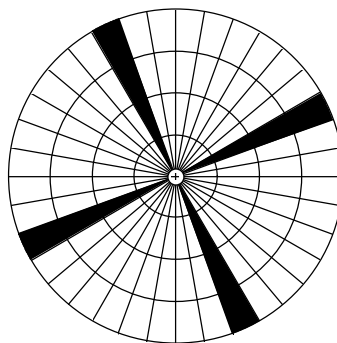


| FR38                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 9                       | Vector Mean = 352.8        |
| Class Interval = 10 degrees | Conf. Angle = 55.56        |
| Maximum Percentage = 55.6   | R Magnitude = 0.449        |
| Mean Percentage = 20.00     | Standard Deviation = 18.74 |
|                             | Rayleigh = 0.1624          |

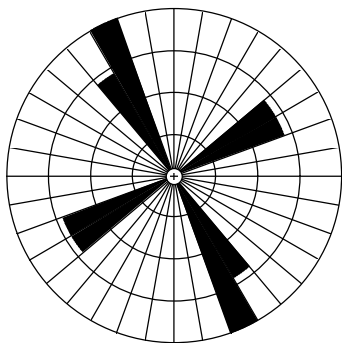
Coal in tongue of Fruitland Formation:



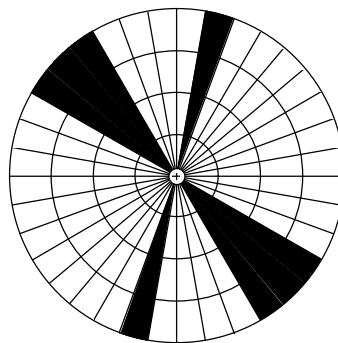
| FR04                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 335.2        |
| Class Interval = 10 degrees | Conf. Angle = 86.59        |
| Maximum Percentage = 50.0   | R Magnitude = 0.363        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.4536          |



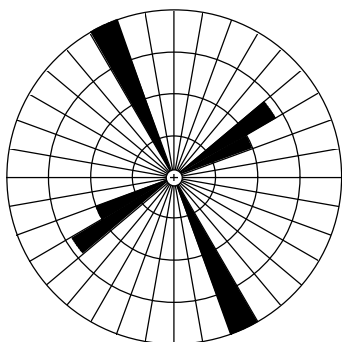
| FR06                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 20.0        |
| Class Interval = 10 degrees | Conf. Angle = 672.25      |
| Maximum Percentage = 50.0   | R Magnitude = 0.044       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9849         |



| FR09                        | Statistics                |
|-----------------------------|---------------------------|
| N = 5                       | Vector Mean = 333.1       |
| Class Interval = 10 degrees | Conf. Angle = 177.59      |
| Maximum Percentage = 40.0   | R Magnitude = 0.196       |
| Mean Percentage = 25.00     | Standard Deviation = 9.26 |
|                             | Rayleigh = 0.8254         |

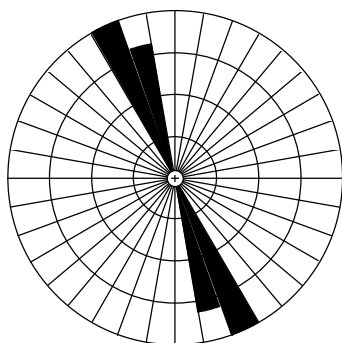


| FR25                        | Statistics                |
|-----------------------------|---------------------------|
| N = 4                       | Vector Mean = 323.0       |
| Class Interval = 10 degrees | Conf. Angle = 55.12       |
| Maximum Percentage = 25.0   | R Magnitude = 0.631       |
| Mean Percentage = 25.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.2037         |



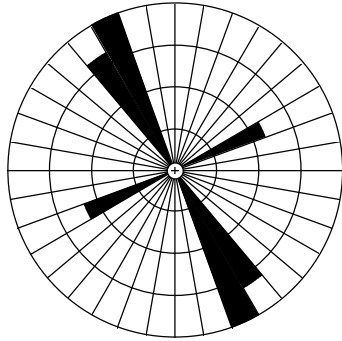
| FR29                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 354.8        |
| Class Interval = 10 degrees | Conf. Angle = 128.27       |
| Maximum Percentage = 57.1   | R Magnitude = 0.232        |
| Mean Percentage = 33.33     | Standard Deviation = 19.52 |
|                             | Rayleigh = 0.6869          |

Sandstone in tongue of Fruitland Formation:

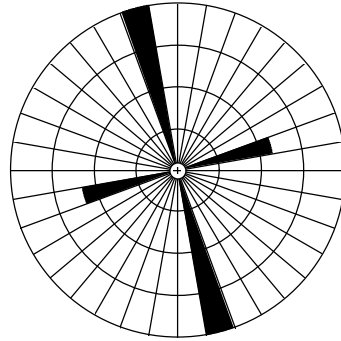


| FR30                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 5                       | Vector Mean = 339.6        |
| Class Interval = 10 degrees | Conf. Angle = 7.13         |
| Maximum Percentage = 60.0   | R Magnitude = 0.987        |
| Mean Percentage = 50.00     | Standard Deviation = 11.55 |
|                             | Rayleigh = 0.0076          |

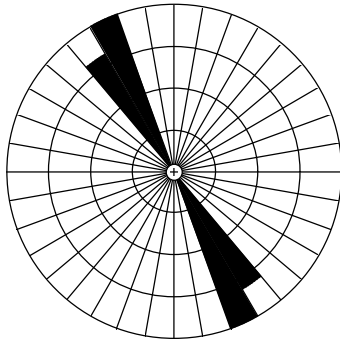
Pictured Cliffs Sandstone, tongue:



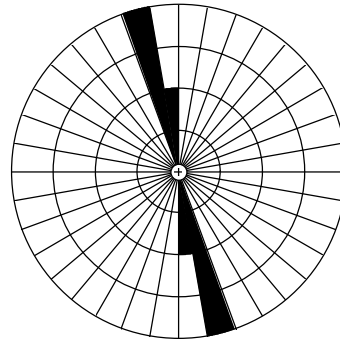
| FR11                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 328.3        |
| Class Interval = 10 degrees | Conf. Angle = 42.21        |
| Maximum Percentage = 50.0   | R Magnitude = 0.659        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.0737          |



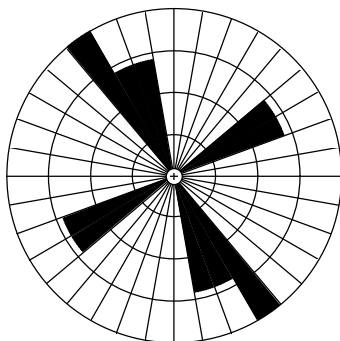
| FR14                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 4                       | Vector Mean = 343.5        |
| Class Interval = 10 degrees | Conf. Angle = 73.80        |
| Maximum Percentage = 75.0   | R Magnitude = 0.499        |
| Mean Percentage = 50.00     | Standard Deviation = 28.87 |
|                             | Rayleigh = 0.3689          |



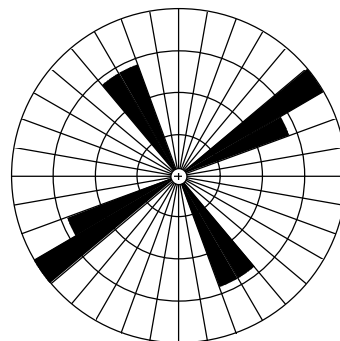
| FR15                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 5                       | Vector Mean = 331.2        |
| Class Interval = 10 degrees | Conf. Angle = 10.12        |
| Maximum Percentage = 60.0   | R Magnitude = 0.975        |
| Mean Percentage = 50.00     | Standard Deviation = 11.55 |
|                             | Rayleigh = 0.0086          |



| FR26                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 5                       | Vector Mean = 348.4        |
| Class Interval = 10 degrees | Conf. Angle = 10.08        |
| Maximum Percentage = 60.0   | R Magnitude = 0.983        |
| Mean Percentage = 50.00     | Standard Deviation = 34.64 |
|                             | Rayleigh = 0.0080          |

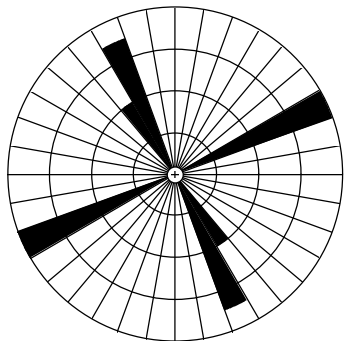


| FR33                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 332.8       |
| Class Interval = 10 degrees | Conf. Angle = 102.02      |
| Maximum Percentage = 33.3   | R Magnitude = 0.310       |
| Mean Percentage = 20.00     | Standard Deviation = 7.03 |
|                             | Rayleigh = 0.5628         |

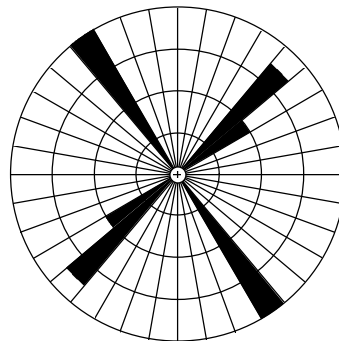


| FR39                        | Statistics                |
|-----------------------------|---------------------------|
| N = 5                       | Vector Mean = 63.9        |
| Class Interval = 10 degrees | Conf. Angle = 177.29      |
| Maximum Percentage = 40.0   | R Magnitude = 0.197       |
| Mean Percentage = 25.00     | Standard Deviation = 9.26 |
|                             | Rayleigh = 0.8244         |

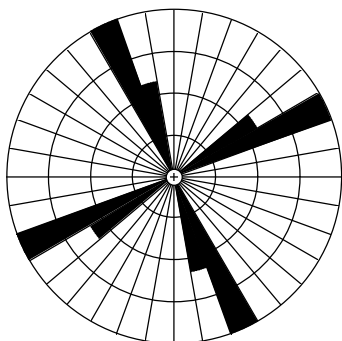
Fruitland Formation, lower coal interval:



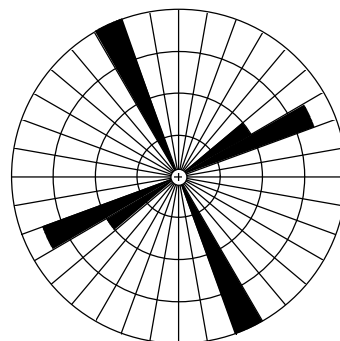
| FR12                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 285.8        |
| Class Interval = 10 degrees | Conf. Angle = 2459.00      |
| Maximum Percentage = 50.0   | R Magnitude = 0.013        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9996          |



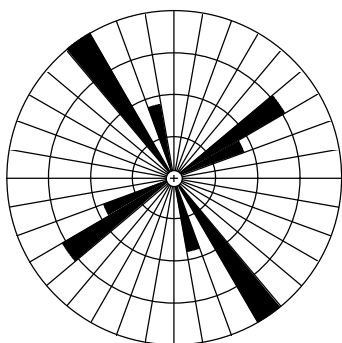
| FR13                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 5.4          |
| Class Interval = 10 degrees | Conf. Angle = 280.71       |
| Maximum Percentage = 50.0   | R Magnitude = 0.100        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9238          |



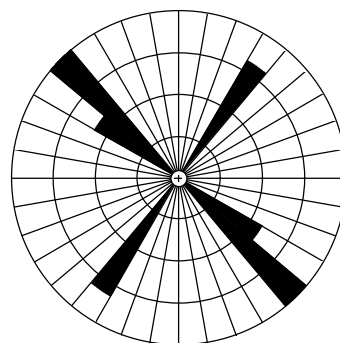
| FR16                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 19.9         |
| Class Interval = 10 degrees | Conf. Angle = 280.16       |
| Maximum Percentage = 37.5   | R Magnitude = 0.100        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.9232          |



| FR18                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 18.0         |
| Class Interval = 10 degrees | Conf. Angle = 672.99       |
| Maximum Percentage = 50.0   | R Magnitude = 0.043        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9850          |

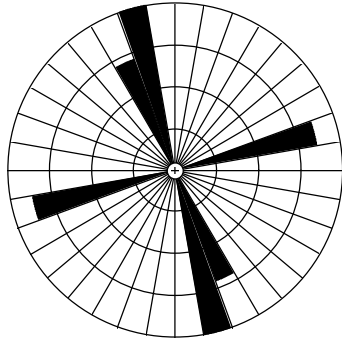


| FR27                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 329.9        |
| Class Interval = 10 degrees | Conf. Angle = 129.48       |
| Maximum Percentage = 50.0   | R Magnitude = 0.194        |
| Mean Percentage = 25.00     | Standard Deviation = 17.73 |
|                             | Rayleigh = 0.6855          |

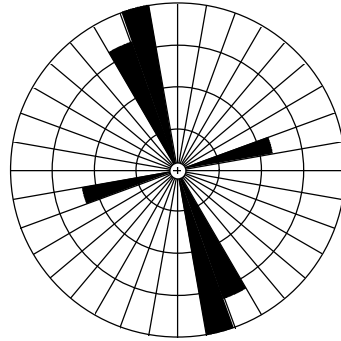


| FR34                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 317.1        |
| Class Interval = 10 degrees | Conf. Angle = 89.42        |
| Maximum Percentage = 50.0   | R Magnitude = 0.352        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.4764          |

## Fruitland Formation, sandstone No. 1:

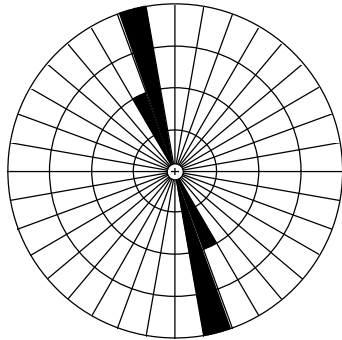


| FR10                        | Statistics                |
|-----------------------------|---------------------------|
| N = 9                       | Vector Mean = 340.7       |
| Class Interval = 10 degrees | Conf. Angle = 77.85       |
| Maximum Percentage = 44.4   | R Magnitude = 0.330       |
| Mean Percentage = 33.33     | Standard Deviation = 9.94 |
|                             | Rayleigh = 0.3743         |

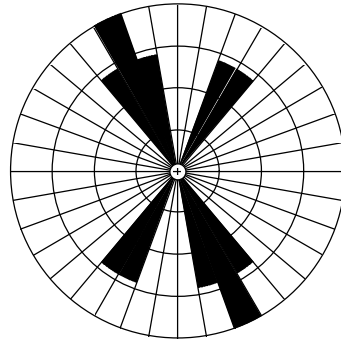


| FR17                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 338.8        |
| Class Interval = 10 degrees | Conf. Angle = 41.31        |
| Maximum Percentage = 50.0   | R Magnitude = 0.669        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.0683          |

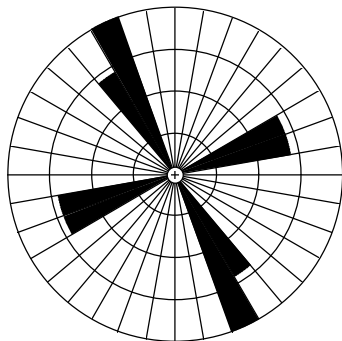
## Fruitland Formation, sandstone No. 2:



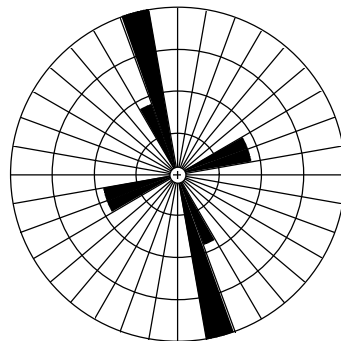
| FR19                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 5                       | Vector Mean = 342.6        |
| Class Interval = 10 degrees | Conf. Angle = 7.11         |
| Maximum Percentage = 80.0   | R Magnitude = 0.993        |
| Mean Percentage = 50.00     | Standard Deviation = 34.64 |
|                             | Rayleigh = 0.0072          |



| FR31                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 350.1       |
| Class Interval = 10 degrees | Conf. Angle = 42.17       |
| Maximum Percentage = 33.3   | R Magnitude = 0.660       |
| Mean Percentage = 20.00     | Standard Deviation = 7.03 |
|                             | Rayleigh = 0.0730         |

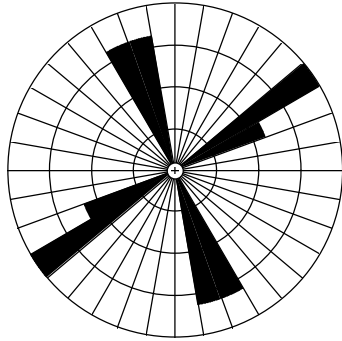


| FR35                        | Statistics                |
|-----------------------------|---------------------------|
| N = 5                       | Vector Mean = 323.0       |
| Class Interval = 10 degrees | Conf. Angle = 159.51      |
| Maximum Percentage = 40.0   | R Magnitude = 0.220       |
| Mean Percentage = 25.00     | Standard Deviation = 9.26 |
|                             | Rayleigh = 0.7855         |

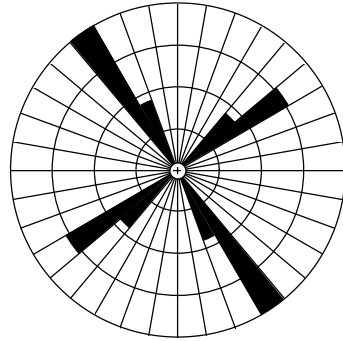


| FR36                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 344.9        |
| Class Interval = 10 degrees | Conf. Angle = 51.14        |
| Maximum Percentage = 62.5   | R Magnitude = 0.506        |
| Mean Percentage = 25.00     | Standard Deviation = 23.15 |
|                             | Rayleigh = 0.1288          |

Fruitland Formation, coal below sandstone No. 3:

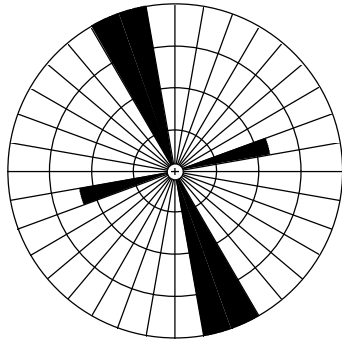


| FR37                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 15.2        |
| Class Interval = 10 degrees | Conf. Angle = 116.20      |
| Maximum Percentage = 37.5   | R Magnitude = 0.236       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.6402         |

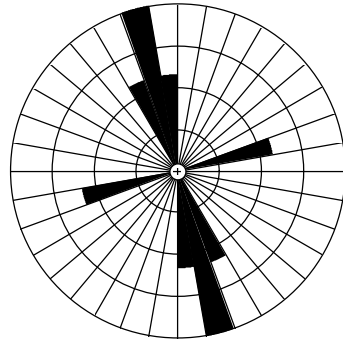


| FR40                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 337.6        |
| Class Interval = 10 degrees | Conf. Angle = 112.62       |
| Maximum Percentage = 50.0   | R Magnitude = 0.220        |
| Mean Percentage = 25.00     | Standard Deviation = 17.73 |
|                             | Rayleigh = 0.6152          |

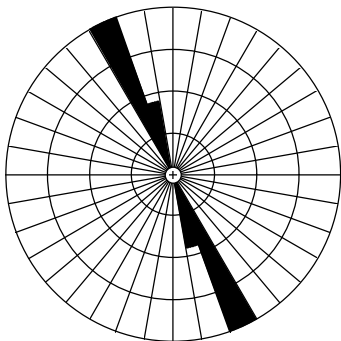
Fruitland Formation, sandstone No. 3:



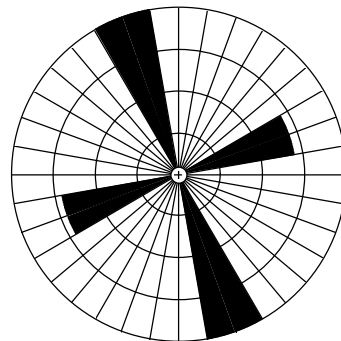
| FR20                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 340.4        |
| Class Interval = 10 degrees | Conf. Angle = 34.92        |
| Maximum Percentage = 42.9   | R Magnitude = 0.711        |
| Mean Percentage = 33.33     | Standard Deviation = 14.75 |
|                             | Rayleigh = 0.0289          |



| FR23                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 343.5        |
| Class Interval = 10 degrees | Conf. Angle = 42.97        |
| Maximum Percentage = 50.0   | R Magnitude = 0.654        |
| Mean Percentage = 25.00     | Standard Deviation = 15.43 |
|                             | Rayleigh = 0.0765          |

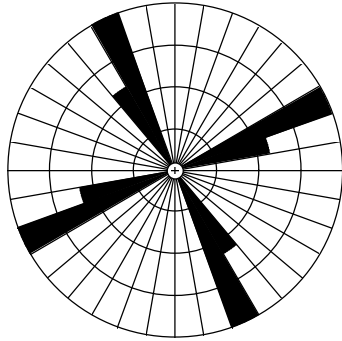


| FR24                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 335.3        |
| Class Interval = 10 degrees | Conf. Angle = 6.51         |
| Maximum Percentage = 83.3   | R Magnitude = 0.988        |
| Mean Percentage = 50.00     | Standard Deviation = 38.49 |
|                             | Rayleigh = 0.0029          |

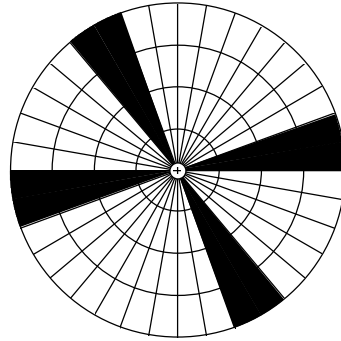


| FR32                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 338.5       |
| Class Interval = 10 degrees | Conf. Angle = 95.29       |
| Maximum Percentage = 33.3   | R Magnitude = 0.331       |
| Mean Percentage = 25.00     | Standard Deviation = 8.91 |
|                             | Rayleigh = 0.5185         |

Fruitland Formation, upper interval coal:



| FR21  | Statistics           |
|---|----------------------|
| N = 8   | Vector Mean = 291.1  |
| Class Interval = 10 degrees                             | Conf. Angle = 465.11 |
| Maximum Percentage = 37.5                               | R Magnitude = 0.061  |
| Mean Percentage = 25.00      Standard Deviation = 13.36 | Rayleigh = 0.9710    |



| FR22   | Statistics          |
|--|---------------------|
| N = 8  | Vector Mean = 294.9 |
| Class Interval = 10 degrees                            | Conf. Angle = 73.10 |
| Maximum Percentage = 25.0                              | R Magnitude = 0.370 |
| Mean Percentage = 25.00      Standard Deviation = 0.00 | Rayleigh = 0.3344   |

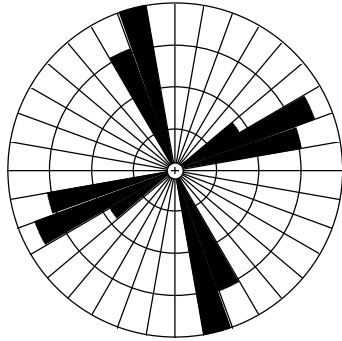
**Table 2-10. Joint and cleat stations established in the South Fork of Texas Creek area, grouped by geologic unit. Stations marked with an asterisk (\*) provided data from more than one geologic unit. No orientations were recorded at stations TA06, TA07, TA09, and TB06. Station locations are shown on plate 6.**

| Kpc   | a coal | Kf1   | b coal | Kf2   | c coal | Kf3   | Kf4  | Kfu  | Kirtland<br>Shale |
|-------|--------|-------|--------|-------|--------|-------|------|------|-------------------|
| TA04* | TA01   | TC03* | TA11   | TA03  | TC06*  | TA08  | TC07 | TB07 | TB03              |
| TA05  | TA02   |       | TC03*  | TD02* | TD04   | TB01  | TD05 | TB08 | TC08              |
| TA10  | TA04*  |       |        | TF03  | TE04   | TC05  | TE05 | TE07 | TD07              |
| TB02  | TB04*  |       |        | TG02  | TE06   | TC06* |      |      |                   |
| TB04* | TB05*  |       |        | TI01  | TF04   | TD06  |      |      |                   |
| TB05* | TC01   |       |        | TJ01  | TJ03   | TI02  |      |      |                   |
| TC02  | TD02*  |       |        |       |        |       |      |      |                   |
| TC03* | TD03   |       |        |       |        |       |      |      |                   |
| TC04  | TE02   |       |        |       |        |       |      |      |                   |
| TD01  | TF02   |       |        |       |        |       |      |      |                   |
| TD02* | TG01   |       |        |       |        |       |      |      |                   |
| TE01  | TJ02   |       |        |       |        |       |      |      |                   |
| TE03  |        |       |        |       |        |       |      |      |                   |
| TF01  |        |       |        |       |        |       |      |      |                   |
| TH01  |        |       |        |       |        |       |      |      |                   |

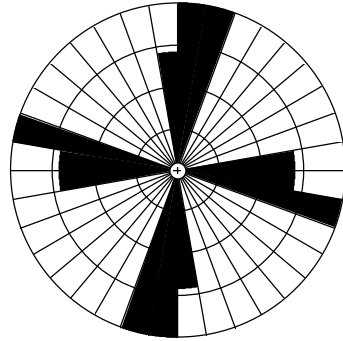
Kpc - Pictured Cliffs Sandstone; Kf1 - Fruitland Formation sandstone number 1; Kf2 - Fruitland Formation sandstone number 2; Kf3 - Fruitland Formation sandstone number 3; Kf4 - Fruitland Formation sandstone number 4; Kfu - Fruitland Formation, upper part; Kk - Kirtland Shale



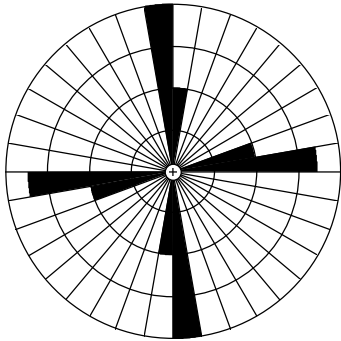
# Pictured Cliffs Sandstone:



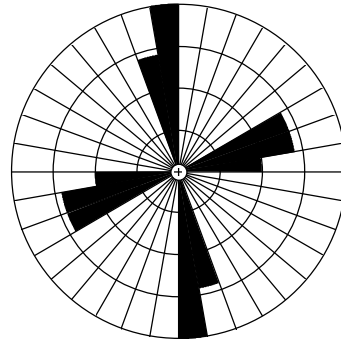
| TA04 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 16                      | Vector Mean = 14.0        |
| Class Interval = 10 degrees | Conf. Angle = 669.37      |
| Maximum Percentage = 31.2   | R Magnitude = 0.029       |
| Mean Percentage = 20.00     | Standard Deviation = 8.74 |
|                             | Rayleigh = 0.9864         |



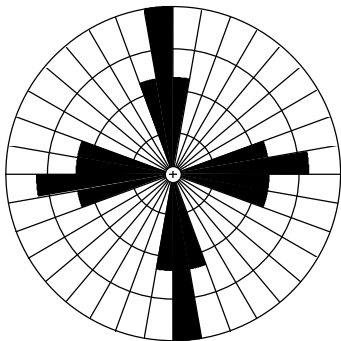
| TA05 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 9                       | Vector Mean = 17.2        |
| Class Interval = 10 degrees | Conf. Angle = 238.44      |
| Maximum Percentage = 22.2   | R Magnitude = 0.111       |
| Mean Percentage = 16.67     | Standard Deviation = 5.80 |
|                             | Rayleigh = 0.8944         |



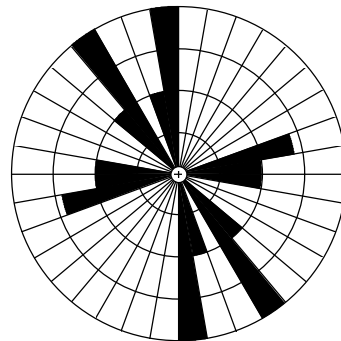
| TA10 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 9                       | Vector Mean = 17.2         |
| Class Interval = 10 degrees | Conf. Angle = 155.33       |
| Maximum Percentage = 44.4   | R Magnitude = 0.168        |
| Mean Percentage = 25.00     | Standard Deviation = 15.43 |
|                             | Rayleigh = 0.7749          |



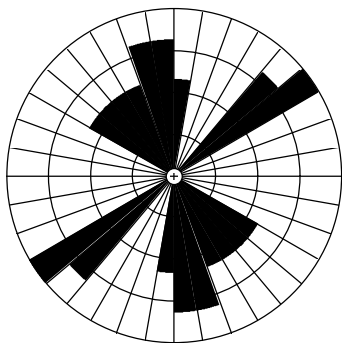
| TB02 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 11                      | Vector Mean = 14.7        |
| Class Interval = 10 degrees | Conf. Angle = 131.59      |
| Maximum Percentage = 36.4   | R Magnitude = 0.181       |
| Mean Percentage = 20.00     | Standard Deviation = 9.39 |
|                             | Rayleigh = 0.6977         |



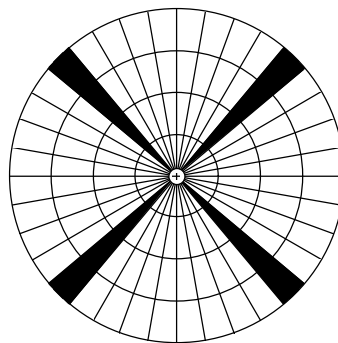
| TB04 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 10                      | Vector Mean = 322.0       |
| Class Interval = 10 degrees | Conf. Angle = 485.95      |
| Maximum Percentage = 30.0   | R Magnitude = 0.053       |
| Mean Percentage = 14.29     | Standard Deviation = 7.56 |
|                             | Rayleigh = 0.9720         |



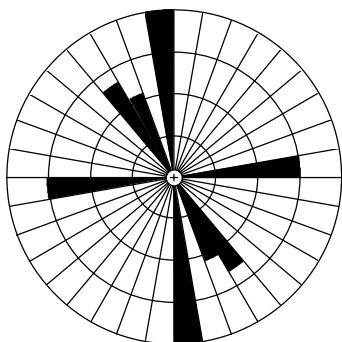
| TB05 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 14                      | Vector Mean = 329.4       |
| Class Interval = 10 degrees | Conf. Angle = 54.95       |
| Maximum Percentage = 28.6   | R Magnitude = 0.374       |
| Mean Percentage = 14.29     | Standard Deviation = 9.71 |
|                             | Rayleigh = 0.1408         |



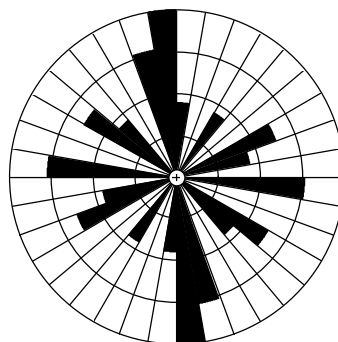
| TC02 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 14                      | Vector Mean = 356.9       |
| Class Interval = 10 degrees | Conf. Angle = 66.47       |
| Maximum Percentage = 21.4   | R Magnitude = 0.312       |
| Mean Percentage = 11.11     | Standard Deviation = 5.03 |
|                             | Rayleigh = 0.2549         |



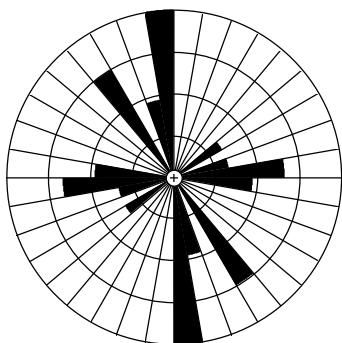
| TC03 JOINTS (Kpc)           | Statistics                |
|-----------------------------|---------------------------|
| N = 2                       | Vector Mean = 357.5       |
| Class Interval = 10 degrees | Conf. Angle = 632.71      |
| Maximum Percentage = 50.0   | R Magnitude = 0.087       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9849         |



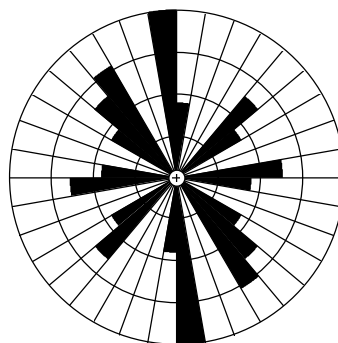
| TC04 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 16                      | Vector Mean = 337.8        |
| Class Interval = 10 degrees | Conf. Angle = 42.63        |
| Maximum Percentage = 43.8   | R Magnitude = 0.442        |
| Mean Percentage = 25.00     | Standard Deviation = 12.50 |
|                             | Rayleigh = 0.0441          |



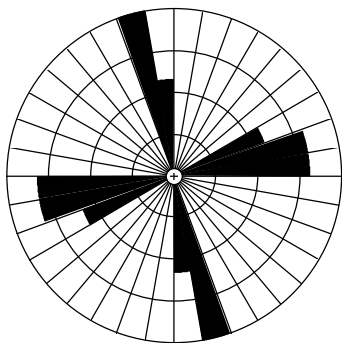
| TD01 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 19                      | Vector Mean = 336.4       |
| Class Interval = 10 degrees | Conf. Angle = 81.26       |
| Maximum Percentage = 26.3   | R Magnitude = 0.223       |
| Mean Percentage = 11.11     | Standard Deviation = 6.97 |
|                             | Rayleigh = 0.3892         |



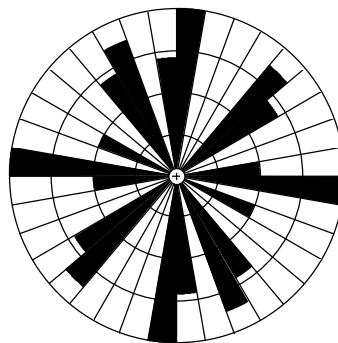
| TD02 JOINTS (Kpc)           | Statistics                 |
|-----------------------------|----------------------------|
| N = 24                      | Vector Mean = 336.2        |
| Class Interval = 10 degrees | Conf. Angle = 52.98        |
| Maximum Percentage = 37.5   | R Magnitude = 0.298        |
| Mean Percentage = 14.29     | Standard Deviation = 11.52 |
|                             | Rayleigh = 0.1195          |



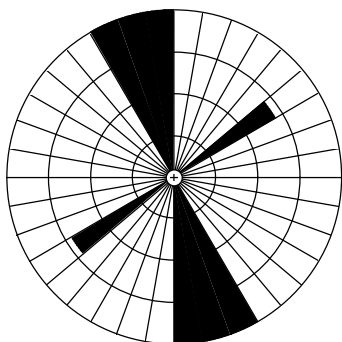
| TE01 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 16                      | Vector Mean = 336.6       |
| Class Interval = 10 degrees | Conf. Angle = 65.94       |
| Maximum Percentage = 27.8   | R Magnitude = 0.276       |
| Mean Percentage = 11.11     | Standard Deviation = 7.13 |
|                             | Rayleigh = 0.2534         |



| TE03 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 9                       | Vector Mean = 78.2        |
| Class Interval = 10 degrees | Conf. Angle = 264.21      |
| Maximum Percentage = 33.3   | R Magnitude = 0.100       |
| Mean Percentage = 20.00     | Standard Deviation = 8.76 |
|                             | Rayleigh = 0.9142         |

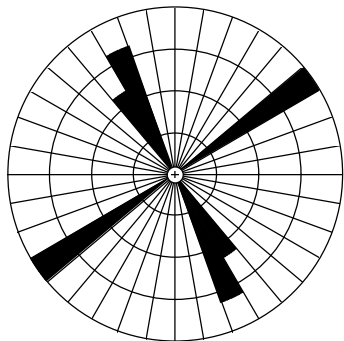


| TF01 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 22                      | Vector Mean = 356.8       |
| Class Interval = 10 degrees | Conf. Angle = 140.77      |
| Maximum Percentage = 18.2   | R Magnitude = 0.120       |
| Mean Percentage = 11.11     | Standard Deviation = 4.98 |
|                             | Rayleigh = 0.7298         |

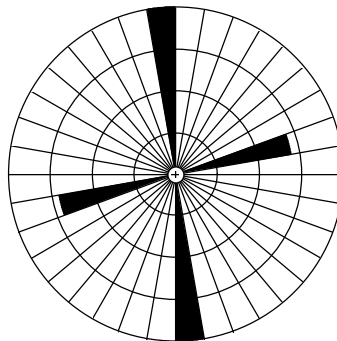


| TH01 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 7                       | Vector Mean = 350.3       |
| Class Interval = 10 degrees | Conf. Angle = 34.84       |
| Maximum Percentage = 28.6   | R Magnitude = 0.715       |
| Mean Percentage = 25.00     | Standard Deviation = 6.61 |
|                             | Rayleigh = 0.0280         |

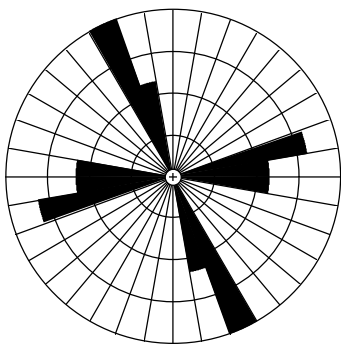
Fruitland Formation, a coal:



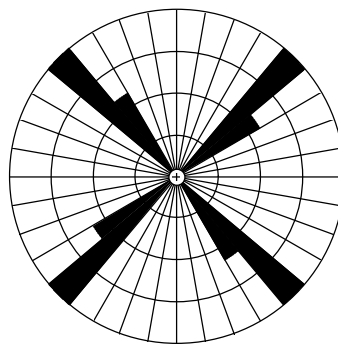
| TA01 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 11.5         |
| Class Interval = 10 degrees | Conf. Angle = 463.87       |
| Maximum Percentage = 50.0   | R Magnitude = 0.070        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.9714          |



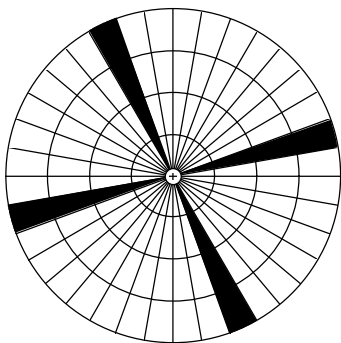
| TA02 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 3                       | Vector Mean = 356.9        |
| Class Interval = 10 degrees | Conf. Angle = 130.16       |
| Maximum Percentage = 66.7   | R Magnitude = 0.343        |
| Mean Percentage = 50.00     | Standard Deviation = 19.25 |
|                             | Rayleigh = 0.7027          |



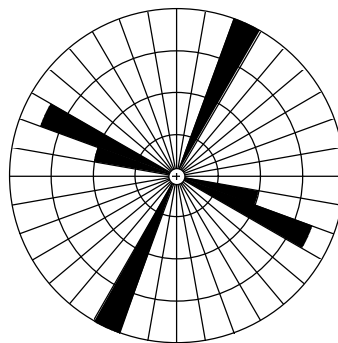
| TB04 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 299.9        |
| Class Interval = 10 degrees | Conf. Angle = 101.37       |
| Maximum Percentage = 37.5   | R Magnitude = 0.273        |
| Mean Percentage = 20.00     | Standard Deviation = 10.54 |
|                             | Rayleigh = 0.5497          |



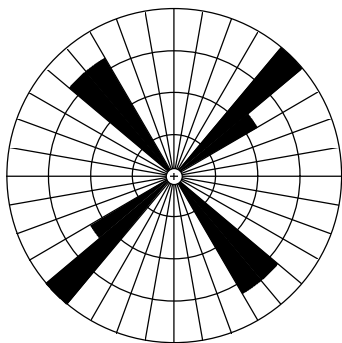
| TB04 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 357.6        |
| Class Interval = 10 degrees | Conf. Angle = 1332.74      |
| Maximum Percentage = 37.5   | R Magnitude = 0.022        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.9961          |



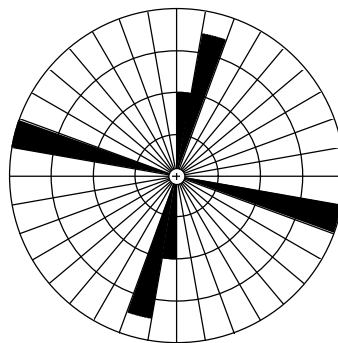
| TB05 CLEATS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 2                       | Vector Mean = 291.0       |
| Class Interval = 10 degrees | Conf. Angle = 400.27      |
| Maximum Percentage = 50.0   | R Magnitude = 0.139       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9620         |



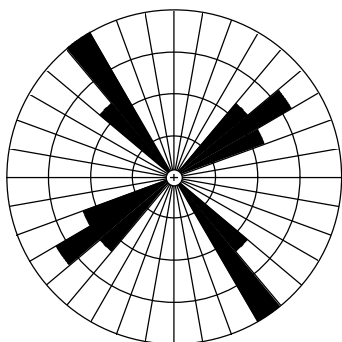
| TC01 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 66.5         |
| Class Interval = 10 degrees | Conf. Angle = 1505.50      |
| Maximum Percentage = 50.0   | R Magnitude = 0.017        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9976          |



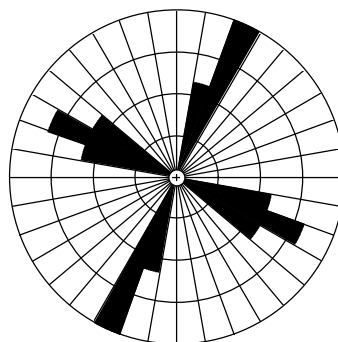
| TD02 CLEATS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 5.0         |
| Class Interval = 10 degrees | Conf. Angle = 1503.11     |
| Maximum Percentage = 37.5   | R Magnitude = 0.017       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.9976         |



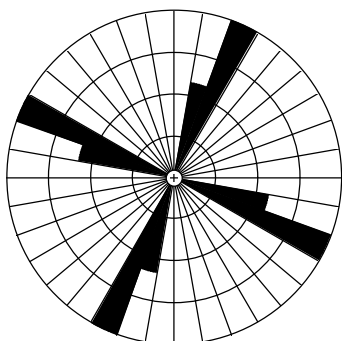
| TD03 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 325.0        |
| Class Interval = 10 degrees | Conf. Angle = 3016.64      |
| Maximum Percentage = 50.0   | R Magnitude = 0.009        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9994          |



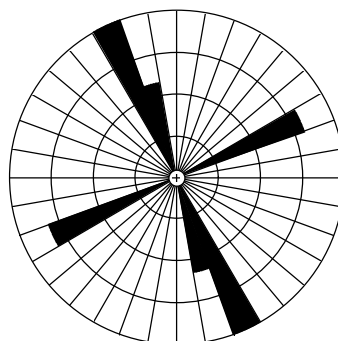
| TE02 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 283.7        |
| Class Interval = 10 degrees | Conf. Angle = 747.60       |
| Maximum Percentage = 37.5   | R Magnitude = 0.035        |
| Mean Percentage = 20.00     | Standard Deviation = 10.54 |
|                             | Rayleigh = 0.9901          |



| TF02 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 2.9          |
| Class Interval = 10 degrees | Conf. Angle = 3494.49      |
| Maximum Percentage = 37.5   | R Magnitude = 0.006        |
| Mean Percentage = 20.00     | Standard Deviation = 10.54 |
|                             | Rayleigh = 0.9997          |

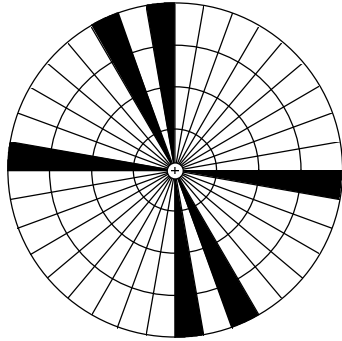


| TG01 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 335.8        |
| Class Interval = 10 degrees | Conf. Angle = 1004.29      |
| Maximum Percentage = 37.5   | R Magnitude = 0.026        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.9946          |



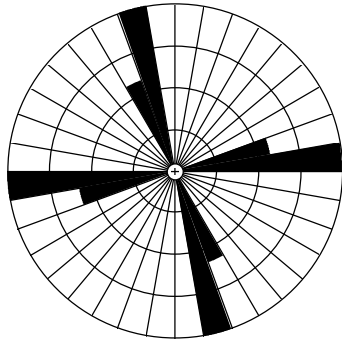
| TJ02                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 338.0        |
| Class Interval = 10 degrees | Conf. Angle = 95.00        |
| Maximum Percentage = 50.0   | R Magnitude = 0.333        |
| Mean Percentage = 33.33     | Standard Deviation = 14.91 |
|                             | Rayleigh = 0.5143          |

Fruitland Formation, sandstone No. 1:

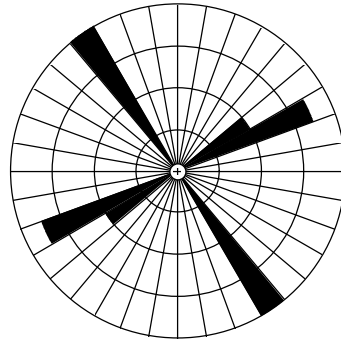


| TC03 JOINTS (Kf)                                       | Statistics          |
|--|---------------------|
| N = 3  | Vector Mean = 326.5 |
| Class Interval = 10 degrees                            | Conf. Angle = 98.93 |
| Maximum Percentage = 33.3                              | R Magnitude = 0.437 |
| Mean Percentage = 33.33      Standard Deviation = 0.01 | Rayleigh = 0.5633   |

Fruitland Formation, b coal:

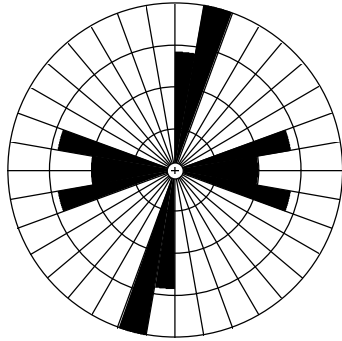


| TA11 CLEATS   | Statistics           |
|---|----------------------|
| N = 8   | Vector Mean = 300.9  |
| Class Interval = 10 degrees                             | Conf. Angle = 345.72 |
| Maximum Percentage = 37.5                               | R Magnitude = 0.082  |
| Mean Percentage = 25.00      Standard Deviation = 13.36 | Rayleigh = 0.9474    |

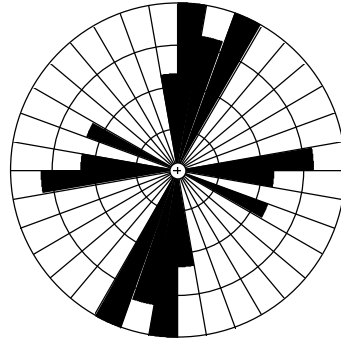


| TC03 CLEATS   | Statistics           |
|---|----------------------|
| N = 8   | Vector Mean = 282.5  |
| Class Interval = 10 degrees                             | Conf. Angle = 308.89 |
| Maximum Percentage = 50.0                               | R Magnitude = 0.091  |
| Mean Percentage = 33.33      Standard Deviation = 17.08 | Rayleigh = 0.9353    |

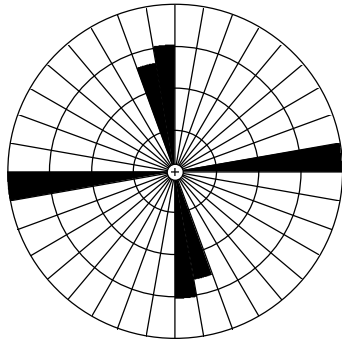
Fruitland Formation, sandstone No. 2:



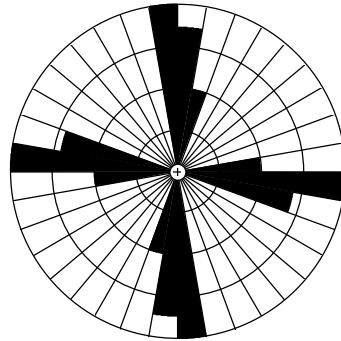
| TA03 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 12                      | Vector Mean = 41.5        |
| Class Interval = 10 degrees | Conf. Angle = 120.82      |
| Maximum Percentage = 33.3   | R Magnitude = 0.186       |
| Mean Percentage = 16.67     | Standard Deviation = 8.70 |
|                             | Rayleigh = 0.6602         |



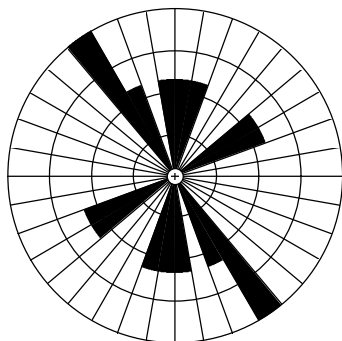
| TD02 JOINTS (Kf)            | Statistics                |
|-----------------------------|---------------------------|
| N = 13                      | Vector Mean = 16.3        |
| Class Interval = 10 degrees | Conf. Angle = 55.57       |
| Maximum Percentage = 23.1   | R Magnitude = 0.382       |
| Mean Percentage = 14.29     | Standard Deviation = 6.65 |
|                             | Rayleigh = 0.1502         |



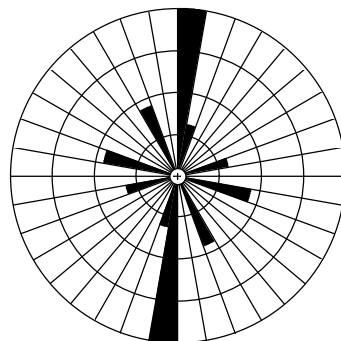
| TF03 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 14                      | Vector Mean = 304.2        |
| Class Interval = 10 degrees | Conf. Angle = 426.05       |
| Maximum Percentage = 33.3   | R Magnitude = 0.050        |
| Mean Percentage = 33.33     | Standard Deviation = 13.30 |
|                             | Rayleigh = 0.9662          |



| TG02 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 15                      | Vector Mean = 346.5       |
| Class Interval = 10 degrees | Conf. Angle = 288.49      |
| Maximum Percentage = 26.7   | R Magnitude = 0.072       |
| Mean Percentage = 16.67     | Standard Deviation = 8.76 |
|                             | Rayleigh = 0.9252         |

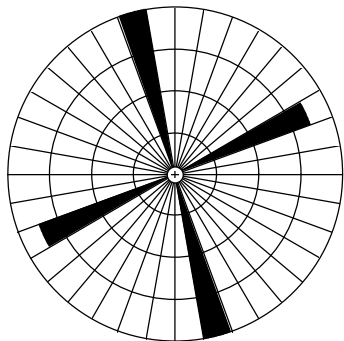


| TJ01                        | Statistics                |
|-----------------------------|---------------------------|
| N = 9                       | Vector Mean = 349.3       |
| Class Interval = 10 degrees | Conf. Angle = 58.14       |
| Maximum Percentage = 33.3   | R Magnitude = 0.434       |
| Mean Percentage = 14.29     | Standard Deviation = 8.07 |
|                             | Rayleigh = 0.1830         |

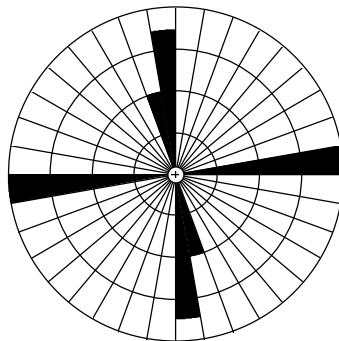


| TJ01 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 16                      | Vector Mean = 2.4          |
| Class Interval = 10 degrees | Conf. Angle = 30.11        |
| Maximum Percentage = 62.5   | R Magnitude = 0.589        |
| Mean Percentage = 20.00     | Standard Deviation = 22.59 |
|                             | Rayleigh = 0.0039          |

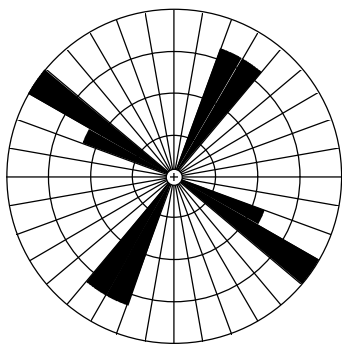
Fruitland Formation, c coal:



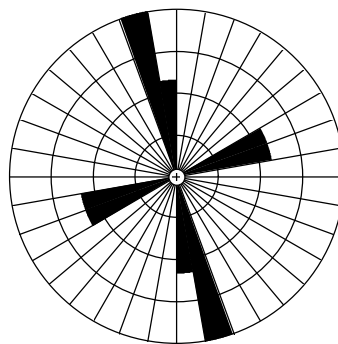
| TC06 CLEATS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 7                       | Vector Mean = 9.4         |
| Class Interval = 10 degrees | Conf. Angle = 128.72      |
| Maximum Percentage = 57.1   | R Magnitude = 0.230       |
| Mean Percentage = 50.00     | Standard Deviation = 8.25 |
|                             | Rayleigh = 0.6905         |



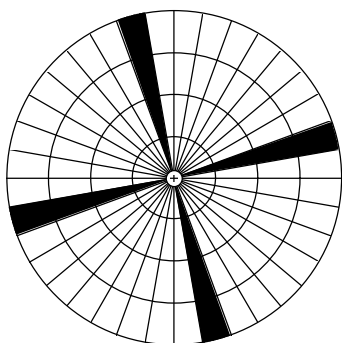
| TD04 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 307.6        |
| Class Interval = 10 degrees | Conf. Angle = 463.90       |
| Maximum Percentage = 50.0   | R Magnitude = 0.061        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9707          |



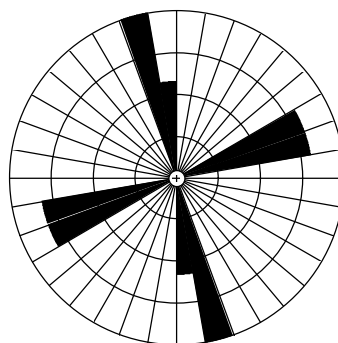
| TE04 CLEATS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 60.6        |
| Class Interval = 10 degrees | Conf. Angle = INF         |
| Maximum Percentage = 37.5   | R Magnitude = 0.005       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.9998         |



| TE06 CLEATS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 354.6        |
| Class Interval = 10 degrees | Conf. Angle = 89.96        |
| Maximum Percentage = 50.0   | R Magnitude = 0.347        |
| Mean Percentage = 25.00     | Standard Deviation = 15.43 |
|                             | Rayleigh = 0.4850          |



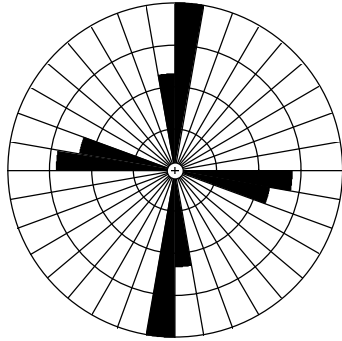
| TF04 CLEATS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 300.1       |
| Class Interval = 10 degrees | Conf. Angle = 414.73      |
| Maximum Percentage = 50.0   | R Magnitude = 0.065       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.9665         |



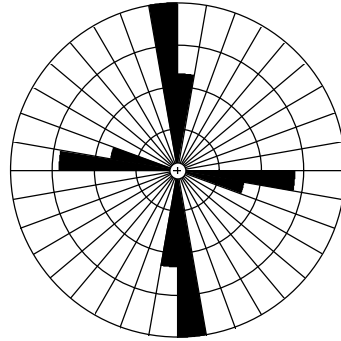
| TJ03                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 28.2        |
| Class Interval = 10 degrees | Conf. Angle = 156.08      |
| Maximum Percentage = 37.5   | R Magnitude = 0.177       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.7787         |



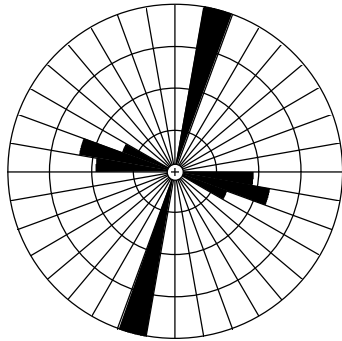
Fruitland Formation, sandstone No. 3:



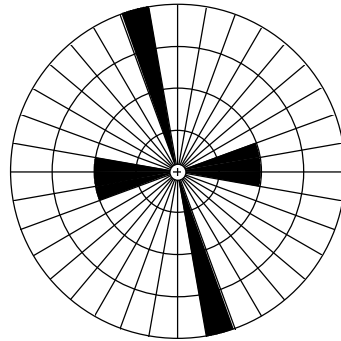
| TA06 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 13                      | Vector Mean = 354.6        |
| Class Interval = 10 degrees | Conf. Angle = 90.59        |
| Maximum Percentage = 46.2   | R Magnitude = 0.239        |
| Mean Percentage = 25.00     | Standard Deviation = 13.48 |
|                             | Rayleigh = 0.4758          |



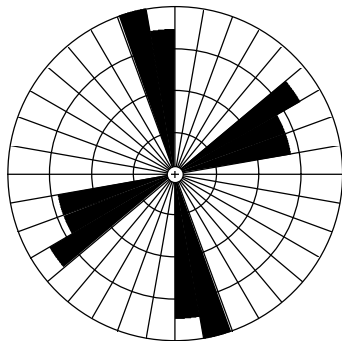
| TB01 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 12                      | Vector Mean = 347.0        |
| Class Interval = 10 degrees | Conf. Angle = 59.88        |
| Maximum Percentage = 50.0   | R Magnitude = 0.368        |
| Mean Percentage = 25.00     | Standard Deviation = 16.67 |
|                             | Rayleigh = 0.1975          |



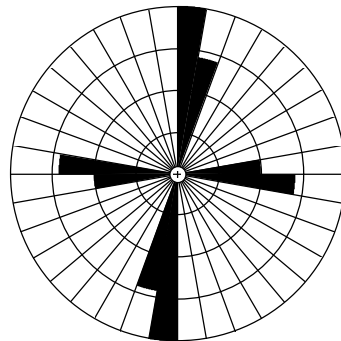
| TC05 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 15                      | Vector Mean = 16.0         |
| Class Interval = 10 degrees | Conf. Angle = 96.72        |
| Maximum Percentage = 60.0   | R Magnitude = 0.209        |
| Mean Percentage = 25.00     | Standard Deviation = 22.18 |
|                             | Rayleigh = 0.5188          |



| TC06 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 325.5        |
| Class Interval = 10 degrees | Conf. Angle = 127.94       |
| Maximum Percentage = 57.1   | R Magnitude = 0.233        |
| Mean Percentage = 25.00     | Standard Deviation = 19.84 |
|                             | Rayleigh = 0.6842          |

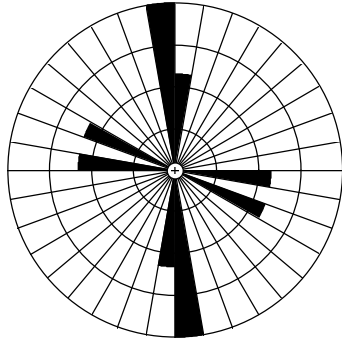


| TD06 JOINTS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 14                      | Vector Mean = 24.4        |
| Class Interval = 10 degrees | Conf. Angle = 86.33       |
| Maximum Percentage = 28.6   | R Magnitude = 0.244       |
| Mean Percentage = 20.00     | Standard Deviation = 5.63 |
|                             | Rayleigh = 0.4334         |

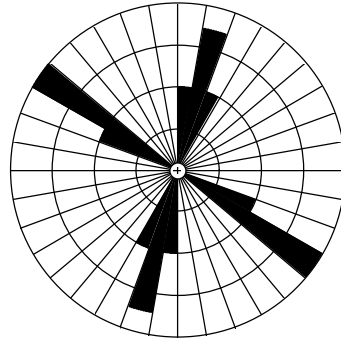


| T102                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 9                       | Vector Mean = 14.5         |
| Class Interval = 10 degrees | Conf. Angle = 75.98        |
| Maximum Percentage = 44.4   | R Magnitude = 0.335        |
| Mean Percentage = 25.00     | Standard Deviation = 12.94 |
|                             | Rayleigh = 0.3632          |

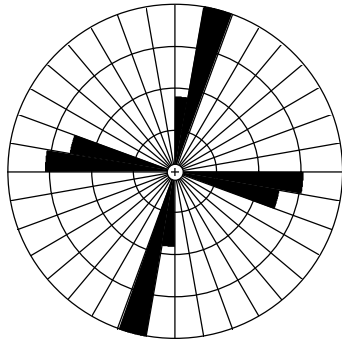
Fruitland Formation, sandstone No. 4:



| TC07 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 345.4        |
| Class Interval = 10 degrees | Conf. Angle = 69.89        |
| Maximum Percentage = 50.0   | R Magnitude = 0.438        |
| Mean Percentage = 25.00     | Standard Deviation = 15.43 |
|                             | Rayleigh = 0.3160          |

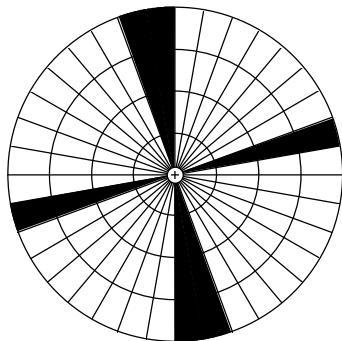


| TD05 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 336.2        |
| Class Interval = 10 degrees | Conf. Angle = 75.93        |
| Maximum Percentage = 40.0   | R Magnitude = 0.324        |
| Mean Percentage = 20.00     | Standard Deviation = 13.33 |
|                             | Rayleigh = 0.3509          |

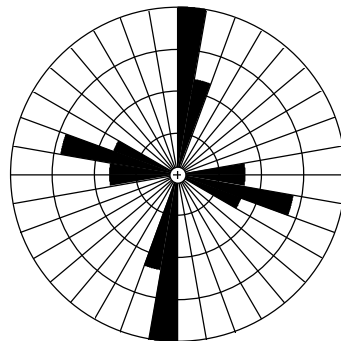


| TE05 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 11                      | Vector Mean = 19.1         |
| Class Interval = 10 degrees | Conf. Angle = 237.65       |
| Maximum Percentage = 45.5   | R Magnitude = 0.101        |
| Mean Percentage = 25.00     | Standard Deviation = 14.37 |
|                             | Rayleigh = 0.8939          |

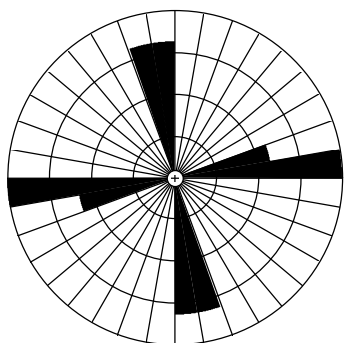
Fruitland Formation, upper part:



| TB07 CLEATS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 3                       | Vector Mean = 355.0       |
| Class Interval = 10 degrees | Conf. Angle = 134.92      |
| Maximum Percentage = 33.3   | R Magnitude = 0.330       |
| Mean Percentage = 33.33     | Standard Deviation = 0.01 |
|                             | Rayleigh = 0.7211         |

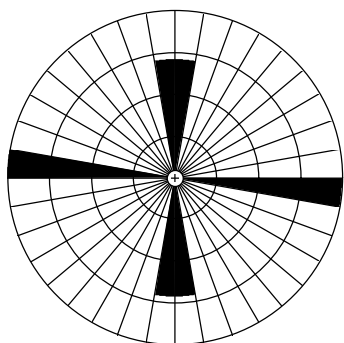


| TB08 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 14                      | Vector Mean = 0.5          |
| Class Interval = 10 degrees | Conf. Angle = 125.50       |
| Maximum Percentage = 42.9   | R Magnitude = 0.166        |
| Mean Percentage = 16.67     | Standard Deviation = 13.39 |
|                             | Rayleigh = 0.6807          |

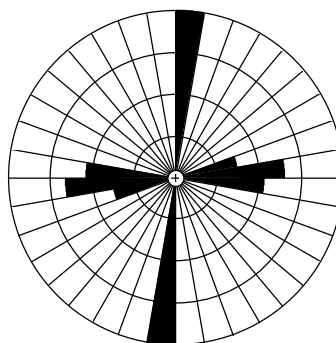


| TE07 CLEATS                 | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 306.1       |
| Class Interval = 10 degrees | Conf. Angle = 573.63      |
| Maximum Percentage = 37.5   | R Magnitude = 0.048       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.9819         |

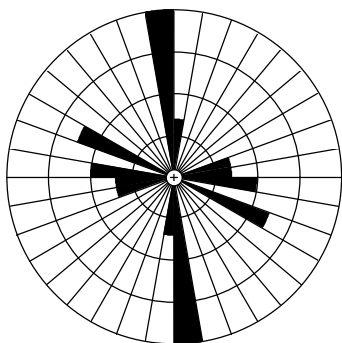
### Kirtland Formation sandstones:



| TB03 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 12                      | Vector Mean = 314.3        |
| Class Interval = 10 degrees | Conf. Angle = 316.28       |
| Maximum Percentage = 50.0   | R Magnitude = 0.075        |
| Mean Percentage = 33.33     | Standard Deviation = 12.91 |
|                             | Rayleigh = 0.9350          |



| TC08 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 13                      | Vector Mean = 27.3         |
| Class Interval = 10 degrees | Conf. Angle = 127.78       |
| Maximum Percentage = 53.8   | R Magnitude = 0.172        |
| Mean Percentage = 25.00     | Standard Deviation = 18.73 |
|                             | Rayleigh = 0.6801          |



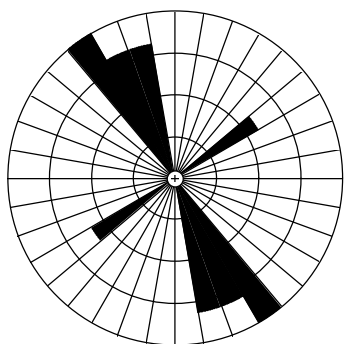
| TD07 JOINTS                 | Statistics                 |
|-----------------------------|----------------------------|
| N = 16                      | Vector Mean = 339.8        |
| Class Interval = 10 degrees | Conf. Angle = 80.85        |
| Maximum Percentage = 50.0   | R Magnitude = 0.244        |
| Mean Percentage = 16.67     | Standard Deviation = 16.28 |
|                             | Rayleigh = 0.3862          |

**Table 2-11. Joint and cleat stations established in the Pine River area, grouped by geologic unit. Station locations are shown on plate 6.**

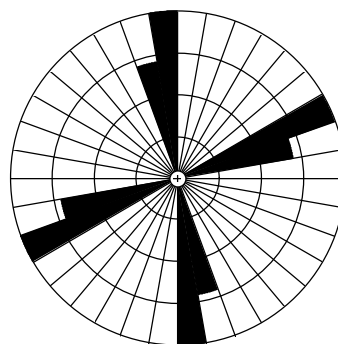
| Kpc  | Kfab | Kf1  | Kf2  | Kfcd | Kf3  | Kf4  |
|------|------|------|------|------|------|------|
| PR01 | PR03 | PR07 | PR02 | PR13 | PR15 | PR18 |
| PR04 | PR06 | PR11 | PR12 | PR16 | PR17 |      |
| PR05 | PR08 | PR23 | PR19 | PR31 | PR32 |      |
| PR09 | PR14 |      | PR21 | PR34 | PR33 |      |
| PR10 | PR20 |      | PR26 | PR37 | PR35 |      |
| PR22 | PR25 |      | PR30 |      | PR36 |      |
| PR24 | PR28 |      |      |      |      |      |
| PR27 | PR29 |      |      |      |      |      |
| PR38 |      |      |      |      |      |      |

Kpc - Pictured Cliffs Sandstone; Kfab - Fruitland Formation, lower coal interval; Kf1 - Fruitland Formation sandstone number 1; Kf2 - Fruitland Formation sandstone number 2; Kfcd - Fruitland Formation, middle coal interval; Kf3 - Fruitland Formation sandstone number 3; Kf4 - Fruitland Formation sandstone number 4

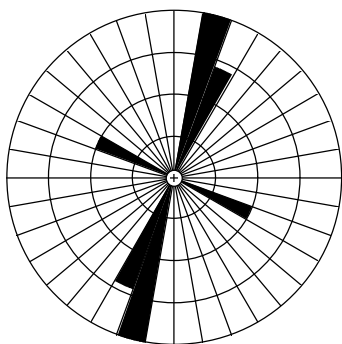
#### Pictured Cliffs Sandstone:



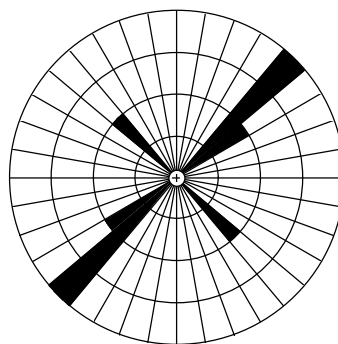
| PR01                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 334.6       |
| Class Interval = 10 degrees | Conf. Angle = 30.47       |
| Maximum Percentage = 37.5   | R Magnitude = 0.742       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.0123         |



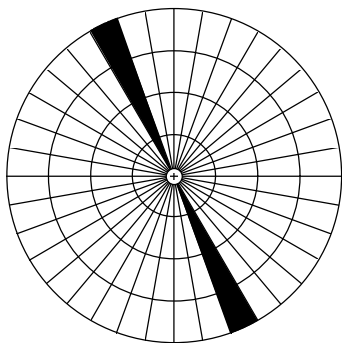
| PR04                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 26.9        |
| Class Interval = 10 degrees | Conf. Angle = 106.25      |
| Maximum Percentage = 33.3   | R Magnitude = 0.296       |
| Mean Percentage = 25.00     | Standard Deviation = 8.91 |
|                             | Rayleigh = 0.5914         |



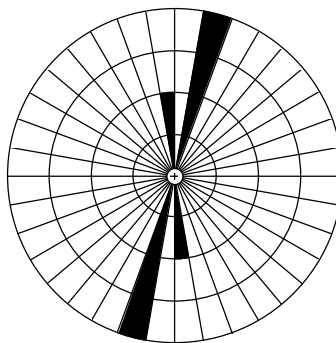
| PR05                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 18.0         |
| Class Interval = 10 degrees | Conf. Angle = 34.93        |
| Maximum Percentage = 57.1   | R Magnitude = 0.711        |
| Mean Percentage = 33.33     | Standard Deviation = 19.52 |
|                             | Rayleigh = 0.0290          |



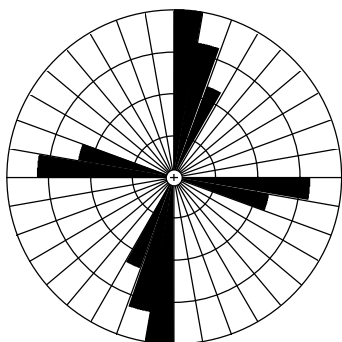
| PR09                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 6                       | Vector Mean = 47.7         |
| Class Interval = 10 degrees | Conf. Angle = 42.09        |
| Maximum Percentage = 66.7   | R Magnitude = 0.663        |
| Mean Percentage = 33.33     | Standard Deviation = 25.82 |
|                             | Rayleigh = 0.0716          |



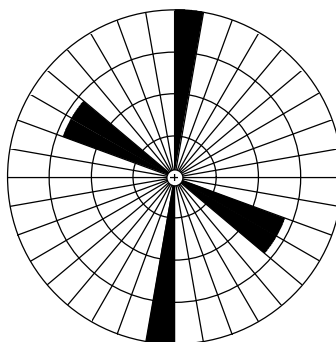
| PR10                        | Statistics                |
|-----------------------------|---------------------------|
| N = 7                       | Vector Mean = 334.0       |
| Class Interval = 10 degrees | Conf. Angle = 6.00        |
| Maximum Percentage = 100.0  | R Magnitude = 0.996       |
| Mean Percentage = 100.00    | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.0010         |



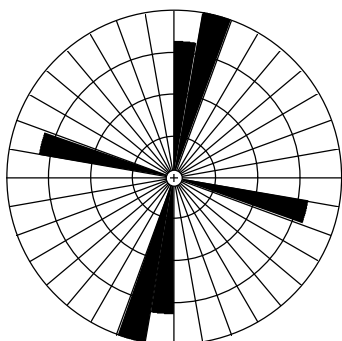
| PR22                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 5                       | Vector Mean = 10.4         |
| Class Interval = 10 degrees | Conf. Angle = 16.05        |
| Maximum Percentage = 80.0   | R Magnitude = 0.954        |
| Mean Percentage = 50.00     | Standard Deviation = 34.64 |
|                             | Rayleigh = 0.0106          |



| PR24                        | Statistics                |
|-----------------------------|---------------------------|
| N = 9                       | Vector Mean = 15.2        |
| Class Interval = 10 degrees | Conf. Angle = 77.65       |
| Maximum Percentage = 33.3   | R Magnitude = 0.332       |
| Mean Percentage = 20.00     | Standard Deviation = 8.76 |
|                             | Rayleigh = 0.3705         |

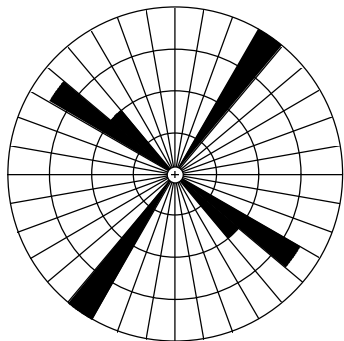


| PR27                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 4                       | Vector Mean = 333.8        |
| Class Interval = 10 degrees | Conf. Angle = 77.15        |
| Maximum Percentage = 50.0   | R Magnitude = 0.482        |
| Mean Percentage = 33.33     | Standard Deviation = 12.91 |
|                             | Rayleigh = 0.3941          |

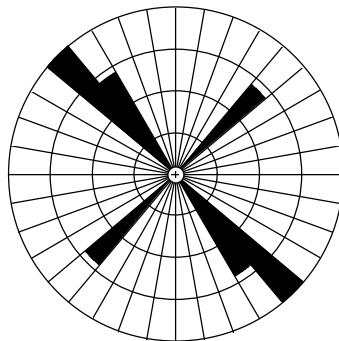


| PR38                        | Statistics                |
|-----------------------------|---------------------------|
| N = 7                       | Vector Mean = 8.0         |
| Class Interval = 10 degrees | Conf. Angle = 68.32       |
| Maximum Percentage = 42.9   | R Magnitude = 0.416       |
| Mean Percentage = 33.33     | Standard Deviation = 7.38 |
|                             | Rayleigh = 0.2972         |

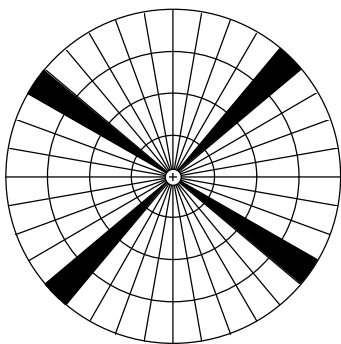
Fruitland Formation, lower coal interval:



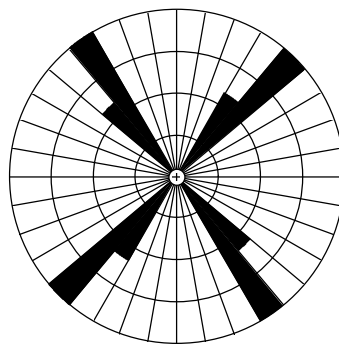
| PR03                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 350.5        |
| Class Interval = 10 degrees | Conf. Angle = 235.64       |
| Maximum Percentage = 50.0   | R Magnitude = 0.117        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.8955          |



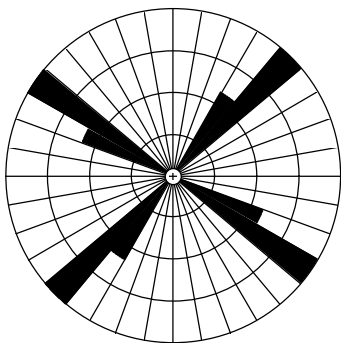
| PR06                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 4                       | Vector Mean = 319.5        |
| Class Interval = 10 degrees | Conf. Angle = 75.73        |
| Maximum Percentage = 50.0   | R Magnitude = 0.487        |
| Mean Percentage = 33.33     | Standard Deviation = 12.91 |
|                             | Rayleigh = 0.3870          |



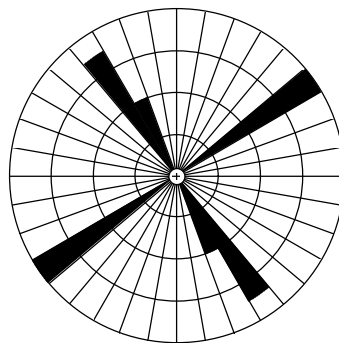
| PR08                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 84.6        |
| Class Interval = 10 degrees | Conf. Angle = 214.90      |
| Maximum Percentage = 50.0   | R Magnitude = 0.130       |
| Mean Percentage = 50.00     | Standard Deviation = 0.00 |
|                             | Rayleigh = 0.8732         |



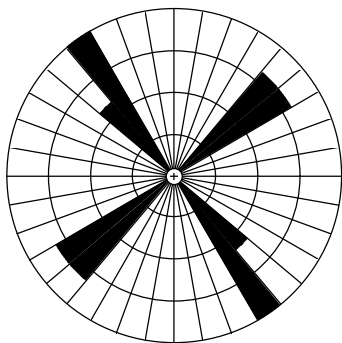
| PR14                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 359.2        |
| Class Interval = 10 degrees | Conf. Angle = 303.27       |
| Maximum Percentage = 37.5   | R Magnitude = 0.095        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.9306          |



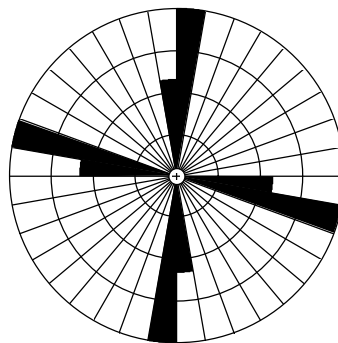
| PR20                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 81.4         |
| Class Interval = 10 degrees | Conf. Angle = 233.35       |
| Maximum Percentage = 37.5   | R Magnitude = 0.120        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.8916          |



| PR25                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 11.4         |
| Class Interval = 10 degrees | Conf. Angle = 573.23       |
| Maximum Percentage = 50.0   | R Magnitude = 0.048        |
| Mean Percentage = 33.33     | Standard Deviation = 17.08 |
|                             | Rayleigh = 0.9818          |

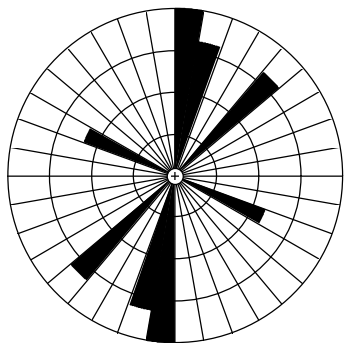


| PR28                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 6.3         |
| Class Interval = 10 degrees | Conf. Angle = 345.71      |
| Maximum Percentage = 37.5   | R Magnitude = 0.082       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.9474         |

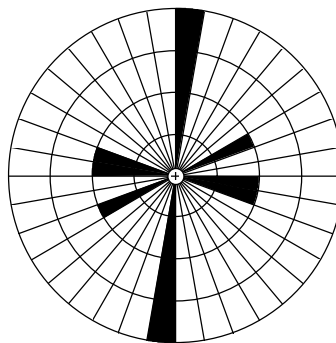


| PR29                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 8                       | Vector Mean = 322.6        |
| Class Interval = 10 degrees | Conf. Angle = 174.80       |
| Maximum Percentage = 37.5   | R Magnitude = 0.159        |
| Mean Percentage = 25.00     | Standard Deviation = 13.36 |
|                             | Rayleigh = 0.8166          |

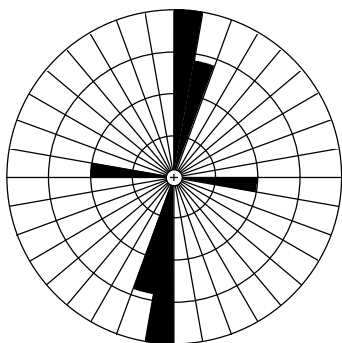
# Fruitland Formation, sandstone No. 1:



| PR07                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 17.7        |
| Class Interval = 10 degrees | Conf. Angle = 44.31       |
| Maximum Percentage = 37.5   | R Magnitude = 0.574       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.0715         |

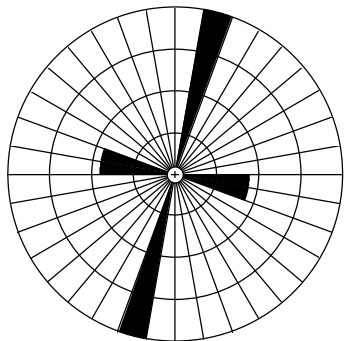


| PR11                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 12.3         |
| Class Interval = 10 degrees | Conf. Angle = 136.12       |
| Maximum Percentage = 57.1   | R Magnitude = 0.216        |
| Mean Percentage = 25.00     | Standard Deviation = 19.84 |
|                             | Rayleigh = 0.7224          |

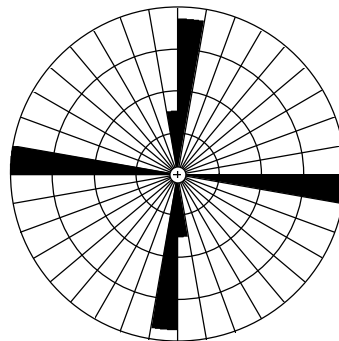


| PR23                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 7.4          |
| Class Interval = 10 degrees | Conf. Angle = 35.00        |
| Maximum Percentage = 57.1   | R Magnitude = 0.708        |
| Mean Percentage = 33.33     | Standard Deviation = 19.52 |
|                             | Rayleigh = 0.0299          |

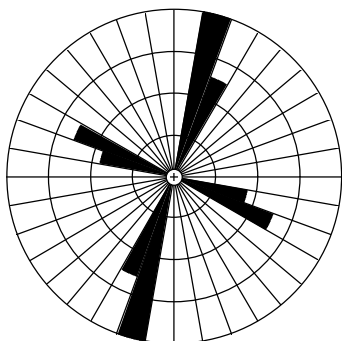
Fruitland Formation, sandstone No. 2:



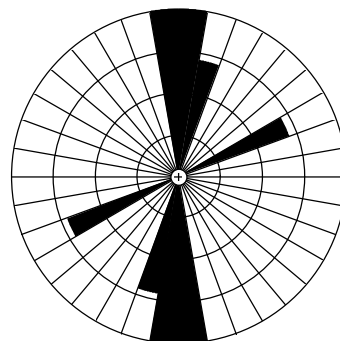
| PR02                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 16.3         |
| Class Interval = 10 degrees | Conf. Angle = 66.07        |
| Maximum Percentage = 71.4   | R Magnitude = 0.432        |
| Mean Percentage = 33.33     | Standard Deviation = 29.51 |
|                             | Rayleigh = 0.2700          |



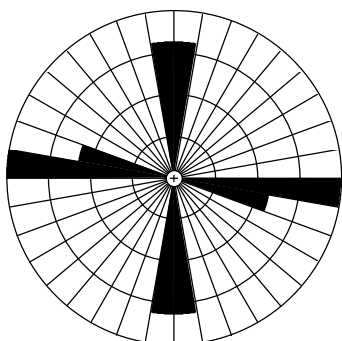
| PR12                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 14                      | Vector Mean = 54.8         |
| Class Interval = 10 degrees | Conf. Angle = 1115.29      |
| Maximum Percentage = 50.0   | R Magnitude = 0.018        |
| Mean Percentage = 33.33     | Standard Deviation = 20.54 |
|                             | Rayleigh = 0.9954          |



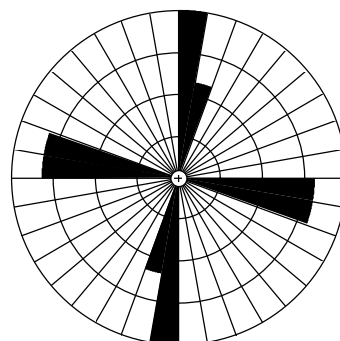
| PR19                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 13.7         |
| Class Interval = 10 degrees | Conf. Angle = 58.40        |
| Maximum Percentage = 50.0   | R Magnitude = 0.411        |
| Mean Percentage = 25.00     | Standard Deviation = 16.04 |
|                             | Rayleigh = 0.1851          |



| PR21                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 5.7         |
| Class Interval = 10 degrees | Conf. Angle = 36.13       |
| Maximum Percentage = 33.3   | R Magnitude = 0.727       |
| Mean Percentage = 25.00     | Standard Deviation = 8.91 |
|                             | Rayleigh = 0.0419         |



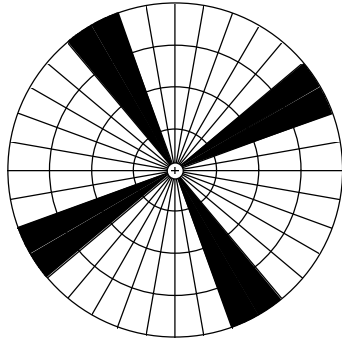
| PR26                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 319.4       |
| Class Interval = 10 degrees | Conf. Angle = 162.82      |
| Maximum Percentage = 37.5   | R Magnitude = 0.172       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.7885         |



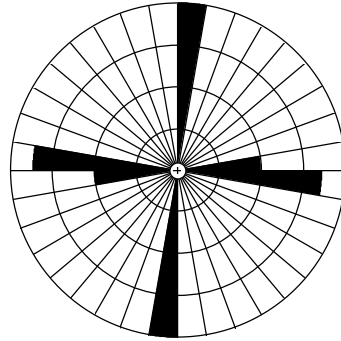
| PR30                        | Statistics                |
|-----------------------------|---------------------------|
| N = 8                       | Vector Mean = 325.7       |
| Class Interval = 10 degrees | Conf. Angle = 317.85      |
| Maximum Percentage = 37.5   | R Magnitude = 0.086       |
| Mean Percentage = 25.00     | Standard Deviation = 9.45 |
|                             | Rayleigh = 0.9421         |



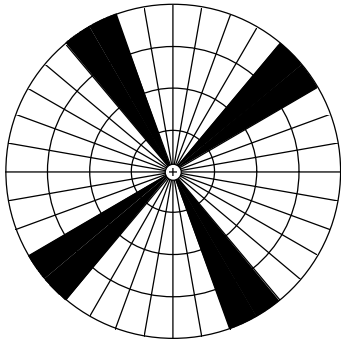
Fruitland Formation, middle coal interval:



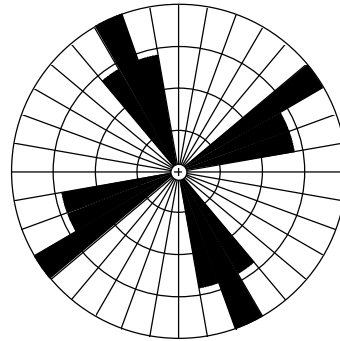
| PR13   | Statistics           |
|--|----------------------|
| N = 8  | Vector Mean = 14.8   |
| Class Interval = 10 degrees                            | Conf. Angle = 932.93 |
| Maximum Percentage = 25.0                              | R Magnitude = 0.030  |
| Mean Percentage = 25.00      Standard Deviation = 0.00 | Rayleigh = 0.9927    |



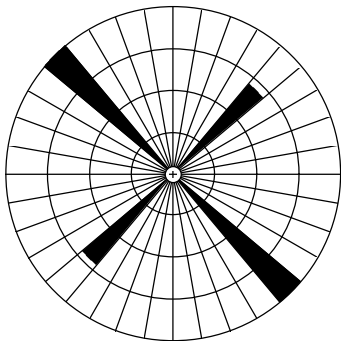
| PR16  | Statistics            |
|---|-----------------------|
| N = 8   | Vector Mean = 28.7    |
| Class Interval = 10 degrees                             | Conf. Angle = 1575.86 |
| Maximum Percentage = 50.0                               | R Magnitude = 0.016   |
| Mean Percentage = 33.33      Standard Deviation = 17.08 | Rayleigh = 0.9980     |



| PR31   | Statistics           |
|--|----------------------|
| N = 8  | Vector Mean = 9.3    |
| Class Interval = 10 degrees                            | Conf. Angle = 197.98 |
| Maximum Percentage = 25.0                              | R Magnitude = 0.142  |
| Mean Percentage = 25.00      Standard Deviation = 0.00 | Rayleigh = 0.8506    |

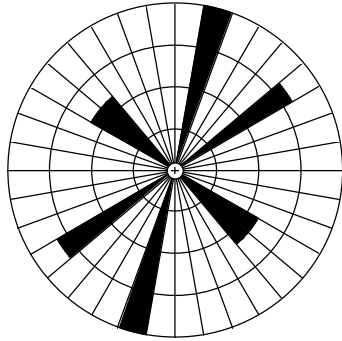


| PR34   | Statistics           |
|--|----------------------|
| N = 8  | Vector Mean = 3.6    |
| Class Interval = 10 degrees                            | Conf. Angle = 868.68 |
| Maximum Percentage = 25.0                              | R Magnitude = 0.035  |
| Mean Percentage = 16.67      Standard Deviation = 6.15 | Rayleigh = 0.9904    |

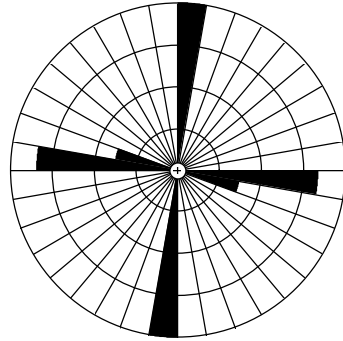


| PR37  | Statistics          |
|---|---------------------|
| N = 6   | Vector Mean = 314.0 |
| Class Interval = 10 degrees                             | Conf. Angle = 95.64 |
| Maximum Percentage = 66.7                               | R Magnitude = 0.328 |
| Mean Percentage = 50.00      Standard Deviation = 19.25 | Rayleigh = 0.5234   |

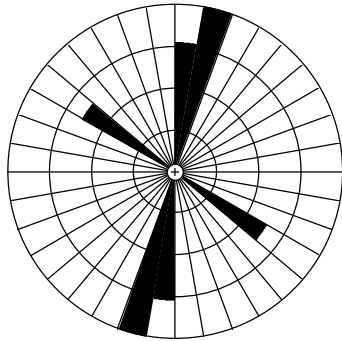
Fruitland Formation, sandstone No. 3:



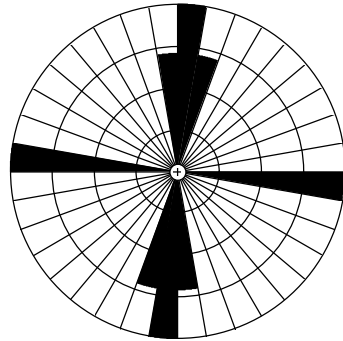
| PR15                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 7                       | Vector Mean = 19.7         |
| Class Interval = 10 degrees | Conf. Angle = 86.07        |
| Maximum Percentage = 42.9   | R Magnitude = 0.336        |
| Mean Percentage = 25.00     | Standard Deviation = 12.66 |
|                             | Rayleigh = 0.4535          |



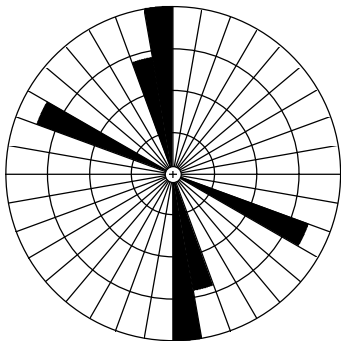
| PR17                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 13                      | Vector Mean = 356.5        |
| Class Interval = 10 degrees | Conf. Angle = 271.21       |
| Maximum Percentage = 53.8   | R Magnitude = 0.082        |
| Mean Percentage = 33.33     | Standard Deviation = 21.02 |
|                             | Rayleigh = 0.9160          |



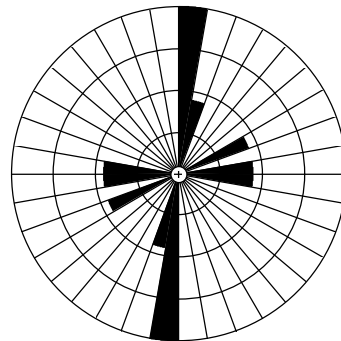
| PR32                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 10                      | Vector Mean = 4.5          |
| Class Interval = 10 degrees | Conf. Angle = 32.69        |
| Maximum Percentage = 50.0   | R Magnitude = 0.660        |
| Mean Percentage = 33.33     | Standard Deviation = 13.66 |
|                             | Rayleigh = 0.0129          |



| PR33                        | Statistics                |
|-----------------------------|---------------------------|
| N = 6                       | Vector Mean = 2.4         |
| Class Interval = 10 degrees | Conf. Angle = 99.05       |
| Maximum Percentage = 33.3   | R Magnitude = 0.317       |
| Mean Percentage = 25.00     | Standard Deviation = 8.91 |
|                             | Rayleigh = 0.5472         |

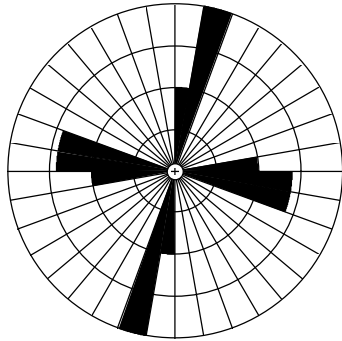


| PR35                        | Statistics                |
|-----------------------------|---------------------------|
| N = 9                       | Vector Mean = 336.3       |
| Class Interval = 10 degrees | Conf. Angle = 40.01       |
| Maximum Percentage = 44.4   | R Magnitude = 0.593       |
| Mean Percentage = 33.33     | Standard Deviation = 9.94 |
|                             | Rayleigh = 0.0422         |



| PR36                        | Statistics                 |
|-----------------------------|----------------------------|
| N = 9                       | Vector Mean = 15.8         |
| Class Interval = 10 degrees | Conf. Angle = 60.23        |
| Maximum Percentage = 55.6   | R Magnitude = 0.417        |
| Mean Percentage = 20.00     | Standard Deviation = 18.74 |
|                             | Rayleigh = 0.2097          |

Fruitland Formation, sandstone No. 4:



| PR18  | Statistics           |
|---|----------------------|
| N = 10  | Vector Mean = 53.6   |
| Class Interval = 10 degrees                             | Conf. Angle = 166.06 |
| Maximum Percentage = 40.0                               | R Magnitude = 0.151  |
| Mean Percentage = 20.00      Standard Deviation = 11.55 | Rayleigh = 0.7968    |

