Subsurface correlation of Late Cretaceous Fruitland Formation coal beds in the Pine River, Florida River, Carbon Junction, and Basin Creek gas-seep areas, La Plata County, Colorado

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INTRODUCTION

The Pine River, Florida River, Carbon Junction, and Basin Creek areas are located in the northern part of the San Juan Basin in La Plata County, Colorado (figure 1-1). These areas are the sites of the major known natural-gas seeps along the Cretaceous Fruitland Formation outcrop in La Plata County (not including the Southern Ute Indian Reservation). Each of the gas seep areas is located in a place where the steeply dipping Hogback Monocline has been breached by a stream cut, therefore, the seeps are in areas that are topographically, relatively low.

The Fruitland Formation is the major coal-bearing rock unit in the San Juan Basin of New Mexico and Colorado. The Fruitland contains in excess of 200 billion tons of coal throughout the basin (Fassett and Hinds, 1971) and crops out around most of the margin of the basin. Fruitland coal is strip mined in three large mines in northwestern New Mexico. Fruitland coal has been mined , mostly underground, in many small workings around the north and northwest rim of the basin; nearly all of those mines are now abandoned. A relatively small Fruitland strip-mining operation in the northeast part of the basin, the Chimney Rock mine, is also now abandoned.

The geology and distribution of Fruitland coal in the San Juan Basin is described in detail in a U.S. Geological Survey Professional Paper (Fassett and Hinds, 1971). That study shows that Fruitland coals are present throughout the subsurface of the basin to a maximum depth of slightly more than 4,000 feet and that the deposition of the coals was closely related to the regression of the Western Interior Seaway as it retreated from the

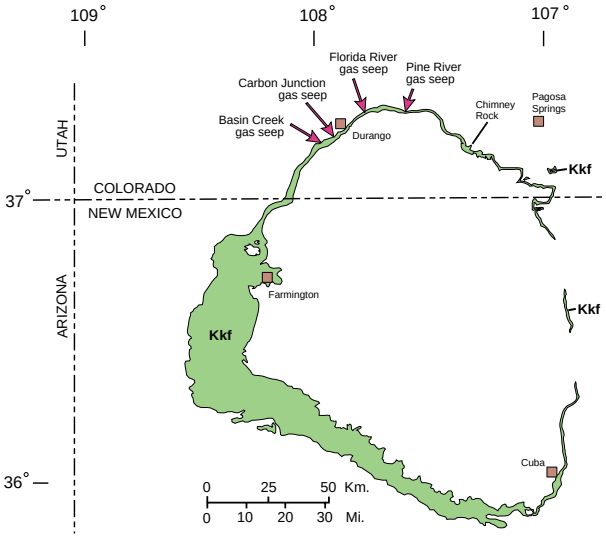


Figure 1-1. Index map showing the locations of the Pine River, Florida River, Carbon Junction, and Basin Creek gas seeps. Kkf is the outcrop of the Fruitland Formation and Kirtland Shale, undivided (from Fassett and Hinds, 1971).

San Juan Basin area in Late Cretaceous time. The study also showed that Fruitland coals formed in a time-transgressive manner; radiometric age dates (Fassett and Steiner, in press) indicate that Fruitland coals in the southwest part of the basin are 3 million years older than coals in the northeast part of the basin. Fruitland coals occur in a complicated, stratigraphically rising, en-echelon geometry across the basin, however it is possible to correlate Fruitland coals using guidelines in the Fassett and Hinds (1971) report.

During the past ten years, the northern San Juan Basin has experienced a gas-drilling boom targeting coal-bed methane in the Fruitland Formation. As a result, thousands of Fruitland

coal-bed wells now produce large volumes of natural gas in this part of the basin. Many wells are located within a mile or two of the margin of the basin where the Fruitland coals crop out. The geophysical logs from these gas wells provide most of the basic data for subsurface correlation of Fruitland coal beds in the La Plata County gas seep areas.

PINE RIVER AREA

Coal-bed correlation

The Pine River gas seep area is located where the Los Pinos river (Pine River) has cut through the Hogback Monocline at the northern margin of the San Juan Basin (figure 1-2). The steeply dipping Hogback Monocline, is formed by the massive, cliff-forming, Pictured Cliffs Sandstone (see chapters 2 and 3 for details of the geologic structure in this area). All of the Fruitland Formation coal-gas wells in the vicinity of the Pine River seeps are shown on figure 1-2. Monitor holes were drilled near the gas seeps in an effort to determine the source of the escaping gas (figures 1-2 and 1-4 through 1-6). Geophysical logs from five of these holes were used to correlate Fruitland coal beds in the Pine River seep area; three of these holes were cored. Examination of core from these holes by the author provided detailed corroboration of the lithologies penetrated in these holes as interpreted from geophysical logs. Two sets of structural and stratigraphic cross sections were constructed to illustrate the correlation of Fruitland coals in the subsurface adjacent to the gas seeps (figures 1-3 and 1-4). The location of the cross sections (A-A' and B-B') are shown on figure 1-2.

Figure 1-3a, a stratigraphic cross section along line A-A' shows the detailed correlation of Fruitland coal beds and major sandstone beds in this area. The line of section is about 4.5 miles long and roughly parallels the outcrop of the rocks shown. This cross section ranges from less than a mile to about 1.5 miles downdip (south) from the outcrop of the Pictured Cliffs in the Pine River area (figure 1-2). The depth from the surface to the base of the Fruitland ranges from 1,260 to nearly 1,700 feet along the line of section. The datum for this section is the top of the lower part of the Pictured Cliffs. Coal beds and non-coal partings within coal beds more than one foot thick are shown on this figure, and on all subsequent cross sections. In order to illustrate these relatively thin beds, it was necessary to construct coal-correlation cross sections with a large element of vertical exaggeration. The geophysical log depths of all of the lithologic units shown on this and the other correlation diagrams in this report are listed in appendix 1-1. Geophysical log depths are shown in 100-foot increments for each drill hole shown on these cross sections as are the total depths of each drill hole. Surface elevations for each drill hole are listed in appendix 1-1.

Three large channel sandstones are present on section A-A'. Sandstone no. 2 is the most continuous and was mapped at this same stratigraphic level at the surface (see geologic map in chapter 2). Sandstone no. 3 was also mapped at the surface. An unnamed sandstone bed is present at the east end of the cross section; this bed apparently does not crop out at the surface west of the Pine River. This cross section shows that the large channel sandstones constrained the geometry of some of the coal beds shown on this cross section by differential compaction of the rocks in this interval. The sandstones clearly compacted less than the coals and other finer-grained lithologies as burial and lithification of these rocks progressed. For example, coals C and D (formed as an essentially horizontal deposit as peat built up in Late Cretaceous coal swamps), owes its present, somewhat twisted form, to differential compaction of it and associated underlying and overlying sedimentary rock layers.

A significant stratigraphic rise in the top of the Pictured Cliffs Sandstone is seen on the east end of the cross section in the Wommer and the Magoon wells (figure 1-3a). Coal bed A splits and thins at the base of the large Pictured Cliffs Sandstone tongue and coal beds of zone B terminate opposite this large sandstone bed. Coals C and D were mapped separately at the surface, west of the Pine River seeps (see chapter 2), but as shown in this cross section, these coals merge eastward in the subsurface. Coal bed E, shown at the west end of the cross section (also mapped at the surface) is discontinuous in the subsurface, but another coal bed is present at about the same level on the eastern end of the section. Two thin coals are present in the uppermost Fruitland in the Magoon well on the east end of the cross section.

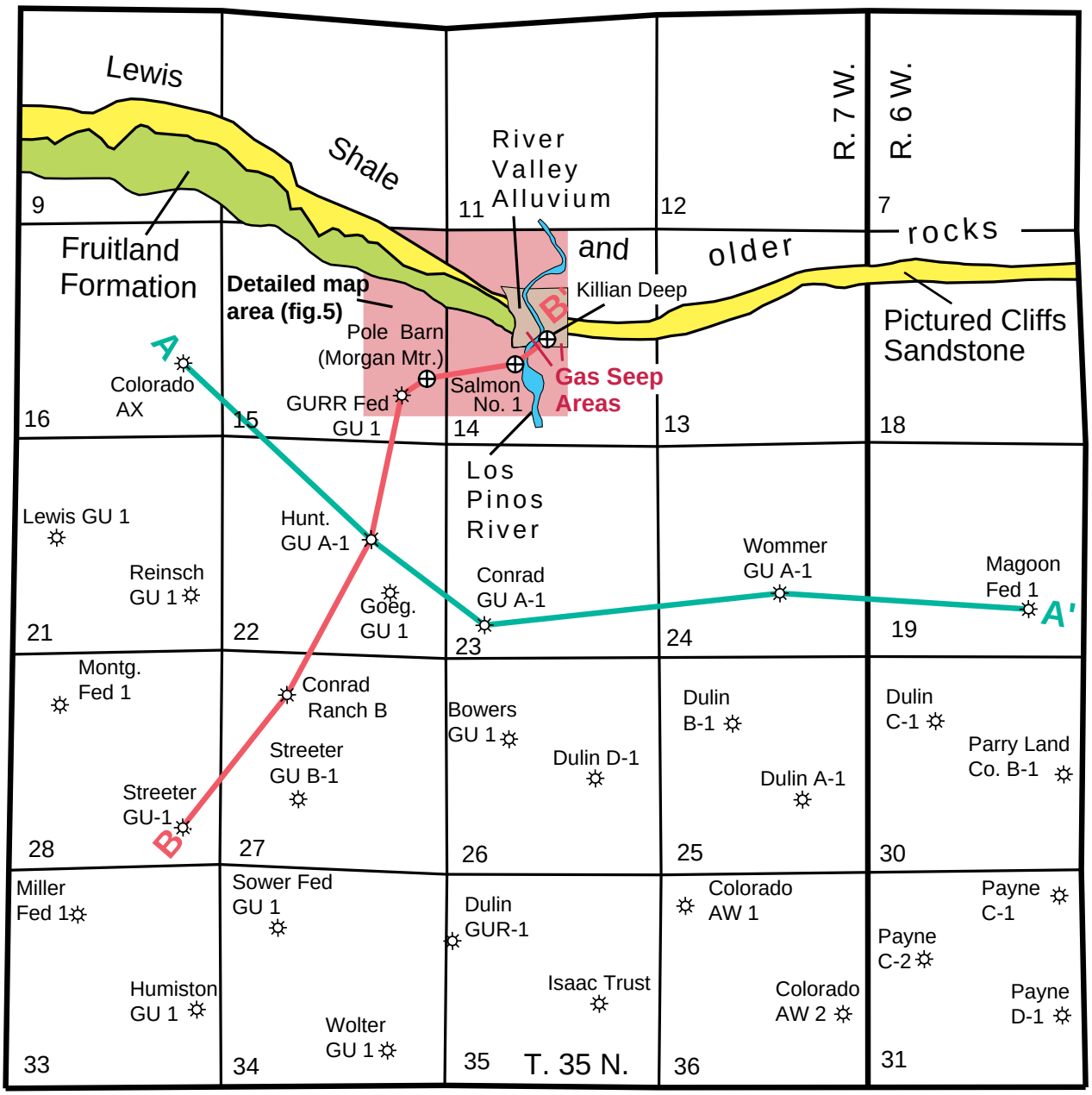


Figure 1-2. Index map of the Pine River gas seep area. Gas seeps are in the river-valley alluvium overlying the Fruitland Formation subcrop in section 14. Producing Fruitland Formation coal-bed methane wells and lines of geologic cross sections A-A' and B-B' are also shown. Figure 1-5 is a large-scale map of the gas seep area. Geology west of Los Pinos river is from plate 5, chapter 2 of this report. Geology east of the river is from Barnes (1953).

Figure 1-3b is a structural cross section along line A-A'. This section was contructed using mean sea level as the datum and has no vertical exaggeration. This cross section shows that the Fruitland Formation is relatively flat in the subsurface along line A-A' .

Stratigraphic cross section B-B' (figure 1-4a), is oriented at right angles to the Fruitland outcrop in the Pine River area (figure 1-2). The Fruitland is about 2,000 feet below the surface at the southwest end of this section. This cross section is approximately 3 miles long and shows the correlation of Fruitland coal beds from deep in the subsurface to near the surface in the vicinity of the Pine River gas seeps (figure 1-2). Vertical exaggeration on this cross section is 34:1. The four deepest

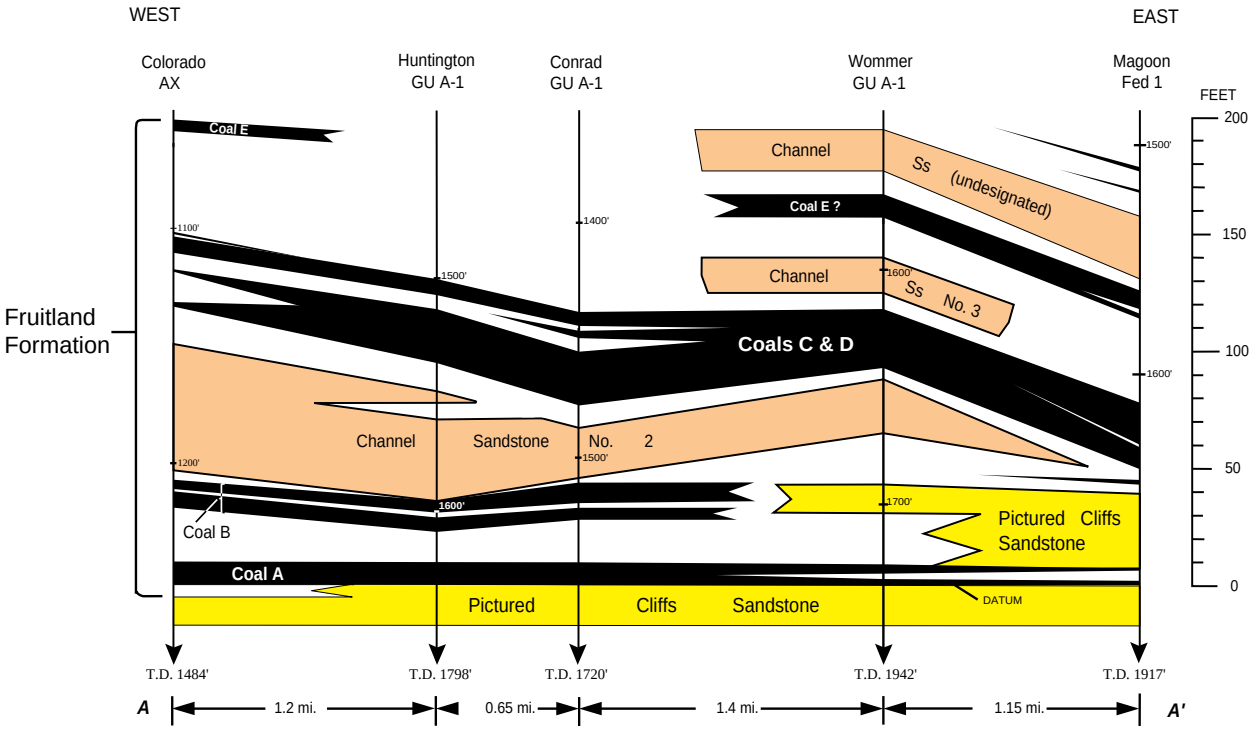


Figure 1-3a. Stratigraphic cross section A-A' showing subsurface coal-bed correlations in the Pine River gas seep area. Coal beds and non-coal partings more than one foot thick are shown. The line of this cross sections is on figure 1-2. Log depths were measured from the Kelly bushing. Vertical exaggeration is 57:1. Tops and bottoms of lithologic units are listed in table 1-1 of appendix 1-1.

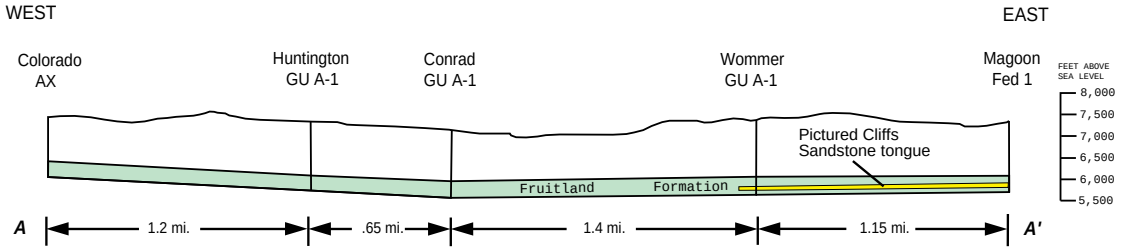


Figure 1-3b. Structural cross section A-A' showing the Fruitland Formation in the subsurface down-dip from the Pine River gas seep area. Line of section is on figure 1-2. There is no vertical exaggeration. Thickness of Pictured Cliffs Sandstone tongue and underlying Fruitland Formation tongue on east end of section is exaggerated about 2.5:1.

holes were drilled as Fruitland coal-bed methane wells and the three near-surface holes, Pole Barn, Salmon No. 1, and Killian Deep, were drilled to provide subsurface information regarding the Pine River gas seeps. Cores from these three shallow holes were examined and described as part of this study.

Coal A, the lowermost Fruitland coal bed, directly overlies the Pictured Cliffs across the entire line of section B-B' (figure 1-4a). At the southwest end of the section in the Streeter well, coal A is 25 feet thick but less than a mile to the northeast, it splits into two thinner coal beds. The upper coal bed pinches out between the Huntington and the GURR wells. The lower part of bed A splits in the Gurr well but maintains its thickness to very near the outcrop in the Salmon No. 1 hole. This basal-Fruitland coal bed thins and becomes

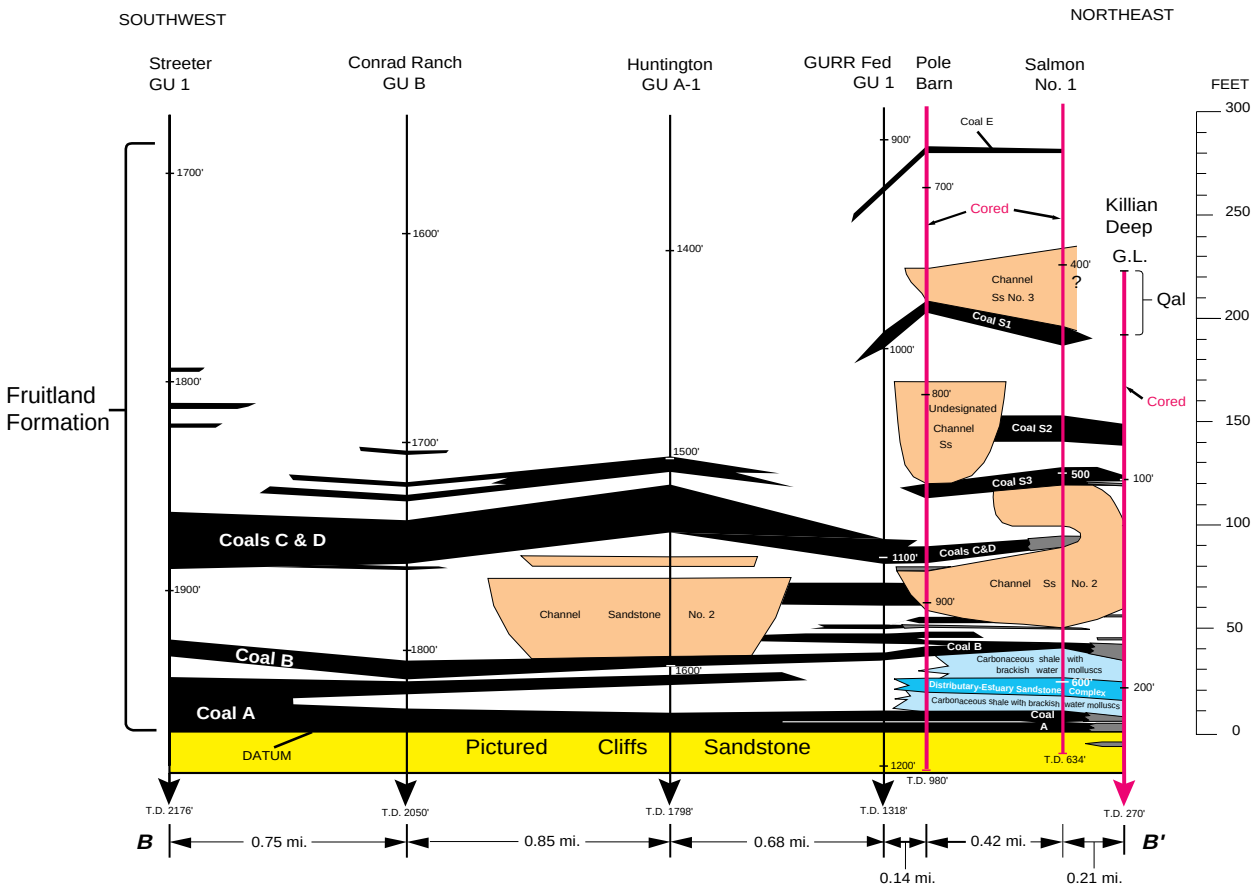


Figure 1-4a. Stratigraphic cross section B-B' showing subsurface coal-bed correlations in the Pine River gas seep area. Vertical exaggeration is 34:1. Coal beds and non-coal partings more than one foot thick are shown. The line of this cross section is on figure 1-2. High-ash coals (density of 1.9 gm/cc) are shown in gray, coals shown in black have a density of 1.75 gm/cc or less). Cores from the GURR Federal, Pole Barn, and Killian Deep drill holes were examined and described to confirm lithologic interpretations based on geophysical logs. Depths to tops and bottoms of lithologic units are listed in table 1-2 of appendix 1-1. Log depths were measured from Kelly bushing.

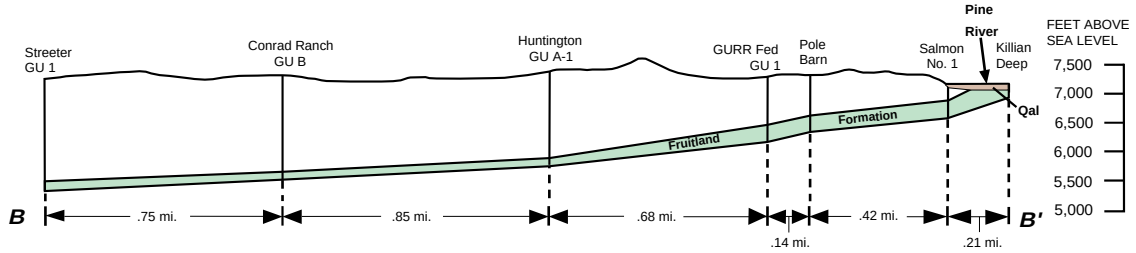


Figure 1-4b. Structural cross section B-B' showing the Fruitland Formation in the subsurface adjacent to the Pine River gas seeps area, no vertical exaggeration. The line of section B-B' is shown on figure 1-2. Thickness of Pine River alluvium (Qal) is exaggerated about 2.5:1.

extremely high ash (density of 1.9 gm/cc) in the Killian Deep hole. Coal bed B generally thins northeastward but maintains its continuity across the entire line of section. This coal bed, however, also becomes very high ash in the Killian Deep drill hole. Coal C and D maintains a thickness of more than 20 feet through the Streeter, Conrad Ranch, and the Huntington wells, but thins to 12 feet

in the GURR well. Northeastward, this bed is thinner and is very high ash in the Salmon hole, pinches out into a sandstone bed, and is absent in the Killian Deep hole. Coal E is a thin, continuous bed in the GURR, Pole Barn, and Killian holes and probably crops out beneath the Pine River alluvium between the Salmon and the Killian holes. Thin, discontinuous coal beds are present above the C and D coal bed in the Streeter, Conrad Ranch, and Huntington wells but none of these coals are continuous into the Pine River gas seep area.

Several discontinuous coal beds in holes adjacent to the seep area (apparently present only in the subsurface) are labeled coal S1 through coal S3 on figure 1-4a. Coal bed S1 might be interpreted as three separate pods of coal in the GURR, Pole Barn, and Killian holes, but it is here portrayed as a continuous coal bed that was draped over the undesignated fluvial sandstone bed in the Pole Barn hole because of differential compaction. This coal bed is apparently not present in the Killian hole but it may have been eroded prior to deposition of the Pine River alluvium (Qal on figure 1-4a). Coal S2 is 13 feet thick in the Salmon No. 1 hole and 11 feet thick in the Killian hole, but abuts against the thick fluvial sandstone bed in the Pole Barn hole. Coal S3 is relatively thick in the Pole Barn and Salmon No. 1 holes, but thins and splits at the Killian hole.

Figure 1-4b is a structural cross section oriented at right angles to the Fruitland outcrop terminating at its northeast end near the Pine River gas seeps. This cross section has no vertical exaggeration. The Pine River gas seeps are coming out of the alluvium (here labeled Qal) between the Killian and the Salmon No. 1 holes (Oldaker, 1996).

Figure 1-5, a larger scale map of the gas seep area, shows the outcrop pattern of the Pictured Cliffs Sandstone and the Fruitland Formation west of the Pine River (from plate 5, chapter 2 of this report) and the alluvium that fills the river's flood plain. The northeast end of cross section B-B' is shown plus the locations of the James No. 1 and Salmon No. 3 drill holes and the line of cross section C-C'. Line of cross section C-B' of figure 1-6 is shown. The subcrop of the Fruitland Formation is shown bounded by dotted lines and a hachure pattern. The upper and lower contacts of the Fruitland subcrop in this area were projected from the four drill holes shown in the alluvium area. The gas seep area (drawn on the basis of data in Oldaker, 1996) is shown as the dark area overlying the upper part of the Fruitland subcrop. Gas seeps have been reported east of the gas-seep area shown here, but those seeps have not been evaluated and no attempt was made to project the gas seep area beyond the documented area.

The trace of the larger scale cross section C-C' is shown through the Salmon No. 1, Salmon No. 3 and the James No. 1 holes. This cross section (upper panel, figure 1-6) is about 0.21 miles long. Cross section C-B' (lower panel, figure 1-6)) is an expanded version of the northeast end of cross section B-B' and is also about 0.21 miles long. These cross sections show the geometry and continuity of the Fruitland coal beds in the seep area itself. The Salmon No. 1 drill hole is common to both cross sections. Down-hole videos were made in the Salmon No. 3, James No. 1, and the Killian Deep holes. These videos were viewed to determine the points at which gas bubbles were entering the drill holes; gas-entry points (as noted by the author) are shown on figure 1-6 with heavy arrows and the capital letter G.

On cross section C-C' (figure 1-6) coals S2 and S3 pinch out short of the Pine River alluvium Fruitland subcrop. Coal S4 is present only in the Salmon No. 3 hole, and coal S5 extends through the Salmon No. 3 and James No. 1 drill holes, and presumably to the subcrop. Coal A is present across the line of section but becomes very high ash in its upper part in the Salmon No. 3 drill hole. The extent of coal S1 updip (north) from the Salmon No. 3 hole is not known. It is interesting to note that coal S2 which is apparently continuous across section C-B' has thinned to a feather edge only about 0.1 mile to the south in the Salmon No. 3 hole. It is also interesting to note that coal B on cross section C-C' is not continuous across this line of section but is missing in the Salmon No. 3 drill hole. Cross section C-B' shows in more detail that coals A and B are very high ash in the Killian Deep hole.

Gas flow through coal beds

The key question regarding the Pine River gas seeps and other gas seeps from Fruitland coal beds

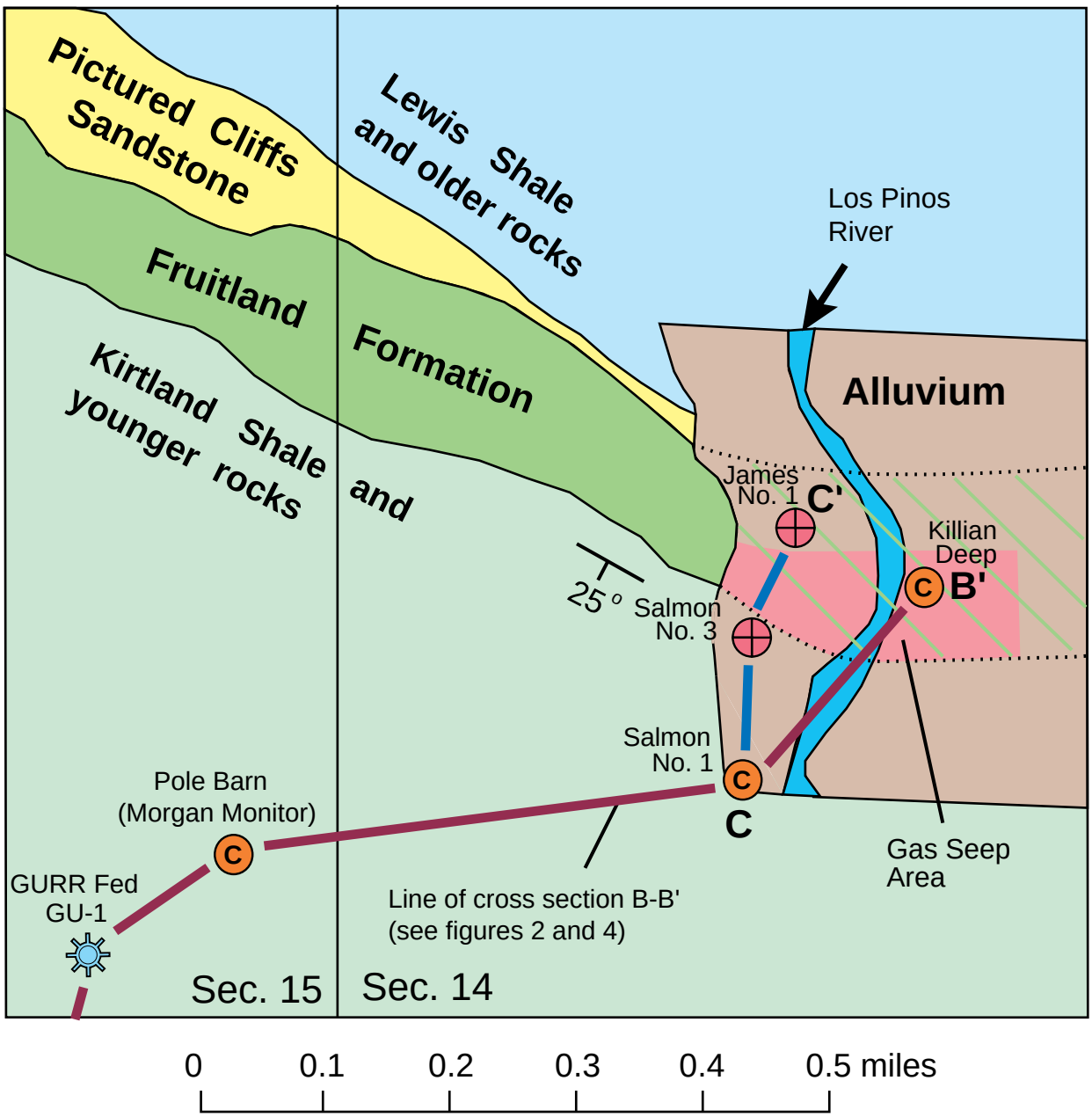
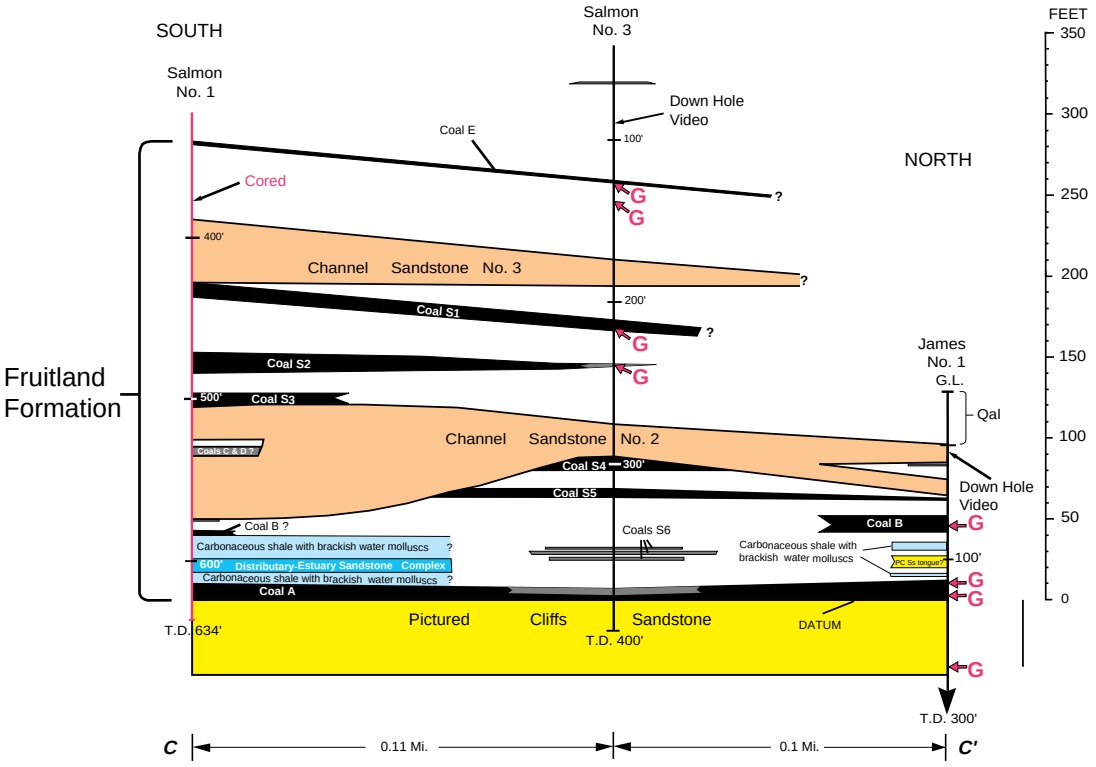


Figure 1-5. Detailed index map of Pine River gas seep area. Geology west of Pine River from plate 5, chapter 2 of this report. Subcrop of Fruitland Formation (hachured area bounded by dotted lines) projected from monitor wells in alluvium area. Gas seep area outline drawn from data in Oldaker (1996). Stratigraphic cross sections C-C' and C-B' are shown on figure 1-6 (section C-B' is the northeast end of section B-B' of figures 1-2 and 1-4). Monitor wells containing the letter C were cored through the Fruitland Formation coal beds and the upper part of the Pictured Cliffs Sandstone.

in the northern San Juan Basin is whether or not the production of water from nearby (down dip, generally southwest) producing coal-bed methane gas wells has liberated adsorbed coal-bed gas and allowed some of this gas to migrate to the surface to emerge as seeps. Figure 1-4a shows that the thicker coals that produce Fruitland gas in the subsurface, notably coal C and D, pinch out before reaching the subcrop in the seep area. Coals A and B do seem to be continuous from the subsurface to the outcrop, however, both of these coals become extremely high ash in the Killian


SOUTH
Salmon No. 1
Salmon No. 3
Down Hole Video
Coal E
NORTH
Cored
Channel Sandstone No. 3
Coal S1
Coal S2
Fruitland Formation
Coal S3
Channel Sandstone No. 2
Coals C & D ?
Coal S4
Coal S5
James No. 1 G.L.
Qal
Down Hole Video
Coal B ?
Coals S6
Coal B
Carbonaceous shale with brackish water molluscs
Distributary-Estuary Sandstone Complex
Coal A
Pictured Cliffs Sandstone
DATUM
T.D. 634'
T.D. 400'
T.D. 300'
C
0.11 Mi.
0.1 Mi.
C'
FEET
350
300
250
200
150
100
50
0

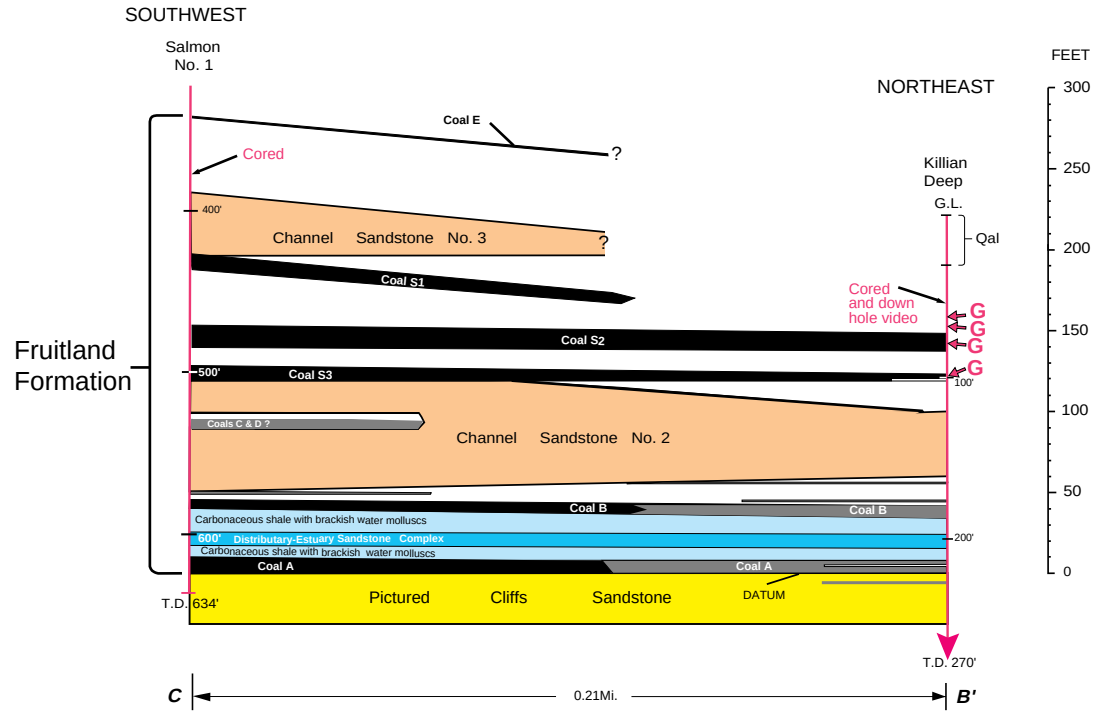

SOUTHWEST
Salmon No. 1
NORTHEAST
Coal E
Cored
Killian Deep G.L.
Qal
Channel Sandstone No. 3
Coal S1
Cored and down hole video
Coal S2
Fruitland Formation
Coal S3
Coals C & D ?
Channel Sandstone No. 2
Coal B
Carbonaceous shale with brackish water molluscs
Distributary-Estuary Sandstone Complex
Coal A
Pictured Cliffs Sandstone
DATUM
T.D. 634'
T.D. 270'
C
0.21Mi.
B'
FEET
300
250
200
150
100
50
0

Figure 6. Geologic cross sections C-C' and C-B' (northeast end of B-B' of figure 1-4a). Lines of sections are on figure 1-5. Vertical exaggeration is 26:1. Lithologic units more than 1 ft thick are shown. Coals shown in black have densities of less than 1.75 gm/cc, coals shown in gray have densities to 1.9 gm/cc. The Salmon No. 1 drill hole is common to both sections. Tops and bottoms of lithologic units and levels of gas bubbles entering hole on down-hole videos are listed in table 1-3 of appendix 1-1. Log depths measured from Kelly bushing. Cores of the Salmon No. 1 and Killian Deep holes were examined to confirm geophysical-log interpretation. Down-hole videos of the Salmon No. 3, Killian Deep, and the James No. 1 holes were viewed to confirm geophysical log interpretations in those holes. These videos also showed gas bubbles entering the drill holes as shown by the arrows and letter G.

hole near where they may subcrop beneath the Pine River alluvium. High-ash coals usually have poorly developed cleat and thus are normally less permeable than low-ash coals. Figure 1-5 shows that the Pine River seeps overlie the upper Fruitland coal beds (coals E, S1, S2, and S3 on figure 1-4a and figure 1-6). Figure 1-4a shows that these upper coal beds are discontinuous and do not extend far into the subsurface and thus have not been major producers of water or gas from commercial gas wells.

Gas-bubble entry points detected on the down-hole videos are shown by heavy arrows and the letter G on cross section C-B' of figure 1-6. Gas emanating from the Killian-hole is entering the hole from noncoal rocks (siltstone beds) above coal S2 and from coals S2 and S3 (cross section C-B', figure 6. No gas whatsoever was entering this drill hole from the lower Fruitland coal beds B or A. It has been argued that the greater water pressure on these deeper coal beds may be preventing the desorption of gas from these coals. However, if these lowermost Fruitland coal beds were serving as conduits for gas moving up from the subsurface, gas liberated by production of coal-bed methane at depth, this gas would be moving through the fractures in these coal beds as free gas (not adsorbed gas) and would be seen bubbling into the Killian hole in the down-hole videos, which is not the case.

Down hole video data from wells on cross section C-C' confirms this interpretation. In the Salmon No. 3 hole, gas is entering the hole only from the higher less continuous coal beds E, S1, and S2 and no gas bubbles are entering the hole from the lower coals S4, S5, S6, and coal A. In the James No. 1 hole, gas bubbles are entering the drill hole from lower Fruitland coal beds A and B; this gas was probably desorbed from these coals due to the presence of the Killian hole which has lowered the pressure on these coal beds. If coal bed A were a conduit for gas from the subsurface, gas would be entering the Salmon No. 3 drill hole from this coal bed and it clearly is not.

FLORIDA RIVER, CARBON JUNCTION, BASIN CREEK AREAS

Cross Section A-A'

Figure 1-7 is a map showing the location of the Florida River, Carbon Junction, and Basin Creek seep areas. The outcrop of the Pictured Cliffs Sandstone is shown as are all of the gas-producing wells within two miles of the Pictured Cliffs outcrop. Lines of cross section A-A', B-B', C-C', and D-D' are shown on figure 1-7. Section A-A' (figure 1-8) is nearly 7 miles long, trends northeast, and parallels the steeply-dipping Pictured Cliffs outcrop on the Hogback Monocline. Depths from the surface to the base of the Fruitland range from less than 2,000 to 2,350 feet along this line of section. The datum for this section is the top of the lower Pictured Cliffs Sandstone (at two levels on this cross section). Section A-A' shows the occurrence and correlation of Fruitland coal beds and the stratigraphic changes in the Pictured Cliffs Sandstone along the line of section. The most striking feature shown on section A-A' is the large stratigraphic rise in the position of the top of the Pictured Cliffs Sandstone in the Federal 4-1 well. The top of the Pictured Cliffs is nearly 100 feet higher in this well than it is at the University 9-2 well less than a mile to the southwest. The large stratigraphic rise in the top of the Pictured Cliffs Sandstone was mapped at the surface in Carbon Junction Canyon (chapter 2 of this report).

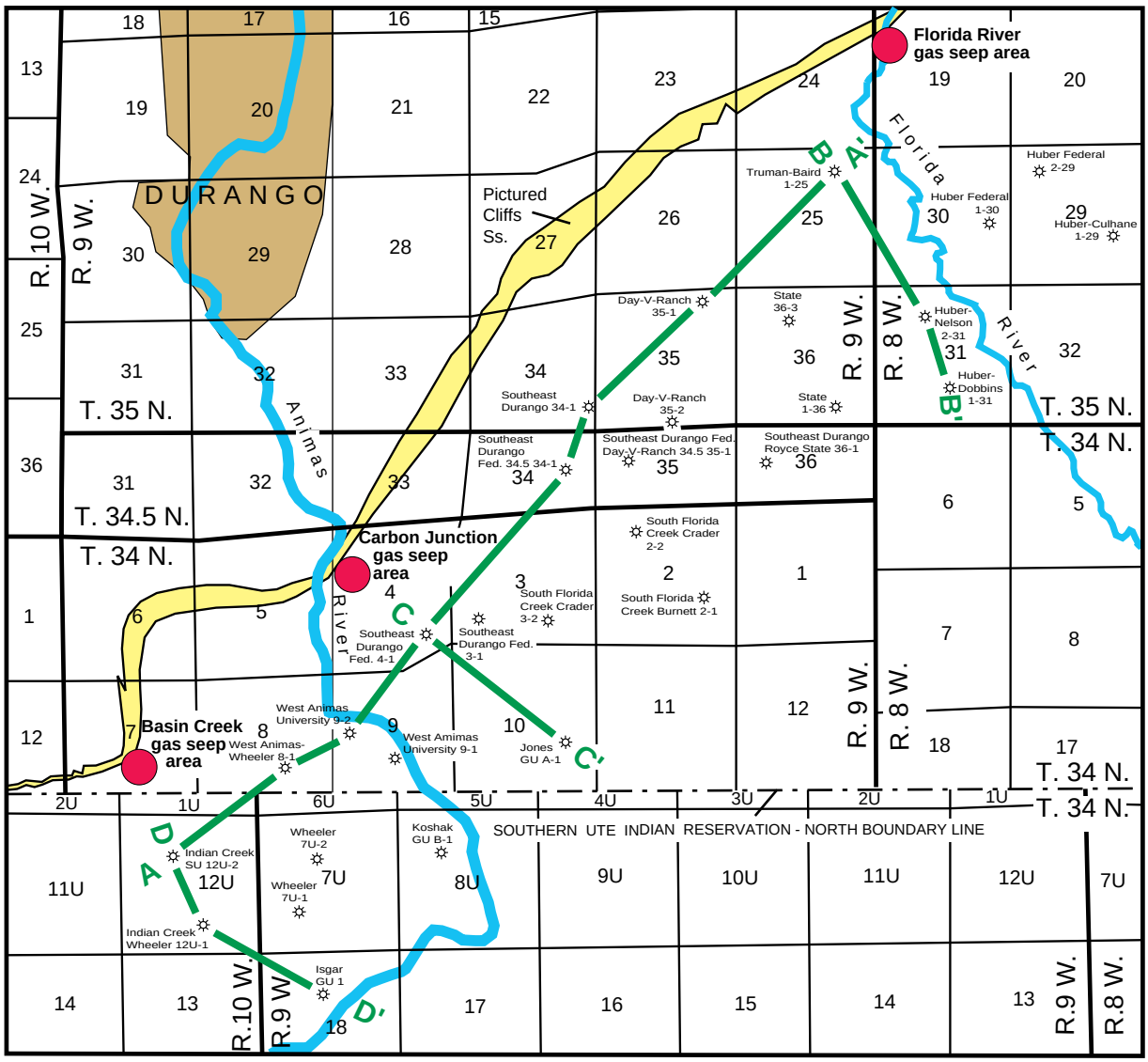


Figure 1-7. Index map of the Florida River, Carbon Junction, and Basin Creek gas seep areas. Gas wells within two miles of the outcropping Pictured Cliffs Sandstone are shown. Lines of cross sections A-A', B-B', C-C', and D-D' show the traces of coal correlation diagrams on figures 1-8, 1-9, 1-10, and 1-11, respectively.

The lack of continuity of the coal beds shown on section A-A' is striking. None of the more than fifty coal beds shown on this cross section are continuous across the entire line of section. The most continuous coal bed on this section is the relatively thin bed lying directly on top of the Pictured Cliffs on the northeast part; this bed extends across most of the line of section but is absent in the Indian Creek and West Animas Wheeler wells at the southwest end. The thick basal Fruitland coal bed present at the southwest end of the section terminates northeastward against the Pictured Cliffs between the West Animas University and the Federal 4-1 wells. The very thick build up of coal in the West Animas University well (a total of 102 feet of coal) is seen to be localized in the vicinity of this well and the West Animas Wheeler well. A very thick coal is present in the Federal 4-1, and Federal 34.5 34-1 wells just above the Pictured Cliffs Sandstone, but this bed thins and pinches out northeastward and is gone at the Truman-Baird well. A slightly higher thick coal is present in the Truman-Baird well, but that bed is not present in the Day-V-Ranch well to the southwest. The only other relatively thick coal is at a depth of about 2,000

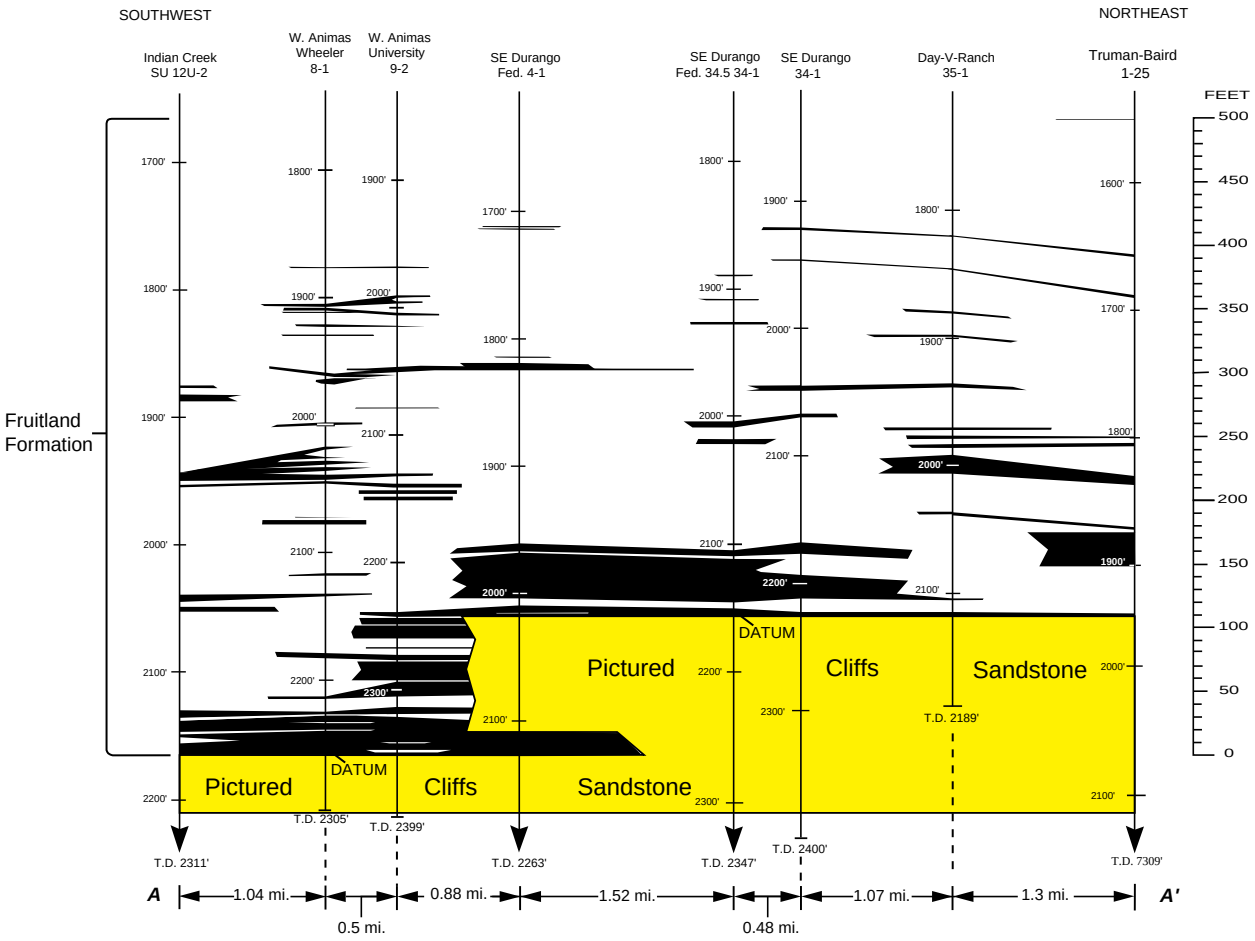


Figure 1-8. Stratigraphic cross section A-A' showing subsurface coal-bed correlations across the Florida River, Carbon Junction, and Basin Creek gas seep areas. Vertical exaggeration is 48:1. Coal beds and non-coal partings more than one foot thick are shown. Trace of cross section on figure 1-7. Tops and bottoms of lithologic units are listed in table 1-4 of appendix 1-1. Log depths measured from Kelly bushing.

feet in the Day-V-Ranch well; this bed thins in the Truman-Baird well and is not present to the southwest. A large number of thinner and more discontinuous coal beds are present throughout the upper part of the Fruitland Formation along this line of section.

Florida River Area

Stratigraphic cross section B-B' (figure 1-9) shows the correlation of Fruitland coals at right angles to the outcrop in the vicinity of the Florida River seep area, the top of the Pictured Cliffs Sandstone is the datum for this section. (This cross section, as well as sections C-C' and D-D', was constructed at the same vertical scale as cross section A-A' to allow for easy comparison of these intersecting cross sections.) This line of section shows relatively good correlation of Fruitland coals; the basal Fruitland coal bed, the two middle coals, and an upper thin coal bed can be correlated across the entire line of section. Coals in the area are relatively thin, with the exception of the thick coal bed in the Truman-Baird well and the thick coal in the Huber-Dobbins well. Surface mapping of Fruitland coals in the vicinity of the Florida River suggests that the coals present in the Truman-Baird well probably extend to the outcrop. However, because the nearest subsurface control point (Truman-Baird well) is a mile away from the Florida gas seep area, continuity of subsurface coals to the outcrop in this area can only be considered speculative, at best.

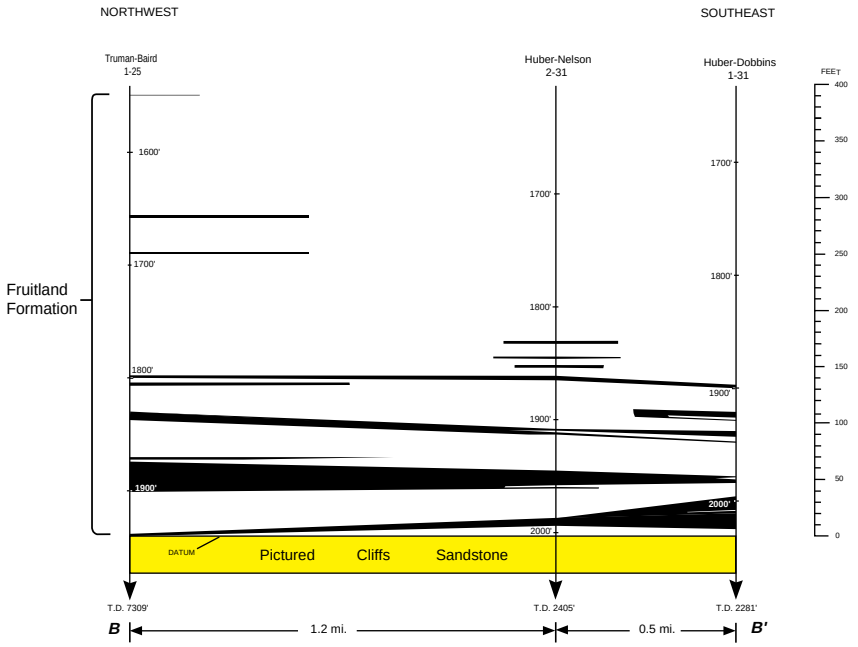


Figure 1-9. Stratigraphic cross section B-B' showing subsurface coal-bed correlations near the Florida River gas seep area. Vertical exaggeration is 17:1. Coal beds and non-coal partings more than one foot thick are shown. Trace of cross section on figure 1-7. Tops and bottoms of lithologic units are listed in table 1-5 of appendix 1-1. Log depths are measured from Kelly bushing.

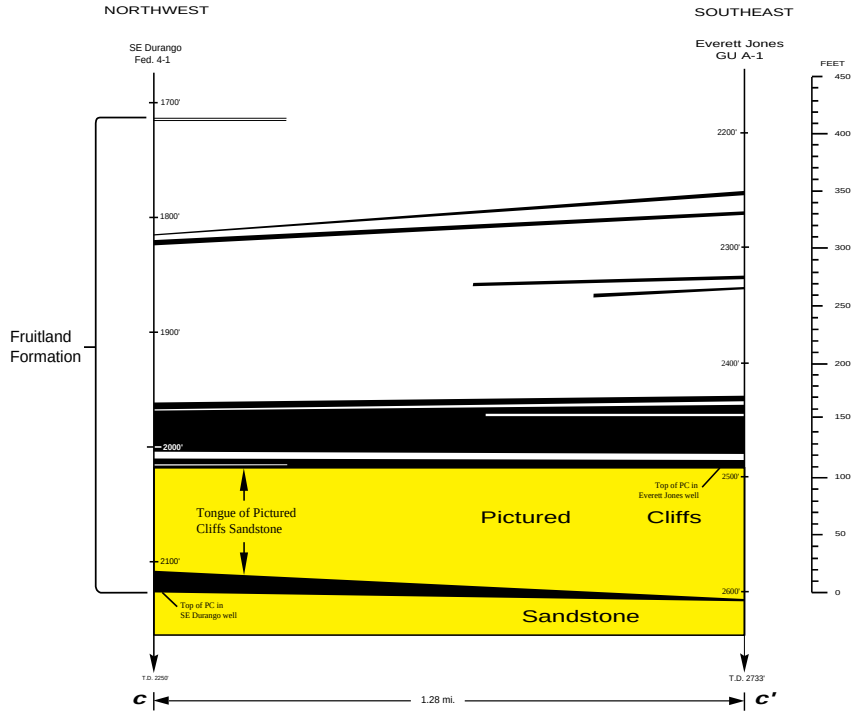


Figure 1-10. Stratigraphic cross section C-C' showing subsurface coal-bed correlations in the Carbon Junction gas seep area. Vertical exaggeration is 13:1. Coal beds and non-coal partings more than one foot thick are shown. The trace of this cross section is shown on figure 1-7. Tops and bottoms of lithologic units are listed in table 1-5 of appendix 1-1. Log depths measured from Kelly bushing. Datum is top of uppermost tongue of Pictured Cliffs Sandstone.

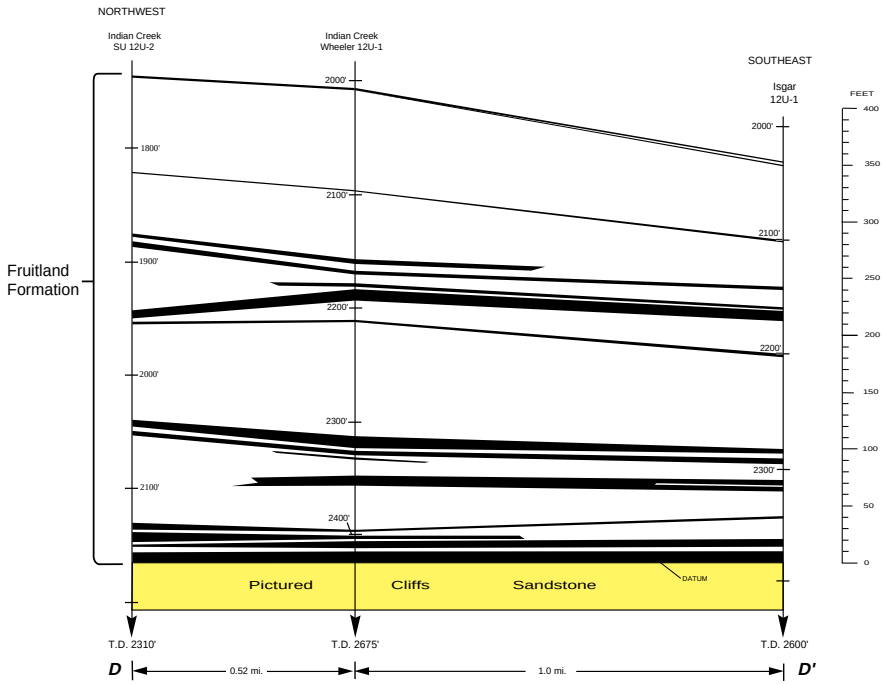


Figure 1-11. Stratigraphic cross section D-D' showing subsurface coal-bed correlations in the Basin Creek gas seep area. Vertical exaggeration is 14:1. Coal beds and non-coal partings more than one foot thick are shown. Line of cross section is on figure 1-7. Tops and bottoms of lithologic units are listed in table 1-6 of appendix 1-1. Log depths measured from Kelly bushing.

Carbon Junction Area

Stratigraphic cross section C-C' (figure 1-10) shows Fruitland coal beds at right angles to the outcrop near the Carbon Junction gas seep area. This two-well cross section shows fairly good continuity of the thick coal bed just above the top of the Pictured Cliffs Sandstone across the line of section, however, this coal bed splits to the southeast. The thinner coal bed lying directly on top of the Pictured Cliffs is also continuous across the line of section. Two thin Fruitland coals extend across both wells in this line of section higher in the Fruitland. The Fruitland coal tongue within the Pictured Cliffs thins to 2-feet thick in the Everett Jones well. At the mouth of Carbon Junction canyon, the thick coal buildup seen at the University 9-2 well on cross section A-A' (figure 1-8) was measured and mapped (see chapter 2), but section C-C' shows that this thick coal zone is not present directly down dip from the Carbon Junction seep area. Because the Federal 4-1 well is only about 0.5 miles from the Carbon Junction gas seep area, and because the thick coals at the outcrop in the gas seep area appear to have the same thickness and geometry in the Federal 4-1 well, there is a high probability that the thick basal Fruitland coal bed is continuous from the subsurface to the outcrop in this area.

Basin Creek Area

Stratigraphic cross section D-D' (figure 1-11) shows the correlation of Fruitland coals in a line of section oriented at right angles to the outcrop. There is excellent correlation of all of the coal zones and most of the coal beds across this line of cross section. Surface mapping at the outcrop near the Basin Creek seep shows thinner and fewer coals than are present in the subsurface, although some of the coal beds shown in the subsurface appear to be present at the outcrop.

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APPENDIX 1-1

Tables 1-1 through 1-6 listing geophysical log depths for lithologic contacts for all drill holes shown on geologic cross sections in this report.

Table 1-1. Geophysical log depths for coal beds in drill holes on Pine River cross section A-A'.

Colorado	Coal	Ss	Above	
AX	Th.	Th.	PC	Notes
0				GL=7467
1053			204	KB=14 ft
1058	5		199	Coal
1101			156	
1102	1		155	Coal
1103			154	
1110	7		147	Coal
1117			140	
1118	1		139	Coal
1131			126	
1133	2		124	Coal
1149			108	
1203		54	54	Sandstone
1207			50	
1211	4		46	Coal
1212			45	
1219	7		38	Coal
1242			15	
1252	10		5	Coal
1257			0	Top PC
1484			-227	T.D.
Total Coal	37			

Wommer	Coal	Ss	Above	
GU A-1	Th.	Th.	PC	Notes
0				GL=7404
1539			195	
1557		18	177	Sandstone
1567			167	KB=12 ft
1577	10		157	Coal
1594			140	
1609		15	125	Sandstone
1616			118	
1641	25		93	Coal
1646			88	
1669		23	65	Sandstone
1691			43	
1703		12	31	Sandstone
1725			9	
1729	4		5	Coal
1731			3	
1734	3		0	Coal
1734			0	Top PC
1942			-208	T.D.
Total Coal	42			

Hunt.	Coal	Ss.	Above	
GU A-1	Th.	Th.	PC	Notes
0				GL=7376
1500			131	KB=12 ft
1507	7		124	Coal
1513			118	
1536	23		95	Coal
1548			83	
1553		5	78	Sandstone
1560			71	
1595		35	36	
1595			36	
1600	5		31	Coal
1602			29	
1608	6		23	Coal
1622			9	
1631	9		0	Coal
1631			0	Top PC
1798			-167	T.D.
Total Coal	50			

Magoon	Coal	Ss.	Above	
Fed 1	Th.	Th.	PC	Notes
0				GL=7382
1508			179	KB=12 ft
1510	2		177	Coal
1518			169	
1519	1		168	Coal
1529			158	
1556		27	131	Sandstone
1561			126	
1569	8		118	Coal
1571			116	
1573	2		114	Coal
1609			78	
1627	18		60	Coal
1628			59	
1637	9		50	Coal
1641			46	
1642	1		45	Coal
1648			39	
1680		32	7	Sandstone
1681	1		6	Coal
1685			2	
1687	2		0	Coal
1687			0	Top PC
1917			-230	T.D.
Total Coal	44			

Conrad	Coal	Ss	Ab	
GU A-1	Th.	Th.		
0				
1437				
1443	6			
1445				
1448	3			
1454				
1477	23			
1483				
1508		25		
1510				
1519	9			
1521				
1526	5			
1544				
1554	10			
1554				
1720				
Total Coal	56			

NOTES: All measurements shown are in feet. Log depths in first column for each drill hole are measured from Kelly bu
PC = Pictured Cliffs Sandstone, T.D. = total depth, GL = ground level.

Killian Deep	Coal Th.	Ss. Th.	Above Kpc	Notes
0			221	GL=7150
31			190	Top bedrk.
73			148	
84	11		137	Coal
98			123	
101	3		120	Coal
102			119	
103	1		118	Hi-ash Coal
121			100	
162		41	59	Sandstone
165			56	
166	1		55	Hi-ash Coal
173			48	
176		3	45	Sandstone
177	1		44	Hi-ash Coal
179			42	
187	8		34	Hi-ash Coal
197			24	CSh, shells
206		9	15	Tongue PC
214			7	CSh, shells
216	2		5	H-ash Coal
217			4	
221	4		0	Hi-ash Coal
221			0	Top P.C.
226		5	-5	Tongue P.C.
228			-7	Tongue Fruit.
270			-49	T.D.
Total C.	31			

Gas bubbles entering hole on video in Killian Deep hole		
Video	Log	Above PC
63-65	61-63	158-160
76-87	73-84	137-148
101-106	98-103	118-123

Hunt. GU A-1	Coal Th.	Ss. Th.	Above PC	Notes
0			1631	GL=7376
1500			131	KB=12 ft
1507	7		124	Coal
1513			118	
1536	23		95	Coal
1548			83	
1553		5	78	Sandstone
1560			71	
1595		35	36	Sandstone
1600	5		31	Coal
1602			29	
1608	6		23	Coal
1622			9	
1631	9		0	Coal
1631			0	Top P.C.
1798			-167	T.D.
Total C.	50			

Salmon No. 1	Coal Th.	Ss. Th.	Above PC	Notes
0			624	GL=7155
342			282	KB=5 ft
344	2		280	Coal
389			235	
428		39	196	Sandstone
437	9		187	Coal
471			153	
484	13		140	Coal
496			128	
505	9		119	Coal
525		20	99	Sandstone
527	2		97	Hi-ash Coal
529			95	
535	6		89	Hi-ash Coal
574		39	50	Sandstone
575	1		49	Hi-ash Coal
581			43	
584	3		40	Coal
598			26	CSh, shells
607		9	17	Tongue P.C.
614			10	CSh, shells
624	10		0	Coal
624			0	Top P.C.
634	45		-10	T.D.
Total C.	53			

Conrad Ranch B	Coal Th.	Above Kpc	Notes
0		1839	GL=7341
1704		135	KB=12ft
1706	2	133	Coal
1719		120	
1721	2	118	Coal
1725		114	
1728	3	111	Coal
1737		102	
1758	21	81	Coal
1759		80	
1761	2	78	Coal
1804		35	
1813	9	26	Coal
1814		25	
1822	8	17	Coal
1827		12	
1839	12	0	Coal
1839		0	Top PC
2050		-211	T.D.
Total C.	59		

Pole Barn	Coal Th.	Ss. Th.	Above PC	Notes
0			962	GL=7244
679			283	KB=4 ft
682	3		280	Coal
737			225	
753		16	209	Sandstone
759	6		203	Coal
776			186	
779		3	183	Sandstone
794			168	
843		49	119	Sandstone
850	7		112	Coal
873			89	
881	8		81	Coal
883			79	
885	2		77	Hi-ash Coal
903		18	59	Sandstone
907			55	
910	3		52	Coal
911			51	
912	1		50	Hi-ash Coal
914			48	
917	3		45	Coal
918			44	
920	2		42	Coal
921			41	
926	5		36	Coal
933			29	
943			19	CSh, shells
951		8	11	Tongue PC
957			5	CSh, shells
958			4	
962	4		0	Coal
962			0	Top P.C.
980			-18	T.D.
Total C.	44			

Streeter Fed. GU 1	Coal Th.	Ss. Th.	Above PC	Notes
0			1968	GL=7330
1794			174	KB=13
1795	1		173	Coal
1813			155	
1814	1		154	Coal
1820			148	
1823	3		145	Coal
1866			102	
1887	21		81	Coal
1928			40	
1934	6		34	Coal
1943			25	
1968	25		0	Coal
1968			0	Top PC
2150			-182	T.D.
Total C.	57			

GURR Fed	Coal Th.	Ss. Th.	A P
0			
822			
824	2		
858			
894		36	
901	7		
906			
918		12	
968			
992		24	
1004	12		
1013			
1024	11		
1025			
1026	1		
1033			
1035	2		
1037			
1042	5		
1043			
1045	2		
1046			
1050	4		
1073			
1079	6		
1080			
1084	4		
1084			
1318			
Total C.	56		

Table 1-2. Geophysical log depths for coal beds in drill holes on Pine River cross section B-B'

NOTES: All measurements shown are in feet. Log depths in first column for each drill hole are measured from Kelly bushing (KB).
PC = Pictured Cliffs Sandstone, T.D. = total depth, GL = ground level, CSh, shells = carbonaceous shale with brackish-water molluscs.
Hi-ash Coal is coal with a density of 1.9 gm/cc on density logs

Table 1-3. Geophysical log depths for coal beds in drill holes on Pine River cross section C-C'

Salmon No. 1	Coal Th.	Ss. Th.	Above Kpc	Notes
0			624	GL=7155
342			282	KB=5 ft
344	2		280	Coal
389			235	
428		39	196	Sandstone
437	9		187	Coal
471			153	
484	13		140	Coal
496			128	
505	9		119	Coal
525		20	99	Sandstone
527	2		97	Hi-ash Coal
529			95	
535	6		89	Hi-ash Coal
574		39	50	Sandstone
575	1		49	Hi-ash Coal
581			43	
584	3		40	Coal
598			26	CSh, shells
607		9	17	Tongue P.C.
614			10	CSh, shells
624	10		0	Coal
624			0	Top P.C.
634	45		-10	T.D.
Total C.	53			

Salmon No. 3	Coal Th.	Ss. Th.	Above Kpc	Notes
0			384	GL=
64			320	
65	1		319	Hi-ash Coal
125			259	
127	2		257	Coal
174			210	
192		18	192	Sandstone
211			173	
217	6		167	Coal
240			144	
241	1		143	Hi-ash Coal
277			107	
294		17	90	Sandstone
304	10		80	Coal
315			69	
321	6		63	Coal
352			32	
353	1		31	Hi-ash Coal
354			30	
356	2		28	Hi-ash Coal
358			26	
359	1		25	Hi-ash Coal
377			7	
381	4		3	Hi-ash Coal
381			3	
384	3		0	Coal
384			0	Top P.C.
400			-16	T.D.
Total C.	37			

Gas bubbles entering hole on down-hole video

Video	Log	
129	127	257
132	130	254
139-140	137-139	245
216	214	170
218	216	168
230	228	156
243	241	143

James No. 1	Coal Th.	Ss. Th.	Above Kpc
0			12
29			9
40		11	8
41			8
42	1		8
49			7
59		10	6
62			6
64	2		6
73			5
83	10		4
98			2
102		4	2
113			1
125	12		
125			
300			-17
Total C.	25		

Gas bubbles entering hole on down-hole video

Video	Log	
79	77	4
115	113	1
120	118	
172	170	-4

NOTES: All measurements shown are in feet. Log depths in first column for each drill hole are measured from Kelly bushing (KB). PC = Pictured Cliffs Sandstone, T.D. = total depth, GL = ground level, CSh, shells = carbonaceous shale with brackish-water molluscs. Hi-ash Coal is coal with a density of 1.9 gm/cc on density logs

Indian Crk.	Coal	Above	
SU-12U-2	Th.	P.C.	Notes
0		2165	GL=6700
1875		290	KB=6
1877	2	288	Coal
1882		283	
1887	5	278	Coal
1943		222	
1950	7	215	Coal
1953		212	
1955	2	210	Coal
2039		126	
2045	6	120	Coal
2049		116	
2053	4	112	Coal
2130		35	
2136	6	29	Coal
2138		27	
2147	9	18	Coal
2149		16	
2151	2	14	Coal
2156		9	
2165	9	0	Coal
2165		0	Top PC
2311		-146	TD
Total Coal	52		

SE Durango	Coal	Above	
34-1	Th.	P.C.	Notes
0		2226	GL=7205
1921		305	KB=14ft
1923	2	303	Coal
1946		280	
1947	1	279	Coal
2045		181	
2049	4	177	Coal
2067		159	
2070	3	156	Coal
2168		58	
2182	14	44	Coal
2195		31	
2212	17	14	Coal
2223		3	
2226	3	0	Coal
2226		0	Top PC
2400		-174	T.D.
Total Coal	44		

W. Animas	Coal	Above	
Wheeler 8-1	Th.	P.C.	Notes
0		2259	GL=6821
1892		367	KB=15
1893	1	366	Coal
1905		354	
1907	2	352	Coal
1908		351	
1910	2	349	Coal
1911		348	
1912	1	347	Coal
1921		338	
1923	2	336	Coal
1929		330	
1930	1	329	Coal
1998		261	
2000	2	259	Coal
2017		242	
2019	2	240	Coal
2025		234	
2026	1	233	Coal
2028		231	
2031	3	228	Coal
2033		226	
2036	3	223	Coal
2039		220	
2043	4	216	Coal
2044		215	
2046	2	213	Coal
2072		187	
2073	1	186	Coal
2074		185	
2078	4	181	Coal
2116		143	
2118	2	141	Coal
2132		127	
2134	2	125	Coal
2156		103	
2162	6	97	Coal
2164		95	
2175	11	84	Coal
2178		81	
2182	4	77	Coal
2213		46	
2215	2	44	Coal
2225		34	
2227	2	32	Coal
2228		31	
2233	5	26	Coal
2234		25	
2239	5	20	Coal
2240		19	
2259	19	0	Coal
2259		0	Top PC
2305		-46	T.D.
Total Coal	89		

W. Animas	Coal	Above	
Univ. 9-2	Th.	P.C.	Notes
0		2351	GL=6720
1968		383	KB=16
1969	1	382	Coal
1990		361	
1992	2	359	Coal
1995		356	
1996	1	355	Coal
2004		347	
2006	2	345	Coal
2014		337	
2015	1	336	Coal
2079		272	
2080	1	271	Coal
2130		221	
2132	2	219	Coal
2138		213	
2141	3	210	Coal
2143		208	
2146	3	205	Coal
2148		203	
2151	3	200	Coal
2239		112	
2242	3	109	Coal
2243		108	
2248	5	103	Coal
2249		102	
2254	5	97	Coal
2256		95	
2257	1	94	Coal
2267		84	
2276	9	75	Coal
2277		74	
2292	15	59	Coal
2293		58	
2305	12	46	Coal
2313		38	
2319	6	32	Coal
2321		30	
2341	20	10	Coal
2342		9	
2347	5	4	Coal
2349		2	
2351	2	0	Coal
2351		0	Top PC
2399		-48	T.D.
Total Coal	102		

SE Durango	Coal	Above	
Fed. 4-1	Th.	P.C.	Notes
0		2127	GL=
1712		415	KB=14ft
1713	1	414	Coal
1714		413	
1715	1	412	Coal
1814		313	
1815	1	312	Coal
1819		308	
1824	5	303	Coal
1961		166	
1967	6	160	Coal
1968		159	
2004	36	123	Coal
2010		117	
2015	5	112	Coal
2016		111	
2018	2	109	Coal
2018		109	
2108		19	
2127	19	0	Coal
2127		0	Top PC
2263		-136	T.D.
Total Coal	76		

Day-V-Ranch	Coal	Above	
35-1	Th.	P.C.	Notes
0		2118	GL=7139
1819		299	KB=13ft
1820	1	298	Coal
1845		273	
1846	1	272	Coal
1880		238	
1881	1	237	Coal
1897		221	
1899	2	219	Coal
1936		182	
1937	1	181	Coal
1969		149	
1974	5	144	Coal
1976		142	
1979	3	139	Coal
1983		135	
1986	3	132	Coal
1991		127	
2006	15	112	Coal
2036		82	
2038	2	80	Coal
2104		14	
2105	1	13	Coal
2115		3	
2118	3	0	Coal
2118		0	Top PC
2189		-71	T.D.
Total Coal	38		

SE Durango	Coal	Above	
Fed 34.5 34-1	Th.	P.C.	
0		2	
1909			
1910	1		
1928			
1929	1		
1946			
1948	2		
2024			
2029	5		
2038			
2042	4		
2125			
2130	5		
2132			
2166	34		
2171			
2177	6		
2177			
2347		-1	
Total Coal	58		

Truman-	Coal	Above	
Baird 1-25	Th.	P.C.	
0		1	
1550			
1551	1		
1656			
1658	2		
1688			
1690	2		
1799			
1800	1		
1804			
1807	3		
1830			
1837	7		
1870			
1872	2		
1874			
1901	27		
1938			
1940	2		
1940			
7309		-53	
Total Coal	47		

NOTES: All measurements shown are in feet. Log depths in first column for each drill hole are measured from Kelly Bushing (KB).
PC = Pictured Cliffs Sandstone, T.D. = total depth, GL = ground level

Table 1-4. Geophysical log depths for coal beds in drill holes in Florida River, Carbon Junction, and Basin Creek areas; cross section A-A'

Table 1-5. Geophysical log depths for coal beds in drill holes on Florida River cross section B-B' and Carbon Junction cross section C-C'.

CROSS SECTION B-B' - - FLORIDA RIVER GAS SEEP AREA											
Truman-	Coal	Above		Huber-	Coal	Above		Huber-	Coal	Above	
Baird 1-25	Th.	P.C.	Notes	Nelson 2-31	Th.	P.C.	Notes	Dobbins 1-31	Th.	P.C.	Notes
0		1940	GL=7323	0		2003	GL=7077	0		2031	GL=7052
1550		390	KB=13ft	1831		172	KB=13.5ft	1897		134	Kb=13ft
1551	1	389	Coal	1832	1	171	Coal	1900	3	131	Coal
1656		284		1844		159		1921		110	
1658	2	282	Coal	1846	2	157	Coal	1926	5	105	Coal
1688		252		1847		156		1928		103	
1690	2	250	Coal	1848	1	155	Coal	1929	1	102	Coal
1799		141		1861		142		1938		93	
1800	1	140	Coal	1865	4	138	Coal	1943	5	88	Coal
1804		136		1908		95		1947		84	
1807	3	133	Coal	1909	1	94	Coal	1948	1	83	Coal
1830		110		1911		92		1978		53	
1837	7	103	Coal	1913	2	90	Coal	1979	1	52	Coal
1870		70		1945		58		1981		50	
1872	2	68	Coal	1958	13	45	Coal	1984	3	47	Coal
1874		66		1960		43		1996		35	
1901	27	39	Coal	1961	1	42	Coal	2008	12	23	Coal
1938		2		1987		16		2010		21	
1940	2	0	Coal	1994	7	9	Coal	2024	14	7	Coal
1940		0	Top Kpc	2003		0	Top PC	2031		0	Top PC
7309		-5369	T.D.	2102		-99		2134		-103	
Total coal	47			2104	2	-101	Coal	2136	2	-105	Coal
				2405		-402	T.D.	2140		-109	
				Total coal	34			2143	3	-112	Coal
								2281		-250	T.D.
								Total coal	50		

CROSS SECTION C-C' - - CARBON JUNCTION GAS SEEP AREA							
SE Durango	Coal	Above		Everett Jones	Coal	Above	
Fed. 4-1	Th.	P.C.	Notes	GU A-1	Th.	P.C.	Notes
0		2127	GL=	0		2492	GL=6876
1712		415	KB=14ft	2250		242	KB=13ft
1713	1	414	Coal	2254	4	238	Coal
1714		413		2268		224	
1715	1	412	Coal	2271	3	221	Coal
1814		313		2324		168	
1815	1	312	Coal	2329	5	163	Coal
1819		308		2334		158	
1824	5	303	Coal	2336	2	156	Coal
1961		166		2429		63	
1967	6	160	Coal	2435	6	57	Coal
1968		159		2437		55	
2004	36	123	Coal	2445	8	47	Coal
2010		117		2447		45	
2015	5	112	Coal	2480	33	12	Coal
2016		111		2485		7	
2018	2	109	Coal	2492	7	0	Coal
2108		19		2492			Top PC
2127	19	0	Coal	2606		-114	
2127		0	Top PC	2608	2	-116	Coal
2250		-123	T.D.	2733		-241	T.D.
Total coal	76			Total Coal	70		

NOTES: All measurements shown are in feet. Log depths in first column for each drill hole are measured from the Kelly bushing (KB). PC = Pictured Cliffs Sandstone, T.D. = total depth, GL = ground level.

Table 1-6. Geophysical log depths for coal beds in drill holes on Basin Creek cross section D-D'.

Indian Crk. SU-12U-2	Coal Th.	Above P.C.	Notes
0		2165	GL
1736		429	KB=6ft
1738	2	427	Coal
1821		344	
1822	1	343	Coal
1875		290	
1878	3	287	Coal
1881		284	
1888	7	277	Coal
1941		224	
1951	10	214	Coal
1952		213	
1956	4	209	Coal
2038		127	
2046	8	119	Coal
2048		117	
2053	5	112	Coal
2129		36	
2136	7	29	Coal
2137		28	
2148	11	17	Coal
2149		16	
2151	2	14	Coal
2152		13	
2165	13	0	Coal
2165		0	Top PC
2310		-145	T.D.
Total Coal	73		

Indian Crk. SU-12U-1	Coal Th.	Above P.C.	Notes
0		2425	GL
1874		551	KB=6ft
1875	1	550	Coal
2007		418	
2009	2	416	Coal
2097		328	
2098	1	327	Coal
2158		267	
2162	4	263	Coal
2168		257	
2171	3	254	Coal
2179		246	
2182	3	243	Coal
2184		241	
2194	10	231	Coal
2211		214	
2213	2	212	Coal
2313		112	
2324	11	101	Coal
2326		99	
2330	4	95	Coal
2332		93	
2334	2	91	Coal
2348		77	
2357	9	68	Coal
2396		29	
2398	2	27	Coal
2401		24	
2404	3	21	Coal
2406		19	
2412	6	13	Coal
2415		10	
2425	10	0	Coal
2425		0	Top PC
2675		-250	T.D.
Total Coal	73		

Isgar GU 1	Coal Th.	Above P.C.	Notes
0		2384	Gl
2031		353	KB=12ft
2032	1	352	Coal
2034		350	
2035	1	349	Coal
2100		284	
2102	2	282	Coal
2141		243	
2144	3	240	Coal
2159		225	
2161	2	223	Coal
2162		222	
2171	9	213	Coal
2200		184	
2203	3	181	Coal
2284		100	
2288	4	96	Coal
2292		92	
2297	5	87	Coal
2311		73	
2316	5	68	Coal
2317		67	
2321	4	63	Coal
2343		41	
2345	2	39	Coal
2363		21	
2370	7	14	Coal
2374		10	
2384	10	0	Coal
2384		0	Top PC
2600		-216	T.D.
Total Coal	58		

NOTES: All measurements shown are in feet. Log depths in first column for each drill hole are measured from the Kelly bushi
PC = Pictured Cliffs Sandstone, T.D. = total depth, GL = ground level.

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