GEOLOGIC MAP OF THE PINE CANYON QUADRANGLE, CARBON COUNTY, UTAH

By Paul B. Anderson

UTAH GEOLOGICAL AND MINERAL SURVEY
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INTRODUCTION

The Pine Canyon quadrangle is located in the western Book Cliffs, between Soldier Creek and Pace Creek (T. 12-14 S., R. 12 and 13 E.) and is northeast of Wellington and northwest of Sunnyside in Carbon County, Utah. Drilling has verified the presence of thick, mineable coal beds in the area of the quadrangle and has expanded the Book Cliffs coal field reserve base.

STRATIGRAPHY

General

The outcropping rocks of the Pine Canyon quadrangle range in age from Late Cretaceous to Tertiary (Eocene) and total approximately 1600 m (5300 ft) in thickness (Anderson, 1978). The oldest rocks are Upper Cretaceous and include (from oldest to youngest), the Mancos Shale, Star Point Sandstone, Blackhawk Formation and Price River Formation. Except for the Mancos Shale, the above-mentioned formations are included in the Mesaverde Group. Overlying the Mesaverde Group is the North Horn Formation which contains rocks of Late Cretaceous and Tertiary (Paleocene) age. Sequentially above the North Horn Formation are the Flagstaff Formation, Colton Formation, and Green River Formation, all of Early Tertiary age. There are no major disconformities in the area. Economic coals occur only in the Blackhawk Formation, the outcrops of which appear along the Book Cliffs. Thick Quaternary deposits are limited to pediment gravels and alluvium.

Cretaceous System

Mancos Shale. The Mancos Shale crops out in the southern one-third of the quadrangle where it has been exposed by erosion of the overlying beds. The best exposures are along Fish Creek and in the south-central portion of the quadrangle. The thickness was not measured by the author, but Clark (1928) gives a thickness of 1,433 to 1,539 m (4,700 to 5,050 ft) for the entire unit. The age of the Mancos Shale in east-central Utah ranges from Cenomanian to early Campanian (Maxfield, 1976). Within the quadrangle, the Mancos Shale is in contact with both the Star Point Sandstone and Blackhawk Formation, both Campanian in age.

The unit consists of gray to dark gray, slightly calcareous, gypsiferous and carbonaceous marine shale. Thin lentils of siltstone and very fine-grained calcareous sandstone are frequently found in the upper part of the formation. The top of the Mancos Shale is arbitrarily drawn where the non-resistant mudstone grades upward into interbedded siltstone and sandstone of the overlying Star Point Sandstone on the west and of the Blackhawk Formation on the east side of the quadrangle.

Star Point Sandstone. Regressive marine sandstone tongues above the Mancos Shale thin easterly into the marine mudstone of the Mancos Shale. The last surface exposures of one of these regressive marine sandstone tongues, the Star Point Sandstone are seen along the base of the Book Cliffs between Soldier Creek and Fish Creek. The thickness ranges from 53 to 70 m (173 to 229 ft) in surface exposures and apparently pinches out into the Mancos east of Fish Creek.

The Star Point Sandstone is composed of gray to gray-tan, very fine- to fine-grained, calcareous sandstone and gray to dark-gray siltstone and mudstone. The rock is thin- to medium-bedded, with the thickest sandstone being 1.2 m (4 ft) near Soldier Creek. The sandstone is intensely bioturbated, with some moderately well-preserved specimens of both smooth and plural curving tubes. An upper sandy unit contains concretionary, sandy structures that are better-cemented than the enclosing rock. The upper contact with the Blackhawk Formation is drawn at the first appearance of better cemented, interbedded sandy siltstone and sandstone.

Blackhawk Formation. The Blackhawk Formation is continuously exposed along the south-facing escarpment of the Book Cliffs from the west to the east edge of the quadrangle. From bottom to top, the Blackhawk Formation contains the Spring Canyon, Aberdeen, Kenilworth, lower Sunnyside and upper Sunnyside tongues, with the Aberdeen and Kenilworth tongues being the main cliff-formers. The Blackhawk has been found in the subsurface in all drill hole locations north of the outcrop and is known in the subsurface throughout much of the Uinta Basin on the north. The thickness on outcrop ranges from 370 m (1,215 ft) on the west to about 277 m (910 ft) on the east near Pace Creek. The formation thins easterly as the Spring Canyon tongue pinches out at the base of the formation.

Like the Star Point Sandstone, the Spring Canyon tongue thins and loses its identity in the Mancos Shale.

The Blackhawk Formation consists of a series of upward-coarsening littoral sequences (tongues) and associated non-marine (coal-bearing) rock, all of which are related to regressions of the Cretaceous sea. The Kenilworth tongue is a complete representation of the lithologies and sedimentary structures found in a typical regressive marine tongue. The base is slightly silty mudstone, gray to dark gray, slightly calcareous and carbonaceous, generally massively bedded and non-resistant. Above this is an intensely bioturbated unit consisting principally of sandy siltstone to very fine-grained, thin sandstone beds with interbeds of mudstone. Overlying this transitional unit is fine-grained, hummocky cross-stratified yellow-gray sandstone, that is thick- to massive-bedded, resistant and bioturbated. Next above is a fine- to medium-grained, trough cross-stratified, mildly bioturbated, resistant yellow-gray sandstone, deposited in a higher energy environment. The uppermost unit of the littoral tongue is a fine-grained, horizontally bedded, resistant sandstone that Young (1955) referred to as the "white cap." On fresh surfaces this sandstone is usually light to dark gray, depending on the amount of carbonaceous material it contains. This vertical sequence of beds can be found in all of the littoral tongues in the lower Blackhawk Formation, but the upper beds completing the sequence may or may not always be present.

The coal-bearing rocks lie over or between the tongues and consist of tan to gray, fine-grained, occasionally cross-bedded and ripple-marked sandstone, tan to gray siltstone, brown to gray mudstone, and black to dark-brown carbonaceous mudstone. All contain variable amounts of carbonaceous material, rare beds of well-preserved plant fossils, and fresh- to brackish-water molluscs. Coal beds are lenticular, and several are of mineable thicknesses. The coal-bearing rocks are generally moderately resistant to erosion.

The top of the Blackhawk Formation is in contact with the Castlegate Sandstone Member of the Price River Formation. In the Pine Canyon quadrangle, the contact appears conformable, but thickness variations in the Castlegate may indicate a disconformable relationship. The contact is mapped where the last thick occurrence of less resistant carbonaceous mudstone of the Blackhawk Formation meets the base of the resistant cliff-forming lower sandstones of the Castlegate.

Price River Formation (Castlegate Sandstone Member). The Price River Formation ranges in age from Campanian to Maestrichtian (Abbott, 1956, p. 122) and consists of a lower cliff-forming sandstone (Castlegate Sandstone Member) and an upper member of moderately-resistant sandstone and mudstone capped by another cliff-forming sandstone. The Castlegate Sandstone Member is found in continuous outcrop as a nearly vertical, generally south-facing cliff from west to east across the quadrangle. North of the outcrop, in the subsurface, it varies in thickness from 49 m (161 ft) to 87 m (286 ft). The variation in thickness of the Castlegate Sandstone may be related to an erosional surface at the top of the Blackhawk Formation (Table 1).

The Castlegate Sandstone is a fine-to medium-grained quartz sandstone that is very light gray to gray and weathers light tan-brown. The unit is cemented with clay and calcium carbonate and has moderate porosity. Sorting is poor, and rounding ranges from subrounded to subangular. The sandstone contains trough, planar, and some tabular cross-bedding, current ripples, convolute bedding, and small-scale graded beds 1 to 5 cm (0.5 to 2.0 in) thick. Locally, there are thin lenticular beds of siltstone and mudstone that contain abundant amounts of carbonaceous plant material. These finer-grained units are most common in the lower and upper parts of the section. Small pyritic nodules, clay intraclasts, and coal streaks and pods are also present in minor amounts.

The Castlegate Sandstone is fluvial in origin, positively skewed, slightly calcareous and is litharenite, sublitharenite, and quartzarenite (Van De Graaf, 1969). Van De Graaf (1969) found that the major clay minerals are kaolinite, illite, and montmorillite, and suggested that the source rocks were mostly of sedimentary origin.

The upper contact of the Castlegate Sandstone Member is placed at a break in slope, where the sandstone becomes finer-grained and interbedded with mudstone and siltsone, giving a "steppy" appearance in outcrop. This contact is sometimes difficult to map at the surface, but is fairly distinctive on the natural gamma logs.

Price River Formation (upper member). The upper member of the Price River Formation is also found in continuous outcrop along the Book Cliffs and is continuously present north of the outcrop in the subsurface. The lower portion is a moderately-resistant slope-former, and the upper portion is a

Table 1. Formation and interval thicknesses from drill hole data, Pine Canyon quadrangle.

	Drill hole No.: 3-1	4-1	4-2	8-1	9-1	9-2	10-1	11-1	14-1	15-1	15-2	16-1	17-1	22-1	Walton
Flagstaff Formation							(110)	(143)							(81)
							360*	470							265
North Horn Formation	(234)					(207)	(200)	(255)		(220)			(187)		(405)
	767					680	655	835		722*			615		1330
Price River Formation (total)	(179)	(119)				(172)	(185)	(221)		(176)	(158)		(162)	(167)	(236)
	588	652				563	608	725		577	517		531	549	775
Upper Member	(115)	(130)				(123)	(126)	(146)		(111)	(100)		(111)	(110)	(149)
	377	426				402	415	480		364	327		364	362	489
Castlegate Sandstone (Kcg)	(64)	(69)		(51)		(49)	(59)	(75)		(65)	(58)		(51)	(57)	(87)
	211	226		166		161	193	245		213	190		167	187	286
Top of the Lower Sunnyside tongue to base of Kcg	(109)	(97)	(96)	(103)		(100)	(82)	(87)		(86)	(102)		(97)	(96)	(101)
	356	319	314	339		329	268	285		283	334		319	315	330

* Incomplete thickness
( ) Interval thickness in meters
411 Interval thickness in feet

resistant cliff-former. The total thickness of the upper member varies from 100 m (328 ft) to 149 m (489 ft).

The lower slope-forming section of the upper member consists of mudstone and siltstone with some fine-grained sandstone and carbonaceous mudstone. These dark-gray to tan units are lenticular and grade into one another. The cliff-former at the top is a thick-bedded to massive, light-gray to very light-gray sandstone. The fair-sorted, mostly medium- to fine-grained sandstone is coarse and porous at the base and is upward fining. Grains are mostly quartz, subrounded to subangular, and moderately well-cemented. Some beds are calcareous, contain disseminated carbonaceous material, casts of tree stems and trunks, and minor bioturbation structures. The sandstone shows horizontal stratification, ripple marks, and trough cross-bedding. The thick and massive sandstone is broken by beds of gray to dark-gray mudstone and siltstone that are less resistant.

These uppermost sandstone beds normally appear on outcrop as three cliff-forming units, each separated by a thin slope-forming unit. Occasionally, these join to form one massive cliff. The top of the uppermost, laterally consistent, cliff-forming sandstone was chosen as the top of the Price River Formation. This contact has good topographic expression and is also traceable in the subsurface using geophysical logs.

Cretaceous-Tertiary System

North Horn Formation. The North Horn Formation lies conformably above the Price River Formation and crops out from west to east across the quadrangle. It is moderately resistant and forms steep slopes interrupted by occasional sandstone ledges. The thickness of the unit varies from 189 m (620 ft) on outcrop near Fish Creek to 405 m (1,330 ft) in the Walton well (SW Sec. 9, T. 12 S., R. 12 E.).

The North Horn Formation was deposited in fluvial and lacustrine environments (Weiss, 1969, p. 1105). Beds at the base of the formation are similar to the fluvial beds of the Price River Formation, but the sandstone is finer-grained and medium- to thin-bedded. The calcium carbonate content of the rocks increases upward in the section. Interbedded sandstone and gray to gray-green calcareous mudstone make up the lower one-half of the sequence. Sandstone beds throughout the unit are fluvial and frequently conglomeratic at the base, with an upward fining trend. The sandstone is gray to light-gray, with occasional "salt and pepper" beds. They weather brown and tan, contain minor amounts of plant detritus, and tree molds and casts. The sandstone beds are very lenticular, and exhibit lateral continuity from a few hundred feet to over 305 m (1,000 ft). Individual channel sandstones are up to 15 m (50 ft) thick.

Fine-grained rocks in the upper part of the formation include yellow-tan to gray marlstone containing small limestone nodules. Mudstone beds are calcareous, gray, gray-green, yellow-tan and purple, with varying amounts of coarse clastics. There are also rare beds of carbonaceous mudstone, and locally, in Soldier Canyon, there is a thin 9 cm (0.3 ft) bed of coal exposed.

Oncolites (algal balls) are found in at least two horizons of the North Horn Formation. Oncolites are present in the middle to upper part of the North Horn Formation in SENW Sec. 24, T. 13 S., R. 12 E., in a road cut, and three locations are found near the top of the unit, in SENESE Sec. 8, T. 13 S., R. 12 E., SWNENW Sec. 15, T. 13 S., R. 12 E., and SWNESE Sec. 15, T. 13 S., R. 12 E. The last location yielded the largest specimens, up to 8 x 15 x 18 cm (3 x 6 x 7 in), which were disc-shaped. Commonly, they range in size from 1 to 4 cm (0.5 to 1.5 in) in diameter (largest dimensions). The oncolites are in a pebble conglomerate which has a limy, argillaceous, sandstone matrix. The conglomerate is intraformational, containing generally yellow-tan, pebble-sized mudstone clasts.

The upper contact of the North Horn Formation is drawn at the base of the first relatively pure limestone bed, which is generally thin (0.3 to 0.9 m); 1 to 3 ft and fossiliferous. These limestone beds are somewhat continuous across the quadrangle, but occasionally grade into marlstone, making the contact difficult to trace. The North Horn Formation contains rocks of both Cretaceous and Tertiary age in the Wasatch Plateau to the west; very Late Cretaceous dinosaur bones are found in the lower North Horn and Paleocene mammals have been found in the upper part (Spieker, 1946, p. 134-135).

Tertiary System

Flagstaff Formation. The Flagstaff Formation has a large area of dip-slope outcrop at the top of the Book Cliffs. This area is wide on the northwest and narrows to the southeast on the quadrangle, because of eastward thinning of the Formation and a decrease in the amount of limestone in the section. Measured stratigraphic thicknesses of the unit range from 81 to 143 m (265 to 470 ft).

The formation is an interbedded sequence of sandstone, mudstone, marlstone, and limestone. The sandstone is fluvial in origin, lenticular calcareous, medium- to fine-grained, tan to brown on outcrop and gray to gray-green when fresh. The mudstone is dominantly gray-green and calcareous, and red-variegated toward the top of the formation. The limestone beds are thin, not ever more than one meter thick. The limestone beds are generally fossiliferous and contain fresh water gastropods, pelecypods, and ostracods.

The Flagstaff Formation forms a moderate dip-slope at the top of the Book Cliffs, with the upper beds of limestone and calcareous sandstone protecting and slowing the retreat of the cliffs. This protective cap is less effective at the extreme eastern edge of the quadrangle. From Pace Creek eastward, the Flagstaff and North Horn Formations were combined and mapped as the North Horn Formation by Stokes and Madsen (1961). The upper contact of the Flagstaff Formation with the Colton Formation is drawn at the top of a sequence of thin-bedded, greenish-gray, sandstone beds and is well-marked by a break in slope at the base of the Roan Cliffs. The Flagstaff Formation is considered Paleocene in age, but the upper beds may extend into the Eocene (Spieker, 1946).

Colton Formation. The main outcrop of the Colton Formation is in the north-east quarter of the quadrangle. A few isolated outcrops are present to the west on the dip of the Flagstaff Formation. The thickness of the Colton Formation is about 405 m (1,330 ft) within the quadrangle. Because of broken outcrop exposures, the thickness is approximate.

The unit consists of sandstone that is gray-green, tan to light reddish-brown, mostly fine-grained, calcareous, with occasional thin clay and marlstone clast conglomerates at the base. The sandstone is generally lenticular and resistant, sometimes interbedded with mudstone or siltstone, and appears to be fluvial. Local beds show moderate to intense bioturbation, and burrows are usually large and less distinct than those found in Cretaceous marine rocks. One sandstone bed contains vertical burrows more than one meter in length.

In the upper and lower portions of the formation, the mudstone and siltstone predominate over the sandstone. The mudstone is mostly dark reddish-brown in color, with some variegated grays, greens, and yellows. The mudstone is usually calcareous and non-resistant, frequently grading into siltstone. The Colton Formation is considered late Paleocene to early Eocene in age (Fouch, 1976, p. C5-C6).

Green River Formation. The Green River Formation has an outcrop of less than 2.59 square kilometers (one square mile) in the extreme northeast corner of the quadrangle. Since the formation has a limited outcrop, it was not measured, but ap-

Table 2. Summary of depositional environments and their characteristics.

Depositional environment	Characteristics				
	Grain size	Structures	Color light to dark	Organics/ Bioturbation	Fossil's P = plant M = Mollusc
Terrestrial					
Swamp	mud silt	thin and irregular bedding	dark	Coal, carbonaceous mudstone, rare bioturbation	abundant P
Fluvial - channel	most fine	cross and horizontal stratification, current ripples, convolute-bedded, intraclasts	light to medium	slightly to moderately carbonaceous and bioturbated	moderate P, but well preserved
Oxidized - Over-bank	fine to mud	convolute, irregular-bedding; minor cross and horizontal stratification and ripples	light to dark	moderately carbonaceous and bioturbated	occasional P
Transitional					
Restricted Marine	fine to mud	contorted and convolute bedding, parallel - tabular units, wave and current ripples, horizontal to cross laminae	light to dark	moderate to non-carbonaceous, moderately bioturbated	occasional P locally abundant M
Marine					
Foreshore	fine with medium	horizontal to slightly inclined bedding, rare trough cross stratification	light to medium	moderately to slightly carbonaceous, rooted, rare bioturbation	rare P and M
Upper Shoreface	fine to medium	dominately trough cross-stratified	light	slightly bioturbated, dominant *Ophiomorpha*, rare carbonaceous material	rare P and M
Lower Shoreface	fine-very fine	horizontal to hummocky cross-stratification	light to medium	slightly carbonaceous, intensely bioturbated	rare P
Transition	light to mud	interbedded sandstone and siltstone thin horizontal bedding, rare cross-laminations	medium to dark	intensely bioturbated, *Orphiomorpha, Teichichnus, Thalassinodes*	
Offshore	silt to mud	horizontally bedding	dark	mildly bioturbated to non-bioturbated	

Source: Anderson (1978)

within a system of predominantly wave-dominated deltas.

Marine Environments. Offshore deposits consist of dark gray (weathered) to black (fresh) horizontally bedded mudstone and silty mudstone that is best exemplified by the Mancos Shale and its westward-extending tongues in the Blackhawk Formation. Occasional thin beds (after Campbell, 1967) of very fine-grained sandstone are also present and were probably derived from beach sands carried offshore during storms. They show hummocky cross-stratification and cross-bedding. Offshore deposits are calcareous to non-calcareous and bioturbated, but individual ichnogenera have not been

proximately 152 m (500 ft) of section is exposed.

Fresh-water limestone and grayish-green calcareous mudstone are the predominant lithologies. The limestone is thin- to medium-bedded and contains abundant fresh-water gastropods, ostracods and pelecypods. The limestone beds are resistant to non-resistant and the mudstone is non-resistant. The contact with the underlying red mudstone of the Colton Formation is drawn at the first thick, gray-green mudstone which is locally followed by a coquina of ostracods. The Green River Formation is Eocene in age (Abbott and Liscomb, 1956).

Quaternary Surficial Deposits

Pediment Gravels. Pediments, with gravel veneers, are especially well-developed in the area below the Book Cliffs escarpment. They are found west to east across the quadrangle, varying in age and elevation. The thickest and coarsest accumulations — up to 15 m (50 ft) thick — lie near the cliffs, and gradually thin southward. Nevertheless, a substantial fraction of boulders are found in the gravels throughout the quadrangle. The pediment gravels of Book Cliffs origin are partially cemented with calcium carbonate, poorly stratified and sorted, and range in size from large boulders to clay.

Alluvium. Younger than the pediment gravels, this unit consists of poorly stratified clays, silts, and some gravels. Alluvium is distributed principally in the drainages that lie between the pediments. There is also a rather thick deposit on the dip slope at the base of the Roan Cliffs. This material is red, muddy silt that can be traced in the bottom deposits of Soldier Creek, well below the base of the Book Cliffs.

STRUCTURE

The Pine Canyon quadrangle straddles the boundary between the Mancos Lowland and the Book Cliffs-Roan Plateau physiographic subprovinces (Stokes, 1977, p. 2). The San Rafael Swell, and locally, the Farnham anticline influence the structure of the quadrangle, although both features are south of the quadrangle.

The regional structure of the Book Cliffs from Price to Green River curves around the north plunge of the San Rafael Swell. The strike on the quadrangle changes from N 82° W on the west to N 60° W on the east, paralleling the approximate strike of the Book Cliffs escarpment. The dip averages about 8 degrees northeast across the quadrangle, but ranges from 6.2 to 11.5 degrees.

Faulting in the Pine Canyon quadrangle is minor. A small fault with a two-foot displacement was found in the salient between the right and left forks of Fish Creek. The fault was traced for 60 to 90 m (200 to 300 ft) along a 55 cm (1.8 ft) thick brecciated zone filled with large calcite crystals. The strike of the fault (N 83° W) parallels the regional strike and the dominant fracture direction. The fault is probably related to slumping or the breaking away of large blocks of resistant rocks from the cliff face. The softer Mancos Shale is deeply eroded below. In the northeast quarter of the quadrangle are several obvious lineations that run along and north of the Roan Cliffs escarpment. These are mapped as probable faults by Clark (1928), but in field checking, visible displacement (8 m; 25 ft) was revealed in only one.

Fracturing parallels the structure and is the result of San Rafael Swell upwarping and isostatic adjustments. In Pine Canyon and in the previously mentioned area north of the Roan Cliffs the fracture pattern is well exhibited.

DEPOSITIONAL ENVIRONMENTS OF THE BLACKHAWK FORMATION

Introduction

The depositional environments of rocks from the Blackhawk Formation in the Pine Canyon quadrangle are divided into three major groups: marine, restricted marine, and terrestrial. These depositional environments are summarized and characterized in Table 2. Within the marine group, five minor or subenvironments are recognized - foreshore, upper shoreface, lower shoreface, transition, and offshore (after Harmes, 1975) - all of which are associated with regressive shoreline deposits. The foreshore, upper shoreface, and lower shoreface beds are dominantly sandstone, and differentiation of the three in drill cores or on geophysical logs is often highly subjective. The restricted marine environment, which includes all dominantly brackish water subenvironments (lagoons, bays, estuaries, washover fans, infilling), represent a transitional condition. Terrestrial deposits originated from swamp (reducing), fluvial-channel, and oxidized-overbank environments. These environments of deposition of the Blackhawk Formation are economically important, considering their swamp forming and swamp restricting properties.

Balsley (1980) has measured sections along the entire escarpment of the western Book Cliffs and integrated this data into a regional depositional setting for the Blackhawk Formation. He interprets the rocks of the Blackhawk Formation as deposited

distinguished. The offshore facies is abundantly represented in the lower part of the Blackhawk Formation, both below and above the sandier, regressive littoral marine sequences, i.e., the base of the Aberdeen, Kenilworth, and upper Sunnyside tongues. At the base of the upper Sunnyside tongue, the offshore mudstone is an excellent subsurface marker bed for correlation purposes. The offshore facies are distinctive in cores (black mudstone) and also on geophysical logs. The resistivity curve shows a peak at the base of the facies, the SP curve shows either a peak or a sharp change, and the natural gamma log count decreases markedly (Figure 1).

The transition facies are gradational from the mudstone of the offshore facies to the sandstone of the lower shoreface. Interbedded, very fine-grained to fine-grained gray sandstone and dark-gray silty mudstone are the dominant rocks. The transition facies is intensely bioturbated and devoid of bedding features. Sandstone beds display less bioturbation and are hummocky cross-stratified to horizontally stratified. In sandy and silty beds, trace fossils such as *Teichnichnus*, chevron trails, smooth tubes, *Asterosoma, Thalassinoides, Chondrites,* and *Zoophycus* have been recognized. Small amounts of carbonaceous material (plant detritus) are also present.

The lower shoreface facies is represented by fine-grained sandstone, tan when weathered and gray to dark-gray in cores. The sandstone is horizontal- to hummocky cross-stratified and massive. Comparable to the transition facies, the lower shoreface rock is intensely bioturbated, but trace fossils are usually better preserved. Several ichnogenera are recognized, i.e., *Ophiomorpha*, smooth and plural curving tubes, and *Asterosoma*, along with numerous unidentified burrows. In cores, the bioturbation is easily recognizable, but identification of specific trace fossils is more difficult. Within a littoral sequence, the lower shoreface rocks are the most common and usually the thickest of all the marine facies, excluding the offshore deposits. They are found in all the littoral tongues above the Spring Canyon. This facies is difficult to distinguish from the overlying upper shoreface and foreshore on subsurface geophysical logs. Occasionally the SP or resistivity curve shows a slight change at the upper contact. This facies is a resistant cliff-former and is well-exposed across the entire quadrangle.

The upper shoreface beds were deposited in a high energy surf zone environment which gives the upper shoreface beds their distinguishing characteristics. This is the coarsest facies; fine- to medium-grained, trough cross-stratified sandstone is dominant. Set heights are about 15 to 60 cm (6 in to 2 ft) and show low-angle cross-stratification. Paleocurrent measurements taken from surface sections in the upper shoreface show predominantly a bi-modal direction (Balsley, 1977, personal communication). The sandstone is tan to tan-gray when weathered and gray in cores, it is slightly argillaceous, moderately porous, calcareous to non-calcareous (more frequently the latter), and contains only a small amounts of carbonaceous material. These beds are moderately bioturbated and the trace fossil is almost exclusively *Ophiomorpha.* The contact with the underlying lower shoreface is well-defined and shows no intertonguing. In cores, the lower contact is difficult to pick, but is placed where the dominantly cross-bedded, fine- to medium-grained upper shoreface sandstone changes to a horizontally-stratified, fine-grained, darker, bioturbated lower shoreface sandstone. On outcrop, the upper shoreface sandstone is part of the typical, near-vertical cliff.

Foreshore deposits are mostly fine-grained sandstone containing slight to moderate amounts of carbonaceous material. This facies is horizontally stratified with very minor amounts of cross-stratification. When weathered, the foreshore facies are sometimes lighter in color than the lower and upper shoreface. Young (1966, p. 13) described the light-weathering foreshore deposits as "white cap" and suggested it was caused by acid waters from the overlying coal swamps percolating down through the beach sediments and leaching out the iron, or reducing the feldspars to kaolin clays. The "white cap" is not, however, an infallible guide in prospecting for thick coals directly above, but merely an indication of reducing environments (such as restricted marine or swamp) overlying it. A similar "white cap" effect has been observed in fluvial sandstone near Soldier Canyon. The upper foreshore sandstone commonly contains roots from the overlying nearshore vegetation. The lower contact with the upper shoreface is sharp, shows no intertonguing, and indicates the tidal range was probably less than a meter (Clifton, 1975). The foreshore facies is usually present at the top of the cliff-forming, regressive marine tongues, but may be missing because of non-deposition or erosion by a transgression or by a fluvial or tidal channel. Identifiable trace fossils are rare. In the Soldier Creek area a bivalve fauna was found. The geophysical log

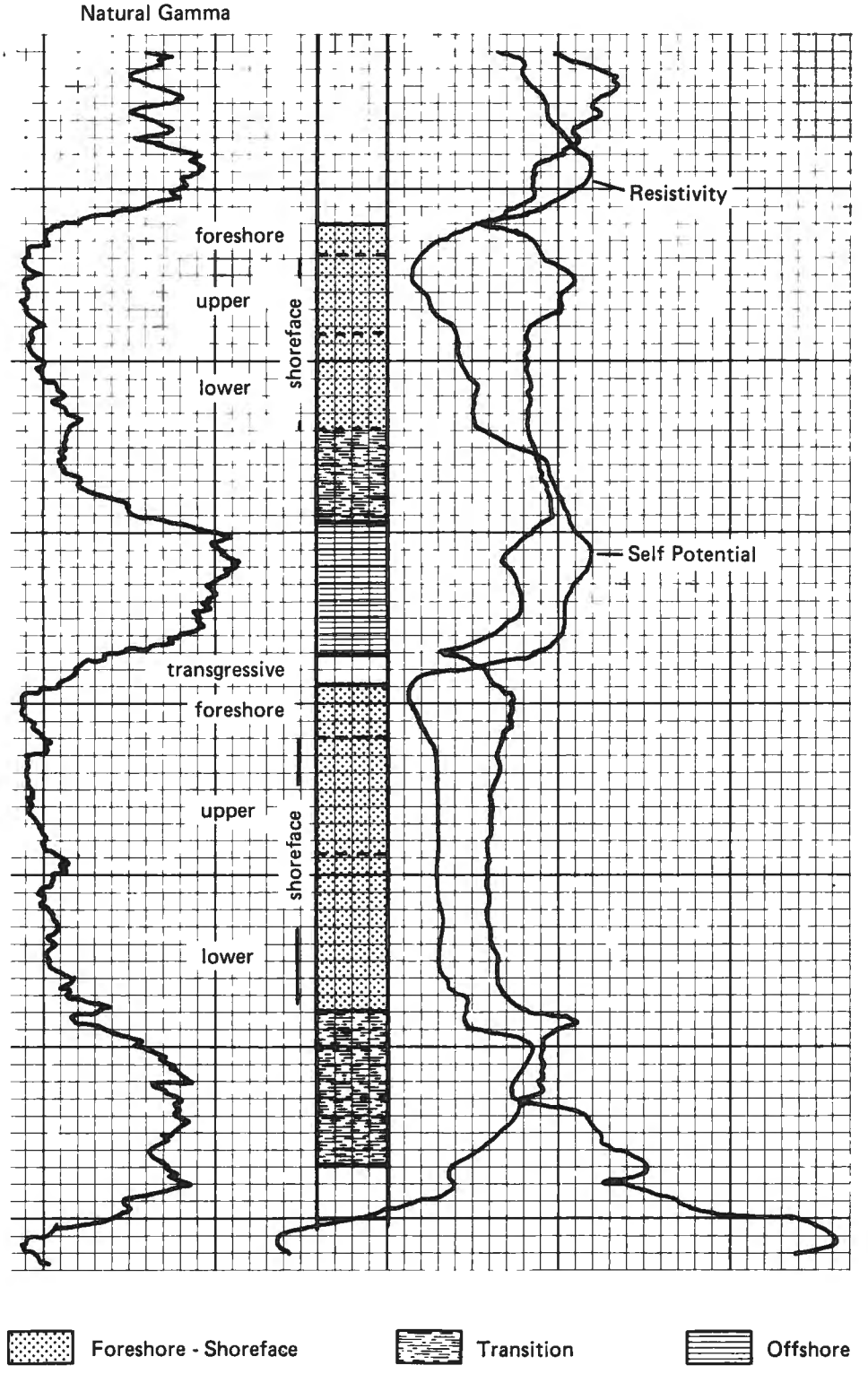

Figure 1. Response of geophysical logs from drill hole 15-1 to the various marine facies (scale 1" = 20').

characteristics are similar to the shoreface environments (Figure 1).

Restricted Marine Environment. This environment includes lagoons, brackish swamps or lakes, estuaries, infilling deposits and small channels. Washover deposits are also grouped into this category. Restricted marine rocks are heterogeneous because of the diversity of subenvironments. Rocks vary from fine- to medium-grained sandstone to mudstone with most in the silt- to mud-size range. Colors range from light to dark gray, with tan and brown weathered surfaces. The sandstone beds are generally tabular and horizontal to ripple-laminated, moderately cross-bedded with moderate amounts of carbonaceous material, chiefly on bedding planes. Bioturbation in restricted marine rocks is common and is sometimes intense. These sediments are generally cemented with calcium carbonate. The presence of brackish water molluscan fossils is the most reliable method for identification of rocks from this environment.

Exposures of the restricted marine facies are often moderately-resistant and form a step-like profile. Within the quadrangle, outcrops are restricted to the middle and upper portions of the Blackhawk Formation. Restricted marine facies overlie the foreshore facies of the Kenilworth and upper Sunnyside tongues throughout the quadrangle. Restricted marine facies frequently lie above and below coal beds, exemplified by the Kenilworth coal zone. The "contact" with the overlying coastal plain fluvial-swamp rocks exhibits considerable intertonguing.

Terrestrial Environments. Swamp deposits are characterized by mudstone and siltstone, which are dark gray to black in color, generally very carbonaceous, often pyritic, and contain abundant plant fragments and coal. Sideritic beds and pods are occasionally found in or associated with swamp facies. The distinction between beds of a swamp environment and of a restricted marine environment is sometimes difficult to make, but large amounts of carbonaceous mudstone and the absence of molluscan fossils in the swamp environment are the main criteria distinguishing the two. At least part of the swamp facies (the coal), is readily detectable on geophysical logs (Figure 2). Swamp facies distribution is of significant economic importance because they contain the coal beds. Rocks of this environment occur from the Kenilworth coal to the top of the Rock Canyon coal, and above the restricted marine deposits overlying the upper Sunnyside tongue. Swamp facies in the quadrangle are lenticular and often discontinuous.

Fluvial-channel deposits are dominantly fine-grained sandstone with some siltstone and mudstone. Most fluvial sequences show a fining upward in grain size. The color of the sandstone is generally light-tan to brown when weathered and light gray in cores. The finer-grained mudstone and siltstone are darker in color. Cross-bedding, current ripples, horizontal-bedding, contorted bedding and mudstone intraclasts are also characteristic of a fluvial deposit. A moderate amount of carbonaceous material is usually present in these deposits, as well as a few worm burrows. One specimen of *Sabalites* was found in a fluvial sandstone in Pace Canyon, and many fluvial sandstone beds contain macerated plants as well as finely preserved specimens. Tree trunk impressions or casts are often observed in this facies. Two point bar sequences have been recognized on outcrop in the area, one in Soldier Creek and the other in Dugout Canyon. Fluvial sandstone beds are generally lenticular, but may also be laterally continuous. This facies can be confused with other sandy facies such as shoreface or possibly sandstone of the restricted marine facies; therefore the stratigraphic position must be carefully examined. Fluvial rocks are present above littoral sequences and above or within restricted marine rocks in the middle and upper parts of the Blackhawk Formation. There is an apparent thickening of fluvial sandstone beds in the eastern part of the quadrangle.

The oxidized-overbank facies is by far the most difficult to interpret. The rocks are mostly devoid of dark to black colors and are fine-grained to very fine-grained sandstone and gray mudstone. The coarser rocks are probably representative of splays and crevassing of channel banks. These sequences are recognized by their characteristic upward coarsening. The gray mudstone and siltstone are representative of a well-drained swamp above the ground-water level and, hence, are oxidized rather than reduced. Both overbank and oxidized rocks contain a small amount of carbonaceous material, are normally plane to convolute bedded, with minor cross-bedding and current ripples. Thin, even laminae are sometimes present in the oxidized-facies overbank, as is occasional bioturbation. Geophysical logs are generally of little help in identifying beds of this environment. The natural gamma log can be helpful in indicating an upward coarsening trend by showing a change from a high count to a moderate

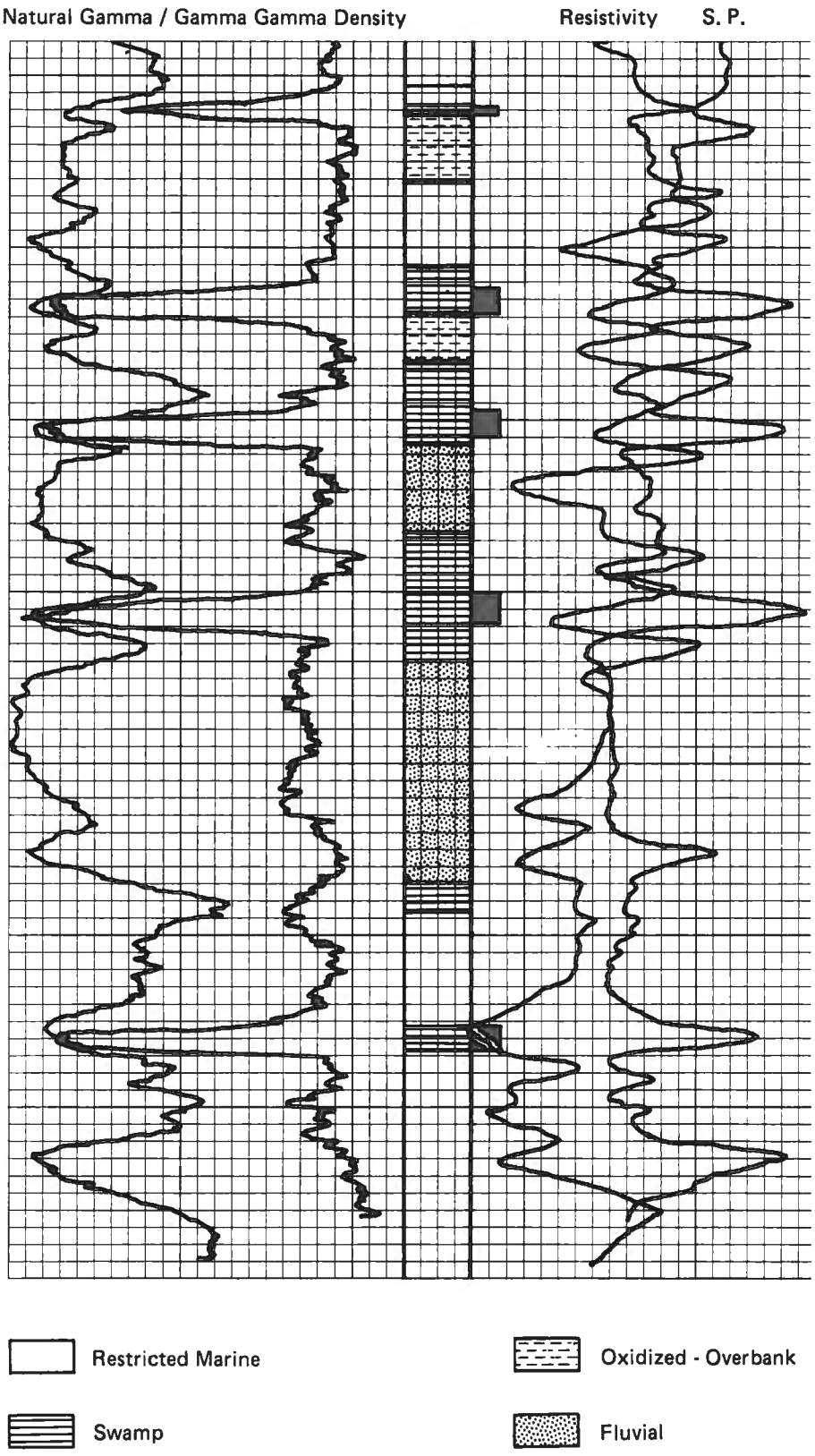

Figure 2. Response of geophysical logs from drill hole 10-1 to restricted marine and terrestrial facies (scale 1" = 20').

or low count. The occurrence of oxidized-overbank facies is dominantly associated with fluvial-channel and swamp facies. The oxidized-overbank facies are lenticular and rarely correlatable between drill holes and outcrop sections.

COAL

Introduction

The coal beds in the Pine Canyon quadrangle are present in the middle 90 m (300 ft) of the Blackhawk Formation. The coals all exhibit lenticularity and correlation is difficult. The coals occur in zones, five of which show lateral continuity; they are, from bottom to top, Kenilworth, Gilson, Fish Creek, Rock Canyon and Sunnyside. The nomenclature for the coal zones is from Clark (1928, p. 26-81).

The coal beds were studied both at the outcrop and by drilling into the subsurface. Coal outcrops are in poor to good condition, depending on the enclosing rocks, cover and vegetation, and the amount of natural burning that has taken place. Coal beds normally are best exposed in or near the bottoms of canyons; those on salients or on ridges are generally badly burned. Coal that has burned on the outcrop leaves the surrounding (chiefly overlying) rocks a rose color (coal bloom), because the heat oxidizes their iron content. The heat generated by the burning bakes and hardens the mudstone.

Kenilworth Coal

The Kenilworth coal zone is stratigraphically the lowest zone in the quadrangle. It is the easiest coal to map on the outcrop because of its stratigraphic position relative to the underlying, prominent cliff-forming Kenilworth Sandstone tongue. The coal lies from several centimeters to about 10 m above the Kenilworth Sandstone and is seldom burned. The coal attains a maximum thickness of 85 cm (2.8 ft) on outcrop and is therefore of little commercial value. The coal, where tested, is also thin in the subsurface.

The Kenilworth coal zone is present within restricted marine beds, indicating deposition near the strandline. Kenilworth coal beds are difficult to correlate in the subsurface. Coals within the zone consist of localized discontinuous beds, which were deposited in an area of fluctuating subenvironments within the restricted marine environment behind the Kenilworth beach. This evidence is not particularly supportive of a barrier bar system, which typically would have large, laterally continuous lagoons and associated coal developed behind the system.

Gilson Coal

The Gilson coal lies an average of 16 m (53.3 ft) above the Kenilworth coal zone, but there is a great deal of variance from that mean. Seam thicknesses vary from less than 30 cm (1 ft) in the Soldier Creek Canyon area to over 5.5 m (18 ft) in the Walton Well in the northwest corner of the quadrangle. The isopach map of the Gilson coal zone (Plate 1), reveals an east-west trending "want" (thinned coal) area. The two-foot isopach is continuous eastward from the western map edge (Sec. 18, T. 13 S., R. 12 E. to Sec. 11, T. 13 S., R. 12 E.), leaving a strip of thinned coal about 8 km (5 mi) long. Both north and south of the "want" the coal thickens appreciably. West and north of Pace Creek the Gilson zone coal thickens to over 4.6 m (15 ft) and contains only minor partings. Elsewhere thick partings are common in the coal zone causing complex correlation problems. Especially complex correlation problems are encountered where the coal splits and thins across the "want" area.

Cross-sections (Plate 2) illustrate a possible correlation for the zone. Small vertical fluctuations were noted in the drill holes, giving a "rollercoaster" effect. Coal "rolls" are commonly encountered in mining Book Cliffs coals (e.g., Soldier Creek mine and Sunnyside mine), hence, a certain amount of "rollercoaster" correlations are believable. Coal beds are also lenticular and can pinch out.

The Gilson coal zone generally marks a temporary end of restricted marine conditions. Above the Gilson zone, rocks consist of fluvial-channel, oxidized overbank, and swamp facies, indicating continued regression or a relative shift to landward environments. The area was dominated by the more landward coastal plain environments until the time of deposition of the Rock Canyon coal. The stratigraphic interval between the Gilson and the Rock Canyon coal zones is thicker over the "want" area and most of the drill holes in the area of the "want" also show an increased thickness of restricted marine rocks below the Gilson coal. In addition, there is an increased percentage of sandstone in the interval between the Gilson zone and the overlying Rock Canyon zone. The greater percentages of sandstone, the thicker rock intervals, and the thinned coal beds in the area of the "want" suggest increased fluvial deposition and local subsidence.

The Gilson coal zone has been commercially worked at the Dugout Canyon mine in a 2.5 m (8 ft) bed. The only other attempt at mining the coal was in Fish Creek Canyon where a cut in the side of the

Table 3. Summary of coal analyses from 1975 drill hole cores, proximate as received and moist, mineral-free Btu determinations.

	Ash %	Sulfur %	Btu/lb.	Moist-Mineral Free Btu
Sunnyside	12.09	0.65	12,080	13,806
Rock Canyon Seam	10.10	0.85	12,061	13,419
Gilson Seam	8.81	0.55	12,529	13,771
Average	10.07	0.70	12,230	13,665

Table 4. In-place coal reserves on the Pine Canyon quadrangle for coal beds greater than 4 feet thick and under less than 3,000 feet of cover in short tons.

Zone or bed	Measured	Indicated	Inferred	Total
Sunnyside	19,978,000	56,845,000	16,195,000	93,018,000
Rock Canyon	38,629,000	94,835,000	16,271,000	149,735,000
Gilson	32,895,000	91,441,000	22,639,000	146,975,000
Totals	91,502,000	243,121,000	55,105,000	389,728,000

Table 5. Gas content from three seams, Pine Canyon quadrangle.

Zone or Bed	Hole	CC/Gram Coal	Cubic Feet/ Ton of Coal		Seam Potential (in million cf)
Sunnyside	4-1	4.57	146		13,580
Rock Canyon (upper)	4-2	2.70	86	(129.5 avg.)	19,391
Rock Canyon (lower)	4-2	5.42	173		
Gilson	10-1	1.25	40		5,879
Total					**38,650**

canyon has exposed a bed and a "dog hole" entry was started.

Fish Creek Coal

Maximum thickness of the Fish Creek coal zone was measured by Clark (1928) as 160 cm (5 ft 2 in) of coal, exclusive of a 15 cm (0.4 ft) parting. This measured section is located about 300 m (1000 ft) southeast of outcrop section 16 (Plate 1). Clark (1928) states that the coal is traceable westerly into T. 13 S., R. 11 E., but it either merges with the overlying Rock Canyon zone or pinches out to the east. This pinching out or merging of the Fish Creek zone takes place between Dugout Canyon and Pace Canyon. The Fish Creek zone also loses its identity to the northwest in the subsurface. Its coal beds are generally too thin to mine within the quadrangle (utilizing four feet as the limit of mineable coal).

The Fish Creek zone lies in terrestrial beds 5 to 14 m (16 to 45 ft) above the Gilson zone. This writer found the thickness ranges from 0 to 1.4 m (0-4.5 ft) and the zone generally contains two or more lenticular seams that are complexly split. On outcrop, the zone is difficult to trace and identify, due in part to its proximity to the Rock Canyon zone and also to the lack of adjacent marker beds.

Rock Canyon Coal

The Rock Canyon coal was named for a small mine in Rock Canyon, located east of the quadrangle. Whether coal in Rock Canyon is actually continuous with that in the quadrangle is questionable. This particular zone is found throughout the quadrangle and provides the largest coal reserve. Coal seam thicknesses vary from 80 cm to over 3.7 m (2.7 to over 12 ft). The thinnest Rock Canyon coal beds are in the same area as the thin beds in the Gilson zone "want" (see isopach maps, Plate 2). However, the Rock Canyon zone "want" turns to the south-southwest at its western end and this may be related to an adjustment of paleostream courses. To the west and north of the Rock Canyon "want" the coal zone thickens rapidly; to the east and south the coal zone thickens as well, but the

splitting of the seam increases. It is interesting to note that there is a thick fluvial sandstone that rests directly on the Rock Canyon coal bed, 2.5 m (8.4 ft) thick, in Pace Creek Canyon which shows that the presence of a thick fluvial sequence above the Rock Canyon zone is not necessarily an indicator of thin coals below.

Mining developments in the Rock Canyon coal zone have been and are more extensive than in any other zone in the quadrangle. Entries have been developed where the coal intersects the three largest drainages; Soldier Canyon, Dugout Canyon, and Pace Canyon. The Soldier Creek mine is the only one presently in operation.

Sunnyside

The Sunnyside coal zone gets its name from well-developed exposures in the Sunnyside, Utah area, where coal has been mined since the late 1800's. Clark (1928, p. 34) divided the zone into upper and lower Sunnyside coal beds, but the upper of these two is so indistinct and thin within the Pine Canyon quadrangle that Clark's nomenclature is of no value. The base of the Sunnyside zone lies 39 to 57 m (128 to 186 ft) above the top of the Rock Canyon coal zone. The rocks in the interval are almost entirely marine (Sunnyside tongues), with the exception of the restricted marine rocks above and below the tongues and local fluvial facies. The Sunnyside coal zone in the quadrangle lies above the upper Sunnyside tongue rather than the lower tongue, as it does at Sunnyside, Utah (Balsley, 1980).

The Sunnyside coal beds are thickest in the northwest corner of the quadrangle (Plate 2), where drill holes encountered a seam of 3.5 m (11.5 ft). The coal is thin along the outcrop, never exceeding 92 cm (3 ft). Burning of the Sunnyside zone is second in severity to the Gilson coal zone. There are no mines operating in the Sunnyside zone within the quadrangle. An old wooden chute remains from an unsuccessful attempt to develop the seam near the Soldier Creek mine. Very thin and lenticular coal beds are found 15 to 23 m (50 to 75 ft) above the main Sunnyside coal zone on the Pine Canyon quadrangle.

Quality, Reserves and Gas Content

The coals of the Pine Canyon quadrangle are ranked as high volatile B bituminous. A generalized proximate analysis and Btu content of the coal is given in Table 3. Coal reserves were calculated for the Sunnyside, Rock Canyon and Gilson coal zones (Table 4). The coal resource classification system (1976) as developed by the U.S. Geological Survey and U.S. Bureau of Mines, was used in designating reserves; measured, indicated and inferred. Acreage estimates were made with a planimeter using the three isopach maps (Plate 2) of the coal zones. Only coal beds greater than 1.2 m (4 ft) and under less than 915 m (3000 ft) of cover are included in the reserve figures. In Dugout and Soldier Creek Canyons, previous mining activities have removed 6,527,000 short tons of coal from the quadrangle. Mined out acreage of the Soldier Creek mine used to determine the production was related to maps that pre-date its 1976 re-opening. Each coal zone was tested for methane gas content inasmuch as the area coals have been designated as "gassy." The lost gas, desorbed gas and residual gas were determined and the results tabulated in Table 5.

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UTAH GEOLOGICAL AND MINERAL SURVEY

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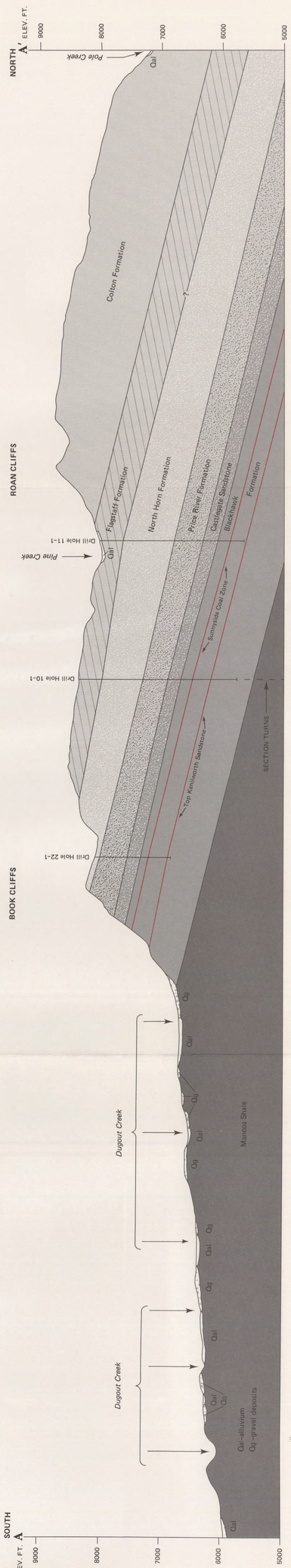
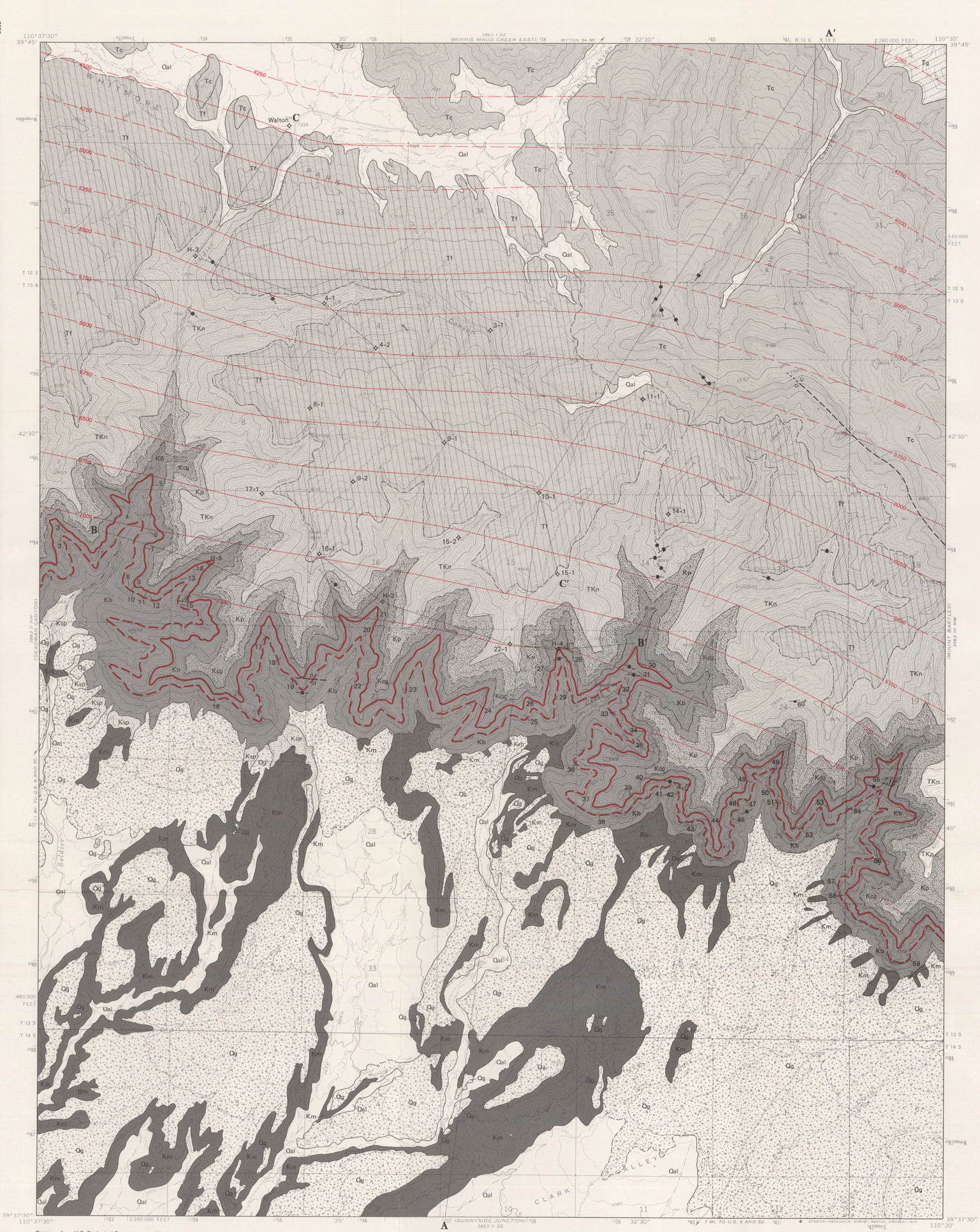
Map 72
Miscellaneous Series
Geologic Map of the Pine Canyon Quadrangle





SYSTEM	SERIES	FORMATION	SYMBOL	LITHOLOGY	THICKNESS IN FEET	DESCRIPTION
QUATERNARY		Alluvium	Qal			silty material in valley bottoms
		Pediment gravels	Qg			gravels, fluvial and colluvial, large boulders to clay sized particles, planar deposits derived from the retreating Book Cliffs
TERTIARY	Eocene	Green River Formation	Tg			limestone, fresh water, interbedded with mudstone, gray-green, fossiliferous (not measured)
		Colton Formation	Tc		1346–?	sandstone, gray-green to red-brown, fine-grained, interbedded with mudstone, variegated, and siltstone, red-brown
	Paleocene	Flagstaff Formation	Tf		290–480	interbedded sandstone, tan, limestone, gray, mudstone, variegated, and marlstone; forms dip-slope capping the Book Cliffs
CRETACEOUS	Danian	North Horn Formation	TKn		600–1330	sandstone, tan, upward fining, with interbeds of siltstone, gray to gray-green, mudstone, marlstone, and thin impure limestone beds in the upper portion of the formation
	Maestrichtian	Price River Formation upper member	Kp		520–775	upper – sandstone, gray, fine to medium grained, upward fining, cliff forming unit lower – sandstone, gray to dark gray, interbedded with mudstone, slope forming unit
		Castlegate Sandstone	Kcg		160–285	sandstone, gray to tan, fine to medium grained, resistant, braided stream deposit
	Campanian	Blackhawk Formation	Kb		910–1215	interbedded sandstone, light to dark gray and tan, siltstone, mudstone, and coal, marine and non-marine units containing the Kenilworth, Gilson, Fish Creek, Rock Canyon, and the Sunnyside coal zones interbedded sandstone, siltstone and mudstone, gray to tan, offshore and nearshore marine units (Spring Canyon, Aberdeen, and Kenilworth tongues)
		Star Point Sandstone	Ksp		0–230	interbedded mudstone, siltstone, and sandstone, gray to dark gray and gray-tan, calcareous, marine
		Mancos Shale	Km			mudstone and siltstone, gray to dark gray, calcareous, gypsiferous, marine

SYMBOLS

Contact
Dashed where inferred

Normal Fault
Dashed where approximately located; dotted where concealed. U, *Upthrown side;* D, *Downthrown side.*

Measured Section Traverse

Bedding Strike and Dip

Vertical Jointing

Jointing Strike and Dip

Drill Hole

37— Location of Coal Measurement
(See Plate 1 for thickness)

Sunnyside Coal Zone

Top Kenilworth Tongue

5250 Structure Contour
Drawn at the base of the Sunnyside Coal contour interval 250 ft

LOCATION MAP

MAP 72 — MISCELLANEOUS SERIES

GEOLOGIC MAP OF THE PINE CANYON QUADRANGLE CARBON COUNTY, UTAH

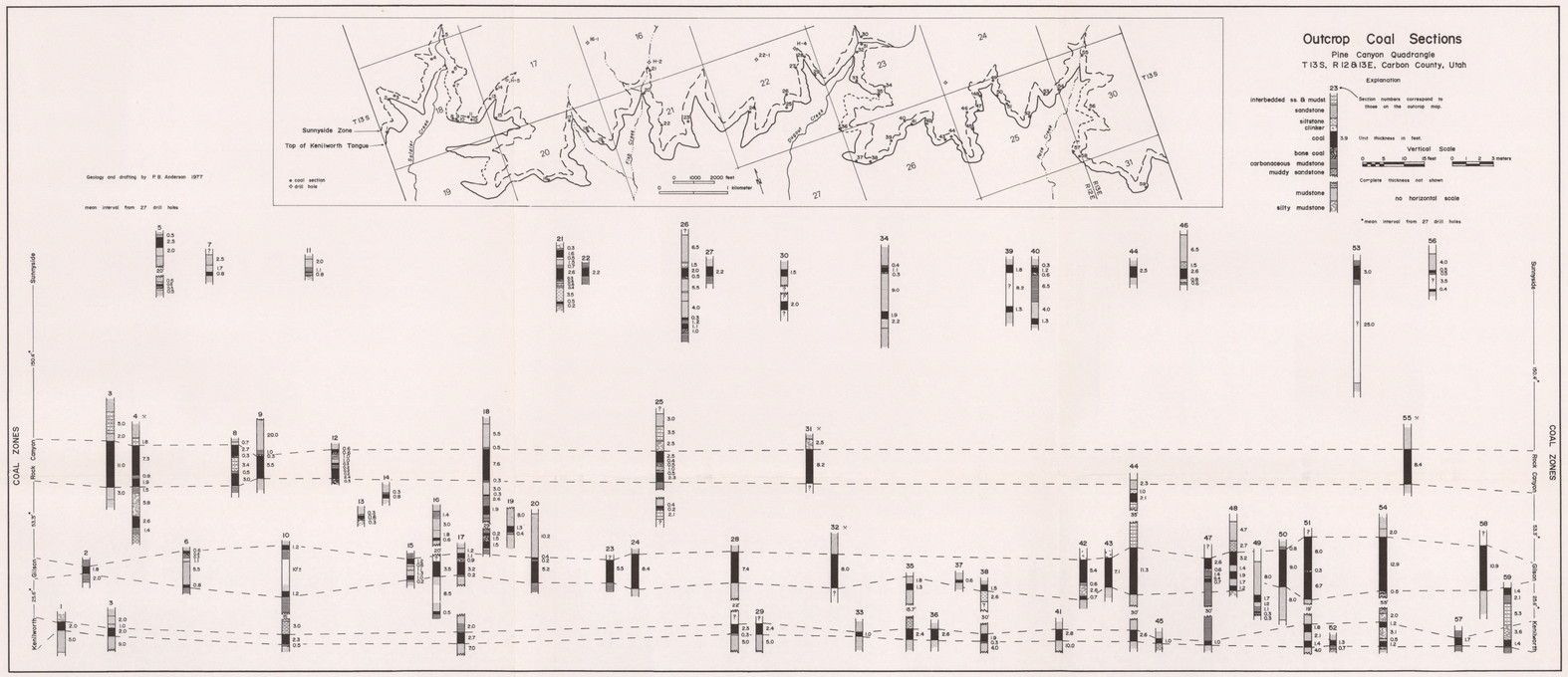
November 1983

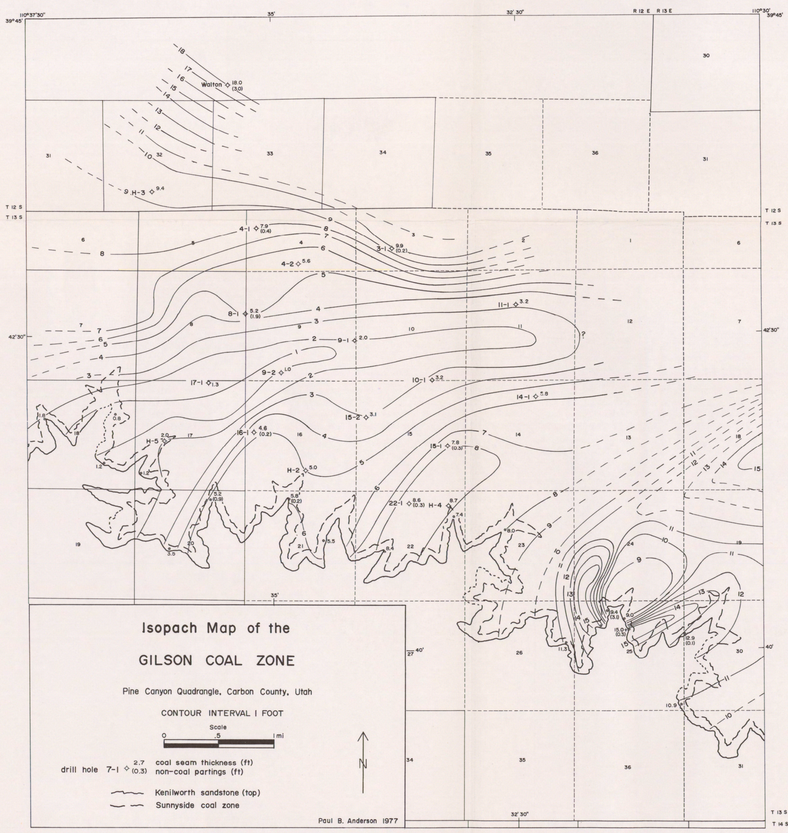
By Paul B. Anderson

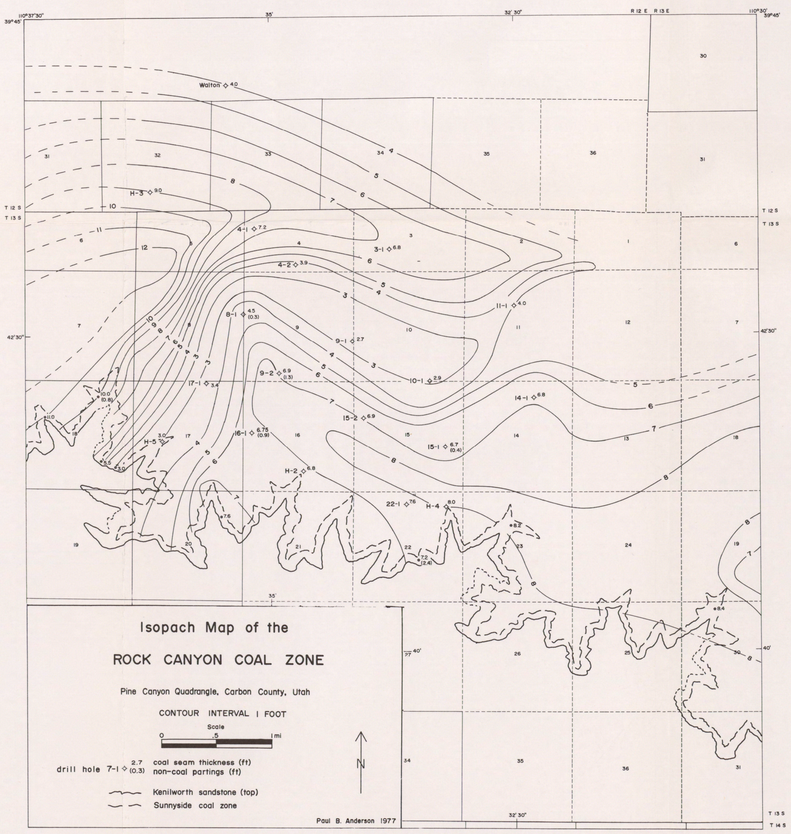
Klaus D. Gurgel, Cartographic Editor
Jessie S. Roy, Cartographer

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
UTAH GEOLOGICAL AND MINERAL SURVEY

Plate 1
To Accompany Map 72 — Miscellaneous Series
Geology of Pine Canyon Quadrangle







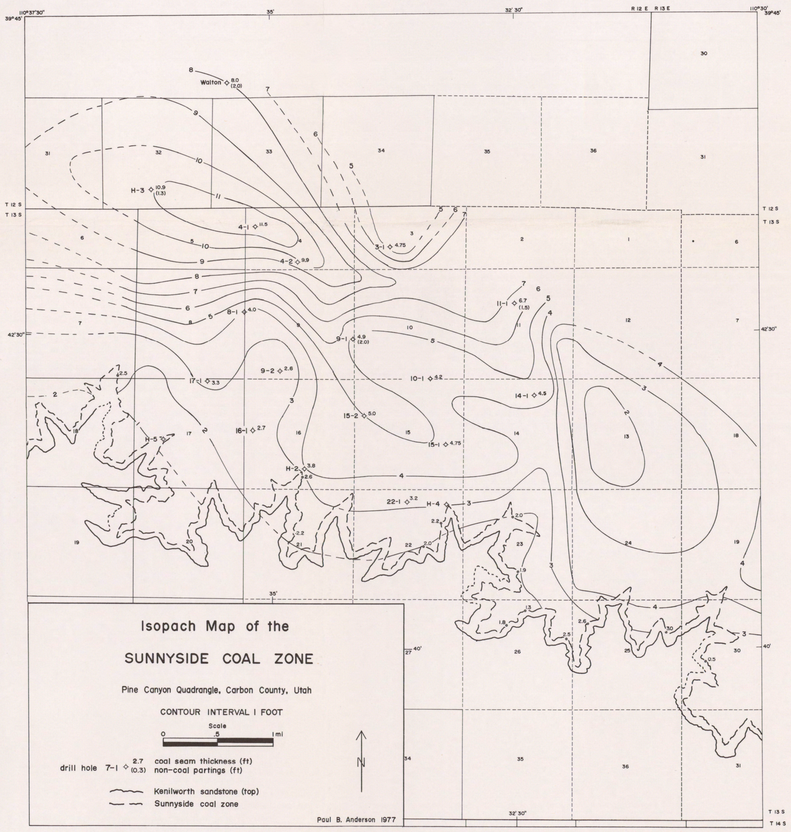


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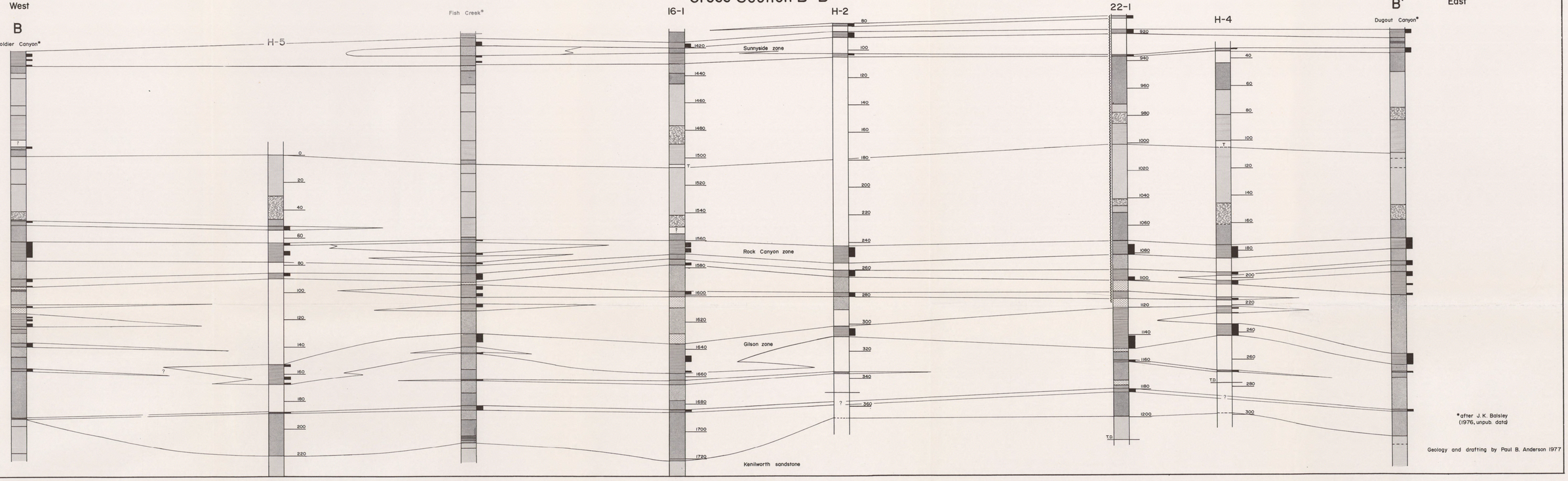
Plate 2
To Accompany Map 72 — Miscellaneous Series
Geology of Pine Canyon Quadrangle

Cross Section B-B'



Cross Section C-C'