GEOLOGY AND COAL RESOURCES OF THE TROPIC AREA, GARFIELD COUNTY, UTAH

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GEOLOGY AND COAL RESOURCES OF THE TROPIC AREA, GARFIELD COUNTY, UTAH

by Richard A. Robison

Eastern part of the Tropic area. Henrieville Creek and U-54 extend across middle foreground. Rocks exposed are: a) pediment deposits, b) Tropic Shale, c) Straight Cliffs Sandstone, d) Wahweap Sandstone, e) Kaiparowits Formation, and f) Claron Formation (photo by John S. Shelton).

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The Colleges of Mines and Mineral Industries
University of Utah, Salt Lake City, Utah

SPECIAL STUDIES 18 • PRICE $1.50 • AUGUST, 1966

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GEOLOGY AND COAL RESOURCES OF THE TROPIC AREA, GARFIELD COUNTY, UTAH

by Richard A. Robison[1]

ABSTRACT

The Tropic area lies within the Colorado Plateau province and includes about 100 square miles in southwestern Garfield County, Utah. It is bounded on the west by the Paunsaugunt fault, which separates the Kaiparowits Plateau on the east from the Paunsaugunt Plateau on the west. Flat or gently folded sedimentary strata are undergoing relatively rapid erosion by headward tributaries of the Paria River. This erosion gradually is pirating drainage area to the west and north from the East Fork of the Sevier River. Less resistant strata generally are eroded to form broad valleys, whereas more resistant strata generally form steep slopes, irregular ledges, and high cliffs. In places, there are extensive remnants of broad gravel-capped pediment surfaces.

All geologic systems from the Jurassic to the Quaternary are exposed in the Tropic area, and all systems from the Mississippian to the Jurassic are known from drill-hole information. Approximately 8,000 feet of rocks crop out at the surface and another 8,200 feet of unexposed rocks have been penetrated by drilling. The Entrada Sandstone of Jurassic age crops out in an irregular band across the southern part of the mapped area. Successively younger formations up to the Claron Formation of Tertiary age are exposed to the north. Pediment deposits and alluvium of Quaternary age are present at many places.

Coal occurs in the Dakota Formation and Straight Cliffs Sandstone of Cretaceous age, but beds of workable thickness occur only in the lower part of the Straight Cliffs Sandstone. The beds in the Straight Cliffs Sandstone are in a 10- to 50-foot section that here is named the Henderson coal zone. The outcrop of the Henderson zone extends in a broad, irregular, 10-mile arc from Henrieville Creek on the east to the Paunsaugunt fault on the west. In this zone the coal generally is in multiple, lenticular beds with a cumulative thickness that ranges up to 32 feet, and averages about 12 feet. Individual coal beds within the zone range up to 12 feet 7 inches in thickness. Rank of the coal generally lies near the boundary between subbituminous A and high-volatile C bituminous. Reserves in the Henderson coal zone of the Tropic area, estimated and classified on a coal-zone basis, total about 950 million short tons, of which 470 are indicated and 480 are inferred.

Other mineral resources that have been mined in the Tropic area include bentonite in the Dakota Formation and the Tropic Shale, and gravel from pediment and alluvial deposits. Four test wells for oil and gas have encountered promising shows of oil, but none of the wells produced oil in commercial quantities.

INTRODUCTION

Location and Extent of Area

The Tropic area is in southwestern Garfield County in south-central Utah (fig. 1). It is bounded on the north by latitude 37°45', on the northeast by the base of Table Cliff Plateau, on the southeast by Henrieville Creek, on the southwest by Utah State Highway 54, and on the west by the Paunsaugunt Plateau (pl. 1). About 100 square miles are included

1. Department of Geology, University of Utah (June, 1966).

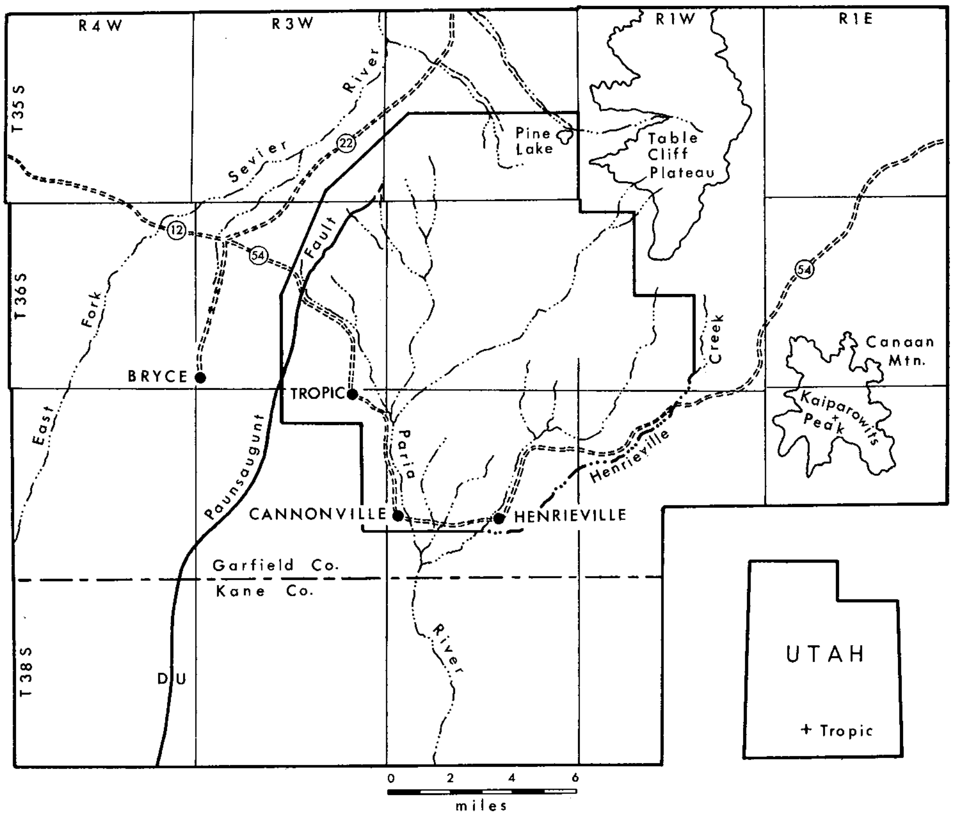

Figure 1. Index map of the Tropic area, Garfield County, Utah.

within these irregular boundaries. Part of Bryce Canyon National Park is within the western part of the area. The small towns of Tropic, Cannonville, and Henrieville are along the southern margin of the area.

Previous Investigations

In 1931 Gregory and Moore published results of a geologic reconnaissance of the Kaiparowits region that includes the Tropic area of this report. Geologic investigations in the region prior to 1931 are summarized in Gregory and Moore's report. Geology of the western part of the Tropic area again was discussed by Gregory (1951) in his report on the Paunsaugunt region. Most of the Cretaceous strata in the northwestern part of the Tropic area, however, were erroneously designated as Wasatch Formation of Tertiary age on the geologic map that accompanies Gregory's report (1951, pl. 1).

Other published discussions of geology and mineral resources in the Tropic area are mostly in papers of a regional nature. Of particular significance are papers by Cobban and Reeside (1952), Bissell (1954), Williams (1954), Alexander and Clark (1954), Heylmun (1958), Olsen and Williams (1960), Robison (1963a, 1963b, 1964), Van De Graaff (1963), Stokes and Heylmun (1965), Munger and others (1965), Lawrence (1965), Kunkel (1965), Averitt and Cashion (1965), and Grose (1965).

Present Investigation

Rapidly expanding energy needs have created much recent interest in the large undeveloped coal resources of southern Utah. Since about 1960 several projects to evaluate coal resources in southern Utah have been started. Systematic coring programs in the Kanab field have been completed by Nevada Power Company and Utah Construction Company. Similar programs in the central and southern parts of the Kaiparowits Plateau field have been completed by Resources Company, Peabody Coal Company, and Richfield Oil Corporation. Also, during the summers of 1964 and 1965, the geology and coal resources in the northeastern and southern parts of the Kaiparowits Plateau were investigated by field parties of the U. S. Geological Survey.

The present investigation is part of a regional study of coal resources and associated geology in southern Utah that was begun by the writer in the summer of 1962. The present study was designed to evaluate coal resources in one of the few coal-bearing areas of southern Utah that has not been the subject of recent detailed commercial or federal investigation. It is hoped that this study will stimulate interest in the development of some of Utah's mineral resources.

Most of the field work for this report was done during the summers of 1964 and 1965. The one productive coal zone, here named the Henderson coal zone, and associated geology were mapped on aerial photographs with a scale of 1:20,000, and the coal zone was measured and sampled at intervals of approximately one mile. Map data then were transferred to a base compiled from preliminary U. S. Geological Survey topographic maps of the following $7\frac{1}{2}$ minute quadrangles: Pine Lake, Henrieville, Adams Head 4 N.E., and Adams Head 4 S.E. Most of the land net indicated on the west half of the geologic map is only tentatively located and is subject to revision. Distribution of coal beds within the Henderson coal zone is illustrated in figure 12, and analyses of coal samples are listed in table 3.

Acknowledgments

The writer is indebted to several people who aided in completion of this study. John C. Lawrence assisted with field work during the summer of 1964, and is particularly acknowledged for measurements and descriptions of stratigraphic sections recorded in the stratigraphic discussions. Information concerning various aspects of the study area was provided by Mr. Bryon Davies of Cannonville, Utah. Mr. Robert Kunkel and Mr. Stanley L. Thayne provided data from coal samples obtained from a core hole in Cameron Wash (Johns Valley). Also, the manuscript and map have benefited from critical review by Harry D. Goode.

Financial support for this study has come from the Uniform School Fund administered by the College of Mines and Mineral Industries of the University of Utah.

GEOGRAPHY

The Tropic area is in the northwest part of the Kaiparowits Plateau, which is part of the much larger Colorado Plateau province. Terrane of the arid Kaiparowits region is characterized by a series of rugged step-like benches that have been deeply dissected by stream erosion. These features are well displayed in the Tropic area where mostly flat or gently folded sedimentary strata are undergoing relatively rapid erosion by headward tributaries of the Paria River. This erosion gradually is pirating drainage area from the East Fork of the Sevier River, which flows across an old-age topography to the west and north. Less resistant strata generally are eroded to form broad valleys, whereas more resistant strata generally form steep slopes, irregular ledges, and high cliffs. In places, there are extensive remnants of broad gravel- to boulder-capped erosional surfaces of Quaternary and probable pre-Wisconsin age that equally bevel resistant and non-resistant strata. These surfaces now are greatly dissected by streams that have cut valleys as much as 500 feet below the surfaces.

Table 1. Geologic formations exposed in the Tropic area, Garfield County, Utah.

System	Series	European Stage	Formation	Thickness (feet)	Generalized description
Quaternary	Recent and Pleistocene?			0-50	Alluvium
	Pleistocene			0-100	Pediment deposits, mostly gravel
			unconformity		
Tertiary	Eocene	(Unknown)	Claron Formation	1,600	Limestone, sandstone, mudstone, and conglomerate; basal 1,000 feet usually stained various shades of red, upper 600 feet usually light gray to white; forms "Pink Cliffs."
		?	unconformity		
Cretaceous	Upper Cretaceous	Maestrichtian	Kaiparowits Formation	2,000	Friable arkosic sandstone interbedded with scattered layers of mudstone; weathers drab bluish gray and forms slopes or badland topography.
		?			
		Campanian ? Santonian	Wahweap Sandstone	1,350	Irregular sequence of sandstone and mudstone with minor conglomerate and no coal; forms irregular series of rugged cliffs, ledges, and steep slopes with massive conglomeratic sandstone cliff at top.
		?			
		Coniacian Turonian	Straight Cliffs Sandstone	1,500-1,800	Irregular sequence of sandstone and mudstone with minor coal and conglomerate; one productive coal zone; forms irregular series of rugged cliffs, ledges, and steep slopes with prominent sandstone cliffs at top and base.
		Cenomanian	Tropic Shale	690-900	Medium- to dark-gray claystone with minor sandstone, bentonite, and fossiliferous limestone concretions; easily eroded to form broad valleys.
	Lower Cretaceous	Albian Aptian	Dakota Formation	150-250	Interbedded mudstone and sandstone with minor conglomerate, coal, bentonite, and claystone; forms irregular ledges and slopes.
			unconformity		
Jurassic	Upper Jurassic	Callovian	Entrada Sandstone	550-730	Dark reddish brown to white, fine-grained sandstone that forms rounded cliffs and steep slopes. Deposition of upper and lower members eolian; [illegible]

Altitude in the area ranges from about 5,800 feet in the south near the confluence of the Paria River and Henrieville Creek to about 8,800 feet in the northeast corner of the mapped area. Table Cliff Plateau, which is adjacent to the northeast edge of the mapped area, has a maximum elevation of 10,292 feet. Along its outcrop, the Henderson coal zone ranges between elevations of about 6,700 to 7,100 feet, but in the subsurface along the axis of the Johns Valley anticline the top of the coal zone was penetrated in a core hole at a depth of 289 feet and at an elevation of about 7,460 feet.

The southern part of the mapped area is accessible by paved Utah State Highway 54, which passes through the towns of Tropic, Cannonville, and Henrieville. The northern part of the area is accessible from two maintained gravel roads; one that leads into Cameron Wash (Johns Valley), and another that leads to the head of Henderson Canyon via Pine Lake. Several dirt roads lead into the interior of the mapped area, but these usually are impassable because of erosion by either spring runoff or summer thunderstorms. The nearest rail terminal is in Cedar City, Utah, about 90 miles to the west.

STRATIGRAPHY

All geologic systems from the Jurassic to the Quaternary are exposed in the Tropic area, and all systems from the Mississippian to the Jurassic are known from drill-hole information. Approximately 8,000 feet of rocks crop out at the surface and another 8,200 feet of unexposed rocks have been penetrated by drilling. The Entrada Sandstone of Jurassic age crops out in an irregular band across the southern part of the mapped area. Successively younger formations up to the Claron Formation of Tertiary age are exposed to the north. Pediment deposits and alluvium of Quaternary age are present at many places throughout the mapped area.

Areal distribution of rock formations is shown on plate 1. The succession, character, and thickness of the exposed rock formations are summarized in table 1.

Subsurface Rocks

Several wells drilled in the Kaiparowits region have penetrated Cambrian rocks and one well reached the Precambrian. Except for the absence of the Silurian and Ordovician, a continuous succession of systems was found in all wells. Discussions of Paleozoic and Early Mesozoic stratigraphy of the Kaiparowits region can be found in summaries by Heylmun (1958), Munger and others (1965), Kunkel (1965), and Wilson (1965).

Four wells have been drilled in the Tropic area, but the deepest penetration was to the Redwall Limestone of Mississippian age. The stratigraphic succession and thickness of formations in three of these wells are given in table 2.

Jurassic System

The oldest rocks exposed in the Tropic area are of Jurassic age. They crop out only in an irregular band across the southernmost part of the area in the vicinity adjacent to and between Cannonville and Henrieville. These rocks display characteristics of both the Winsor Formation as used by some investigators in the extreme western part of the Colorado Plateau and the Entrada Sandstone as used currently over much of the rest of the Colorado Plateau.

Several investigators have discussed the exposed Jurassic rocks of the Tropic area, but because of transitional rock types little agreement has been reached concerning stratigraphic

Table 2. Formations penetrated by drilling in the Tropic area.

System	Formation	Well designation and thickness of formations in feet		
		California Co. Johns Valley No. 1 (Amstrat log, no. 191-R)	Tidewater Johns Valley No. 41-27 (Amstrat log, no. D-2389)	Tenneco U.S.A. Tropic No. 1 (Amstrat log, no. D-2195)
Cretaceous	Straight Cliffs	906+	1160+	
	Tropic	902	790	
	Dakota	196	247	
Jurassic	Entrada	719	728	no log 1830
	Carmel	930	965	
Jur. - Trias.	Navajo	1607	1560	1714
Triassic	Kayenta	261	385	429
	Wingate	214	107	97
	Chinle	560	566	485
	Shinarump	71	78	109
	Moenkopi	1186	1206	1149
Permian	Kaibab	233	198	123
	White Rim	248	145	161
	Toroweap	267	449	453
	Coconino?	65	-	-
	Hermit	39	45	-
	Cedar Mesa	911	73+	286+
	Elephant Canyon	345		
Pennsyl- vanian	Hermosa?	464		
	Molas	64		
Mississip- pian	Redwall	147+		
Total depth		10335	8702	6836

nomenclature and positions of some unit boundaries. In 1931, Gregory and Moore mapped these rocks as "San Rafael group undifferentiated." In 1936, Baker and others assigned them to the Entrada Sandstone. After additional study, Gregory (1951, p. 57) assigned them, as well as underlying strata not exposed in the Tropic area of this report, to the Winsor Formation. Subsequently, Bissell (1954, p. 65) assigned unit 21 of Gregory's (1951, p. 57) Winsor to the Entrada Sandstone and restricted usage of the Winsor Formation to unit 22 of Gregory. On the following pages of the same paper, however, Bissell (1954, p. 66, 67) contradicted himself and described rocks that make up units 21 and 22 of Gregory as being characteristic of the Winsor Formation. In a recent summary paper, Wilson (1965, p. 44) assigned all strata above the Carmel and below the Dakota around the west edge of the Kaiparowits Plateau to the Entrada Sandstone.

The disagreement over stratigraphic terminology for Jurassic rocks in south-central Utah indicates that a detailed regional stratigraphic study is needed. Such a study was beyond the scope of the present investigation. Therefore, pending a detailed study, Jurassic rocks in the Tropic area tentatively are assigned to the Entrada Sandstone as proposed by Baker and others (1936) and Wilson (1965). It is realized that this assignment may require modification when more information is available.

Entrada Sandstone

Three unnamed and unmapped members of the Entrada Sandstone are present in the Tropic area. A middle member appears to be of aqueous origin, and separates upper and lower members of eolian origin. The origin of each member is reflected in its stratification, which together with color and weathering characteristics can be used for identification.

The lower member crops out only in the vicinity of Cannonville where it has a maximum thickness of about 220 feet (fig. 2). It consists predominantly of fine- to very fine-grained quartz sandstone that is moderately to weakly cemented with calcite, iron oxide, and gypsum. In color, the sandstone is mostly medium to dark reddish brown, but a few beds are light gray to white, light red, light greenish gray, and purple. From a distance the member presents a fairly uniform medium- to dark-red aspect. Beds in the lower and middle part of the member generally are thick, lenticular, and display high-angle cross-stratification that suggest eolian deposition. The upper 80 feet of the member grades into progressively more common, light-colored, thin beds with low-angle cross-stratification in sets with fairly persistent horizontal bedding planes. A topographic bench, accompanied by a gradational color change, commonly marks the boundary with the middle member. Sandstone of the lower member generally is more resistant than that of the middle and upper members, and weathers to form rounded, step-like ledges and cliffs.

The middle member is exposed in a more extensive, irregular crescent-shaped outcrop that commences about two miles north of Cannonville and extends eastward to a termination about two miles north of Henrieville (figs. 2, 3). A complete section is exposed north of Highway 54 between Cannonville and Henrieville where it has a total thickness of about 330 feet. It consists predominantly of white to light-gray, fine-grained, friable, quartz sandstone with calcite cement. A few thin interbeds of dark-red sandstone, most common in the lower part of the member near Cannonville, give a banded aspect. Bedding is predominantly thin with low-angle cross-stratification in sets with fairly persistent horizontal bedding planes, which suggests deposition in a subaqueous environment. The member usually weathers to form prominent, light-colored, barren or sparsely vegetated, steep slopes and cliffs, but locally may weather to form picturesque domes, columns, and buttresses.

The greatest thickness of the upper member is exposed along Highway 54 north of Henrieville where it is up to 180 feet thick (fig. 3). It thins westward because of pre-Dakota erosion and pinches out between Henrieville and Cannonville. In general, the unit consists of white to light yellow-brown fine-grained, commonly friable sandstone. The bedding is in sets up to 10 feet thick with internal high-angle cross-stratification that suggests eolian deposition. The uppermost beds in places contain lenses of pebble conglomerate composed of about 75% chert and 25% quartzite. In most places the member weathers to form irregular ledges, but in a few places it forms sheer cliffs.

The Entrada Sandstone of the Tropic area lacks fossils, but its position elsewhere between the fossiliferous Curtis and Carmel Formations indicates that it is early Late Jurassic in age (Imlay, 1952, pl. 1).

Figure 2. Lower and middle members of Entrada Sandstone overlain by Dakota Formation. View is west toward Cannonville with U-54 in foreground.

Figure 3. Middle and upper members of Entrada Sandstone overlain by Dakota Formation and pediment deposits. Alluvium dissected by Dry Creek is in foreground. View is west from U-54 about one mile north of Henrieville.

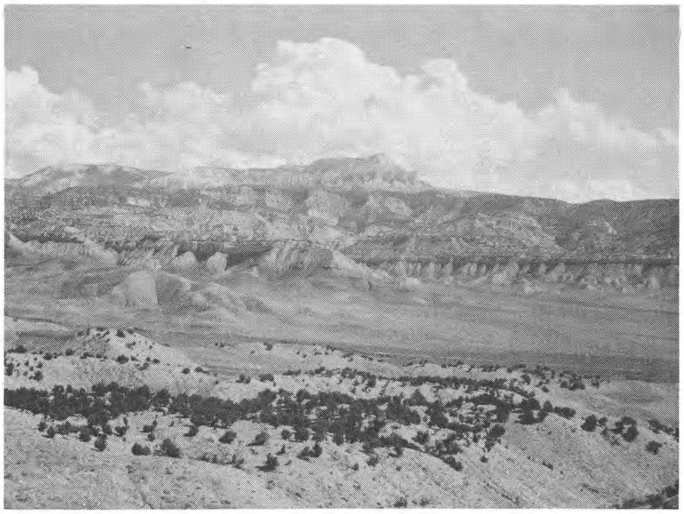

Figure 4. Tropic Shale overlain by Straight Cliffs Sandstone and Wahweap Sandstone. Table Cliff Plateau underlain by Claron Formation in background.

Approximately 6,000 feet of Cretaceous rocks are present in the Tropic area. From oldest to youngest they comprise the Dakota, Tropic, Straight Cliffs, Wahweap, and Kaiparowits Formations. The majority of the rocks are sandstone, mudstone, claystone, and conglomerate. Coal and bentonite make up only a minor part of the stratigraphic column, but are significant because of their economic potential.

The thick succession of Cretaceous rocks records a long interval of marine, transitional, and terrestrial sedimentation without significant interruption. In general, regional subsidence and marine transgression from the southeast began at least by late Early Cretaceous time. Maximum inundation occurred during the early Late Cretaceous when the marine Tropic Shale was deposited. This was followed by a gradual, but fluctuating, eastward retreat of the strand and deposition of sediment in predominantly lagoonal, littoral, estuarine, and swamp environments. During final stages of the regression sediment was deposited mainly in stream, pond, lake, and floodplain environments.

Cretaceous rocks in the study area are bounded below and above by unconformities of low angular discordance. The region of greatest uplift and erosion was apparently to the west. This is indicated by the fact that the lowest Cretaceous formation, the Dakota, progressively overlies older formations from east to west. Near Escalante the Dakota overlies the Morrison Formation of late Late Jurassic age, whereas near Cannonville and farther west the Dakota overlies the Entrada Sandstone of early Late Jurassic age. Similarly, at the boundary between the Cretaceous and Tertiary, the Claron Formation of Early Tertiary age lies on folded and beveled Cretaceous rocks that are successively older from east to west. Approximately 2,000 feet of the Kaiparowits Formation is preserved beneath the Claron in the vicinity of Table Cliff Plateau immediately northeast of the study area, whereas all of the Kaiparowits and all but about 400 feet of the Wahweap Formation were removed by erosion prior to deposition of the Claron in the northwest part of the study area.

Dakota Formation

The stratigraphic term "Dakota" was first used by Meek and Hayden (1861) to designate a 400-foot unit of sandstone, clay, and lignite in northeastern Nebraska. Subsequently, the term was applied to basal Cretaceous rocks throughout much of the Western Interior. Gregory and Moore (1931) first used the term in the Kaiparowits region, but they included only basal Cretaceous rocks of non-marine origin in the formation. This ultimately led to considerable confusion concerning placement of the boundary between the Dakota and the overlying Tropic Shale. Recently, Lawrence (1965) reviewed the problem, and on a rock-stratigraphic basis, proposed a revised definition of the Dakota-Tropic boundary in the Kaiparowits region. He placed the boundary at the top of either the highest coal or ledge-forming sandstone bed beneath the nonresistant uniform claystone of the Tropic Shale. Lawrence's proposal is accepted for this study, and it has been found that his proposed Dakota-Tropic boundary can be easily recognized and mapped in the Tropic area.

The Dakota Formation of the mapped area ranges in thickness from about 150 to 250 feet. It consists predominantly of interbedded mudstone and sandstone with minor amounts of conglomerate, claystone, coal, and bentonite. The mudstone commonly is laminated, and ranges in color from light gray and light green to dark brown and black. Plant debris is common and darker beds usually are highly carbonaceous. The sandstone generally is light gray or light brown. In the lower part of the formation the sandstone tends to be coarser grained--commonly conglomeratic--and poorly sorted, whereas in the middle and upper parts it tends to be finer grained and better sorted. Calcareous (siderite?) cement is common. The sandstone beds generally are thin; possess internal laminae or low-angle cross-stratification; and in places are marked with oscillation, current, and interference ripple marks. The conglomerate, coal, and bentonite beds are lenticular and make up only a small part of the formation. The coal and bentonite are discussed in more detail in the section on economic geology.

Section of Dakota Formation measured by J. C. Lawrence on north side of canyon in NW¼ sec. 13, T. 37 S., R. 3 W.

	Feet
Tropic Shale.	
Dakota Formation:	
Sandstone, light-gray at base and light-brown at top, very fine-grained, base interbedded with light-gray carbonaceous mudstone beds up to 3 inches thick, upper sandstones are platy and form resistant ledge, lower beds are nonresistant and contain numerous clam-shell fragments. Unit is conformable with overlying Tropic Shale	31.5
Sandstone, light- to medium-brown, fine-grained, quartzose with calcareous cement, upper half contains common to abundant pelecypods (*Ostrea prudentia*), forms upper part of cliff	13.3
Mudstone, dark-gray, weathers light-gray, nonresistant	4.0
Sandstone, light-brown, fine-grained, quartzose, evenly bedded, abundantly fossiliferous, forms basal part of cliff	5.8
Coal, nonresistant	1.2
Mudstone, dark brownish gray, carbonaceous, chunky to fissile, slope-former	10.0
Sandstone, light grayish brown, fine-grained, quartzose with calcareous cement, ledge-former	2.3
Mudstone, dark-gray, weathers light-gray, abundant plant debris in some beds, scattered red-brown ferruginous concretions, slope-former	16.8
Sandstone, light-brown, fine- to very fine-grained low-angle cross-stratification, thin mudstone interlayers near base, ledge-former	3.9
Mudstone, dark greenish gray with numerous red-brown ferruginous mudstone interbeds up to 2 inches thick, chunky, nonresistant	8.5
Bentonite, light-gray, weathers to form "popcorn" surface	3.4

Section of Dakota Formation (cont.)	Feet
Mudstone, dark-brown and black with much plant debris	0.5
Bentonite, light-gray, weathers to form "popcorn" surface	3.5
Sandstone, light-brown, very fine-grained, quartzose, friable, evenly bedded, numerous plant fragments	7.3
Mudstone, medium-gray with fine dark laminations	0.6
Coal	1.4
Mudstone, dark-gray, weathers light-gray, numerous brick-red ferruginous mudstone concretions generally less than 10 inches in diameter, nonresistant	7.5
Bentonite, dark-gray	0.7
Coal	0.7
Bentonite, light-gray	1.6
Mudstone, black, carbonaceous with much plant debris, fissile, forms break in slope	0.3
Bentonite, medium- to dark-gray, weathers light-gray	1.7
Sandstone, light-gray, very fine-grained, friable	2.4
Mudstone, dark-brown and black, carbonaceous with much plant debris, fissile, nonresistant	3.3
Sandstone, light-gray, weathers light-brown, fine-grained quartzose, numerous carbonaceous laminations near base, low-angle cross-stratification and common slump structures, beds lenticular, ledge-former	17.0
Bentonite, mudstone, and sandstone interbedded; about one-half of unit is light-gray bentonite, and one-half light-brown fine-grained sandstone and black mudstone	21.3
Sandstone, light-gray, fine-grained, quartzose, evenly bedded, nonresistant	11.3
Bentonite, light-gray, some beds with black plant debris, upper foot very sandy	5.1
Sandstone, light-gray to light-brown, fine- to medium-grained with 3-foot coarse-grained conglomeratic lens at base, some beds contorted, unit rests on scour surface, moderately resistant	27.3

Section of Dakota Formation (cont.)	Feet
Mudstone, dark-brown and black, carbonaceous, fissile	1.7
Sandstone, light-gray to dark-brown, fine- to very coarse-grained and conglomeratic, pebbles and cobbles composed of quartzite and chert; some beds with macerated twigs and logs, all beds lenticular; interfingers along strike with dark-gray weathering bentonite up to 13 feet thick; bottom contact unconformable with relief up to one foot	3.1
Total thickness of Dakota Formation	219

Entrada Sandstone.

The Dakota crops out only in the southern part of the mapped area where it commonly forms steep slopes or cliffs (figs. 2, 3). In places the less resistant overlying Tropic Shale has been eroded back to form broad benches as much as one mile in width.

Evidence suggests that the Dakota Formation accumulated in a variety of transitional environments near the west shore of a broad seaway that ultimately extended from the Gulf of Mexico to the Arctic Ocean. Rock types and fossils indicate that a fluctuating assortment of flood-plain, coal-swamp, beach, littoral, lagoonal, and shoal environments developed during the early transgressive phase of a marine cycle.

Paleontologic investigations by Lawrence (1965, p. 86, 90) indicate that the Dakota Formation of the Kaiparowits region bridges the Early-Late Cretaceous boundary, and is at least Aptian to early Cenomanian in age.

Tropic Shale

The Tropic Shale was named by Gregory and Moore (1931, p. 98-100). Neither a type section nor a type locality was designated, but they state that excellent exposures occur "in the broad, wide valley that lies between the Paunsaugunt and Table Cliff Plateaus and surrounds the village of Tropic, from which the formation is named." That area is included within the mapped area of this report.

As mentioned in the discussion of the Dakota Formation, Lawrence (1965) has redefined the Dakota-Tropic boundary on a rock-stratigraphic basis. For similar reasons, he also redefined the Tropic-Straight Cliffs boundary (1965, p. 87, 88), which he placed "at the top of a transition zone of alternating mudstone and sandstone and below the first prominent ledge-forming sandstone of the Straight Cliffs. The ledge-forming sandstone is more than three feet thick." This definition has been used in mapping the Tropic-Straight Cliffs boundary during this study.

The Tropic Shale is composed principally of nonresistant, medium- to dark-gray claystone with minor amounts of bentonite, mudstone, limestone concretions, and sandstone. It ranges in thickness from about 690 to 900 feet in the mapped area. Mudstone in the uppermost 300 feet of the formation generally weathers medium-gray, whereas mudstone from the remainder of the formation generally weathers light silvery gray. Bentonite beds, generally less than two feet thick, are scattered throughout the Tropic, but are most common in the basal 100 feet. A few limestone concretion zones also are present, and they too are most common in the basal 100 feet of the formation. Concretions within each zone tend to be similar. Some are of septarian-type and are composed of light-gray micrite with yellow spar calcite in the veins. Others are composed of light- to medium-gray micrite and are abundantly fossiliferous with a remarkably large assemblage of well preserved mollusc shells. A few concretions are up to four feet in maximum diameter, but the majority are less than one foot in diameter.

A representative section of the Tropic follows:

Section of Tropic Shale measured by J. C. Lawrence; lower 150 feet in SW¼ sec. 14 and upper 550 feet in sec. 2, T. 37 S., R. 2 W.

	Feet
Straight Cliffs Sandstone.	
Tropic Shale:	
Mudstone, dark-gray; numerous interbeds, generally less than 1.5 feet thick, of light brownish gray, fine-grained, evenly bedded sandstone; nonresistant. Unit is conformable with overlying Straight Cliffs Sandstone	28.0
Claystone, dark-gray, weathers medium gray, contains Selwynoceras woollgari and Inoceramus sp.; gradational with unit above	100.0
Bentonite, white	0.2
Claystone, dark-gray, weathers medium-gray and brown, finely laminated, gypsiferous, chunky when fresh, but fissile when weathered; contains zone of limestone concretions with cone-in-cone structure near top; Selwynoceras woollgari, Inoceramus sp., Ostrea sp., and shark teeth	177.0
Claystone, dark-gray, weathers light silvery gray, fissile; contains several light-gray, very fine grained sandstone beds less than one inch thick; Inoceramus sp.	180.0
Bentonite, white	1.0
Claystone, dark-gray, weathers light-gray, fissile, contains Ostrea sp. and Ptychodus sp	41.0
Bentonite, white	2.0
Claystone, dark-gray, weathers light-gray, fissile, contains micrite concretions usually less than one inch in diameter with various molluscans	4.4
Bentonite, white	0.3

Section of Tropic Shale (cont.)	Feet
Claystone, dark- to medium-gray, nodular, fissile on weathering, contains Inoceramus sp.	51.0
Bentonite, white	0.1
Claystone, medium-gray, weathers light-gray, fissile	11.0
Bentonite, white, forms break in slope	1.4
Claystone, medium gray, weathers light-gray, lower part contains Gryphaea sp., Inoceramus sp., Baculites sp., and miscellaneous cephalopod impressions	53.0
Bentonite, white, forms bench with "popcorn" surface	2.4
Claystone, medium-gray, fissile, nonresistant	12.2
Concretion zone. Concretions: micrite, light-gray, abundantly fossiliferous; two beds of concretions, one at top and one at base of unit. Matrix: claystone as in unit below, contains numerous Gryphaea newberryi	8.0
Claystone, medium- to dark-gray, fissile, nonresistant	2.0
Bentonite, white, forms break in slope	0.4
Claystone, medium- to dark-gray, fissile, nonresistant	1.7
Bentonite, white, forms break in slope	1.4
Claystone, medium- to dark-gray	2.3
Bentonite, light greenish gray and white	1.5
Concretion zone. Concretions: micrite, light-gray septarian with yellow spar calcite veins, generally unfossiliferous. Matrix: claystone as in unit below, contains Exogyra sp. and Gryphaea newberryi	0.4
Claystone, medium-gray, weathers light-gray, bentonitic	1.1
Bentonite, light-gray, biotitic	1.0
Claystone, medium-gray, bentonitic, nonresistant; conformable and gradational with underlying Dakota Formation	4.2
Total thickness of Tropic Shale	689

Dakota Formation.

The Tropic Shale is exposed in a broad arcuate band that extends from the Paunsaugunt fault west of the town of Tropic to Henrieville Creek northeast of the town of Henrieville (figs. 4, 7). The shale is easily eroded and underlies broad valleys. Some parts of the exposure have been weathered to soil, which supports virtually all agriculture in and around the town of Tropic. At scattered localities, particularly near the boundary with the overlying Straight Cliffs Sandstone, the Tropic commonly is littered with talus and landslide debris. At other places, the formation is covered extensively with alluvium and pediment gravels.

Most of the Tropic deposition occurred during the late transgressive and early regressive stages of the marine cycle that began in the Early Cretaceous. At the beginning of Tropic time the transitional environments developed during Dakota time were flooded as the result of renewed and extensive marine transgression. During early and middle Tropic time mostly clay was deposited in an open marine environment below effective wave base. Lawrence (1965, p. 89) has suggested that during late Tropic time, the Tropic sea was cut off from open marine circulation by a barrier to the east. This is indicated by the generally darker claystones with pyrite in the upper 300 feet of the Tropic. He further suggested that the barrier may have been the north-south trending Oyster Ridge Sandstone Member of the Frontier Formation and the Ferron Sandstone Member of the Mancos Shale.

The Tropic Shale is Late Cretaceous (late Cenomanian and early Turonian) in age. Preliminary results of a detailed biostratigraphic study by Lawrence (1965, p. 88-90) indicate that the Tropic is a rock-stratigraphic and probable time-stratigraphic equivalent of the Tununk Member of the Mancos Shale in Utah, and part of the Mancos Shale of Arizona, Colorado, and New Mexico.

Straight Cliffs Sandstone

The Straight Cliffs Sandstone was named by Gregory and Moore (1931, p. 100-104) after the Straight Cliffs that bound the east side of the Kaiparowits Plateau, approximately 25 miles east of the Tropic area. Along the Straight Cliffs, the formation is composed almost entirely of sandstone that has been eroded to form a line of sheer cliffs about 50 miles in length with an average height of about 1,000 feet. In the southern and western parts of the Kaiparowits Plateau, the formation contains appreciable quantities of mudstone and variable numbers of coal beds. Over large areas, the overlying formations have been stripped back by erosion and the upper beds of the Straight Cliffs Sandstone form the surface of the Kaiparowits Plateau.

The Straight Cliffs and Wahweap Formations of the Tropic area were not differentiated on the map that accompanied Gregory and Moore's (1931, pl. 2) study of the Kaiparowits region. The reason given (idem, p. 106) was that

> "most of the study of the Cretaceous beds in the northern Paria Valley was undertaken before mapping of the rocks on the Kaiparowits Plateau, and it is probable that more detailed field work would result in a separation of the two formations in this region."

Part of the Tropic area (northern Paria Valley) was later mapped in conjunction with Gregory's study of the Paunsaugunt region, but on that map (Gregory, 1951, pl. 1) the upper part of the Cretaceous sequence is omitted, and the Wasatch Formation of Tertiary age is shown erroneously to rest unconformably upon the undifferentiated Dakota and Tropic Formations.

The Straight Cliffs Sandstone is well exposed in a broad arcuate band across the northern part of the Tropic area. In the central part of the band, the formation is about 1,800 feet thick, and near Henrieville Creek to the southeast it is about 1,500 feet thick. The East Fork of the Sevier River has developed an old age topography in the northernmost part of the mapped area. There, sandstone beds in the upper part of the Straight Cliffs are exposed only in discontinuous ledges on low rounded slopes. To the south, headward tributaries of the Paria River are pirating the drainage area of the East Fork of the Sevier River, and have carved the flat or gently folded beds of the Straight Cliffs into a series of rugged cliffs, ledges, and steep slopes (see frontispiece).

The base of the only zone of workable coal present in the area is from 400 to 700 feet above the base of the Straight Cliffs Sandstone. That zone here is named the Henderson coal zone after Henderson Canyon in the northeast part of the mapped area. The outcrop of the Henderson coal zone has been mapped (pl. 1), and the base of that zone has been used to divide the Straight Cliffs into informal upper and lower members. At the time field mapping for this study was almost finished, Peterson and Waldrop (1965, p. 62-65) published a description of the Straight Cliffs Sandstone in the southern part of the Kaiparowits Plateau, and defined three informal members. The lower and upper members are mainly sandstone, whereas the middle member contains interbedded sandstone, mudstone, shale, and coal. Similar rock units also can be recognized in the Tropic area, but they have not been differentiated by mapping.

The lower member of the Straight Cliffs ranges in thickness from about 400 to 700 feet, and is composed principally of sandstone and mudstone. Throughout most of the mapped area the sandstone to mudstone ratio is about 3:1, but near Henrieville Creek it is about 4:3. The base of the member is characterized by a prominent cliff-forming unit of light brownish gray, fine-grained, quartzose sandstone that ranges in thickness from about 20 to 125 feet. This unit probably is a rock-stratigraphic equivalent of the lower sandstone member of the Straight Cliffs Formation of Peterson and Waldrop (1965, p. 63).

A persistent zone, 5 to 20 feet thick, of highly carbonaceous mudstone with occasional thin lenticular coal beds occurs about 60 to 130 feet above the base of the lower member. This unit here is named the lower coal zone, though none of the coal beds is known to be of workable thickness. The lower coal zone is discussed in more detail in the section on economic geology.

The upper part of the lower member consists mostly of interbedded sandstone and mudstone. A marker unit of white to light-yellow, conglomeratic, cliff-forming sandstone ranges in thickness from about 60 to 360 feet, and occurs between the lower coal zone and the top of the member. It has its greatest thickness in the central part of T. 36 S., R. 2 W. and thins toward the east and west. The great range in total thickness of the lower member appears to result mostly from the thickening and thinning of this unit.

The upper member of the Straight Cliffs has a relatively uniform thickness of approximately 1,000 feet throughout the Tropic area. In general, it is characterized by the Henderson coal zone at the base, alternating beds of sandstone and mudstone in the middle part, and a prominent cliff-forming sandstone unit at the top. The Henderson coal zone ranges in thickness from about 10 to 50 feet and in most places contains multiple coal beds with interbedded claystone, mudstone, and sandstone (figs. 12, 14). Further details of the zone are discussed in the section on economic geology.

Intermediate beds of the upper member consist of a thick succession of interbedded sandstone and mudstone. The sandstone generally is white to light gray and weathers light brown.

It consists of fine- to medium-grained subangular quartz clasts cemented with calcite. Beds generally are lenticular and commonly contain low-angle cross-stratification and contorted slump structures. The mudstone generally is medium to dark gray, commonly is highly carbonaceous, contains sparse coal stringers, and also commonly contains ferruginous concretions.

The uppermost unit of the upper member consists of 200 to 550 feet of light-brown sandstone and conglomerate. The conglomerate is lenticular and generally consists of granule- and pebble-sized clasts of light-colored quartzite and multicolored chert. Where the unit has been subjected to headward erosion by tributaries of the Paria River, it commonly is exposed in sheer rugged cliffs (fig. 5). Farther north, where it has been eroded by tributaries of the East Fork of the Sevier River, usually only the uppermost beds of the unit are exposed. The sandstone in many places is bleached white and occurs in discontinuous rounded outcrops. The unit probably is a rock-stratigraphic equivalent of the upper sandstone member of Peterson and Waldrop (1965, p. 64), and apparently the top of the unit was used by Alexander and Clark (1954, fig. 3) as a datum surface for structure contours of the Johns Valley anticline.

A representative section of the Straight Cliffs Sandstone follows:

Section of Straight Cliffs Sandstone measured by J. C. Lawrence in sec. 8, T. 37 S., R. 1 W.

	Feet
Wahweap Sandstone.	
Straight Cliffs Sandstone:	
Sandstone, light-brown, generally medium-grained, quartzose with calcite cement, dark reddish brown ferruginous sandstone concretions common at several intervals, low-angle cross-stratification; lenses of granule and pebble conglomerate scattered through unit and particularly common near top, clasts of quartzite and chert; also several thin medium-gray mudstone beds, usually less than 2 feet thick; bone fragments and turtle scutes occur rarely; unit forms prominent cliff; upper beds conformable with overlying Wahweap, beds interfinger along strike	523
Mudstone, medium- to dark-gray, nodular, nonresistant	22
Sandstone, light-brown, fine-grained, low-angle cross-stratification; several layers of lenticular mud-gall conglomerate with mud galls up to 6 inches in diameter; interfingers with mudstone along strike; resistant	11
Mudstone, medium- to dark-gray, nodular to fissile; many beds carbonaceous, some with macerated plant debris; forms irregular slope	101
Sandstone, light-brown, fine-grained, calcite cement, low-angle cross-stratification; forms cliff	16
Mudstone, medium- to dark-gray; several layers of brownish red calcareous and ferruginous mudstone concretions in upper part; nonresistant	48

Section of Straight Cliffs Sandstone (cont.)	Feet
Sandstone, light- to medium-brown, fine- to medium-grained; fossil clams and snails; forms ledge	3
Mudstone, medium- to dark-gray; intergrades in places with very fine-grained sandstone; contains dark reddish brown ferruginous mudstone concretions, forms slope	56
Sandstone, light-brown, fine-grained with thin lentils of rounded mudstone galls up to 3 inches in diameter, low-angle cross-stratification; contains petrified logs in upper beds; forms cliff	23
Mudstone, dark gray-brown, forms slope	40
Sandstone, light- to medium-brown, fine-grained, low-angle cross-stratification and many slump structures; ledge	6
Mudstone, dark-brown, carbonaceous with some macerated plant debris, some beds fissile; forms slope	35
Sandstone, light- to medium-brown, fine-grained, low-angle cross-stratification with some penecontemporaneous folding, clam fossils near base; basal part resistant, upper part friable and nonresistant	22
Mudstone, light-gray at base, becoming dark-brown and carbonaceous near top; oyster fragments 10 feet from top; two thin light-brown sandstone beds near base	83
Sandstone, light-gray, fine-grained, thin-bedded, forms ledge	12
Mudstone, light-gray to black, black carbonaceous logs and coal stringers, upper part contains carbonaceous roots in growth position; nonresistant	8
Sandstone, light-gray, fine-grained, scattered lenses of pebble-conglomerate, pyrite concretions less than 3 inches in diameter; many fossils including pelecypods, gastropods, bone, teeth, ganoid fish scales, and silicified wood; forms irregular ledges	38
Mudstone, light-gray, crumbly, nonresistant	2
Mudstone, light- to dark-gray; some beds carbonaceous, some with macerated plant debris and thin coal stringers, others contain reddish brown ferruginous concretions; forms slope; unit is continuous with Henderson coal zone and contains interbedded coal within one mile to the west. This is section Q of fig. 12	24

	Feet
Sandstone, light-gray, fine-grained, some low-angle cross-stratification, mostly friable and nonresistant	43
Mudstone, medium gray with dark reddish brown calcareous and ferruginous mudstone concretions up to 10 inches in diameter, nonresistant	36
Sandstone, light-brown, fine-grained, forms ledge	3
Mudstone, medium-gray, contains dark reddish brown calcareous and ferruginous concretions up to 8 inches in diameter, nonresistant	25
Sandstone, white at base becoming light- to medium-brown above, fine- to very coarse-grained, low-angle cross-stratification; contains lenses of conglomerate up to 3 feet thick; forms cliff	66
Mudstone, medium olive-gray, numerous dark reddish brown calcareous and ferruginous mudstone concretions, nonresistant	26
Sandstone, light-brown, fine-grained, friable, nonresistant	38
Mudstone, light- to medium gray with reddish brown calcareous and ferruginous concretions up to 10 inches in diameter, nonresistant	18
Sandstone, light-brown, fine-grained, forms ledge	4
Mudstone, light- to medium-gray, crumbly, nonresistant	39
Mudstone, dark-brown and black, carbonaceous with coal stringers in places; this unit represents the "lower coal zone"	9
Mudstone, medium-gray, weathers light-gray, several light-brown fine-grained sandstone beds less than 2 inches thick, partly covered slope	31
Sandstone, light brownish gray, fine-grained, quartzose with calcite cement, evenly bedded; several medium-gray mudstone beds less than 2 inches thick near base; forms prominent cliff; conformable and gradational with underlying Tropic Shale	84
Total thickness of Straight Cliffs Sandstone	1495

Tropic Shale.

Figure 5. Sandstone cliff at top of Straight Cliffs Sandstone overlain by Wahweap Sandstone. View is east with Henrieville Creek in foreground.

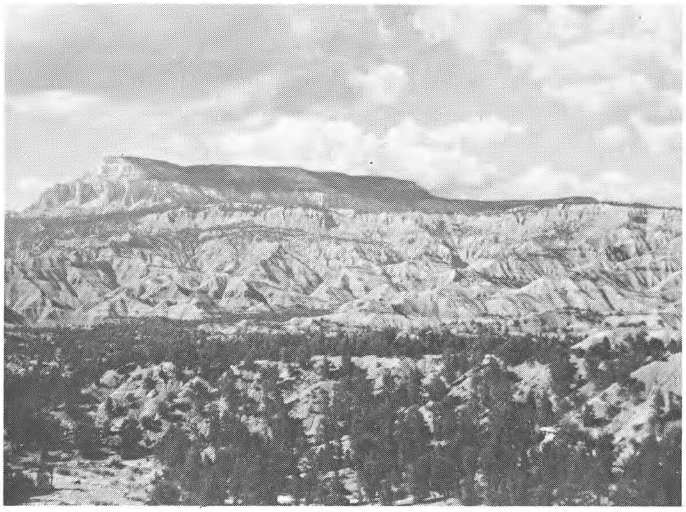

Figure 6. Badlands developed on the Kaiparowits Formation. Claron Formation beneath Table Cliff Plateau is on skyline.

Figure 7. Pediment deposits on beveled beds of Tropic Shale and Straight Cliffs Sandstone.

The Straight Cliffs Sandstone of the Tropic area shows evidence of deposition in a variety of environments during the regressive phase of the Late Cretaceous marine cycle. A large assemblage of marine pelecypods and gastropods commonly occurs in the top of the basal cliff-forming sandstone unit and in places in the lower few feet of overlying mudstones. The fossils as well as bedding structures in the sandstone suggest deposition in a littoral environment. Overlying beds of sandstone, mudstone, and coal possess fossils and primary structures indicative of deposition in deltas, estuaries, swamps, and flood plains. The uppermost cliff-forming unit of conglomeratic sandstone indicates deposition by predominantly fluvial processes. Fossils reported by Gregory and Moore (1931, p. 104) and Peterson and Waldrop (1965, p. 65), as well as those collected during this study, indicate that the Straight Cliffs Sandstone is late Turonian and Coniacian in age.

Wahweap Sandstone

Gregory and Moore (1931, p. 104) proposed the name Wahweap Sandstone for a "series of sandy shale and massive sandstone that conformably overlies the Straight Cliffs Sandstone and underlies the distinctive Kaiparowits Formation." Wahweap Creek on the southwestern part of the Kaiparowits Plateau is the source for the name, but neither a type section nor type locality was designated in the original description of the formation.

The Wahweap Sandstone crops out only in an arcuate, relatively narrow, discontinuous band across the northeastern part of the mapped area. In general, the formation is similar in lithology and topographic expression to the underlying Straight Cliffs Sandstone (see frontispiece), but lacks coal and the mudstones are less carbonaceous. Furthermore, upon weathering, the mudstone often displays a bluish-gray aspect. This affects the over-all color of each formation, and where good exposures occur, results in a subtle tone difference on vertical aerial photographs.

Basal beds of the Wahweap consist commonly of mudstone, less commonly of interbedded mudstone and sandstone, and rarely of moderately- to poorly-resistant sandstone. In most places these beds weather to form a slope above the prominent cliff-forming sandstone unit at the top of the Straight Cliffs (fig. 5). Over much of the Kaiparowits Plateau erosion has stripped back the Wahweap and formed wide benches on top of the Straight Cliffs, but such benches have not developed in the Tropic area. The Straight Cliffs-Wahweap contact is gradational, and interfingering of beds occurs locally.

Near Henrieville Creek, the Wahweap Sandstone is about 1,360 feet thick. The lower and middle parts consist of alternating units of resistant sandstone and nonresistant mudstone that form an irregular succession of cliffs, ledges, and steep slopes. It is capped with a cliff-forming unit that consists of more than 370 feet of conglomeratic sandstone, which is similar to the unit found at the top of the Straight Cliffs Sandstone.

The following section appears to be representative of the formation in the Tropic area.

Section of Wahweap Sandstone measured by J. C. Lawrence west of Highway 54 in secs. 4 and 9, T. 37 S., R. 1 W.

Kaiparowits Formation. Feet

Wahweap Sandstone:

Sandstone, light-brown, mostly fine- to medium-grained, but ranges to very coarse-grained and contains lenses of

Section of Wahweap Sandstone (cont.)	Feet
conglomerate, quartzose with calcite cement; 200-foot sheer cliff at base contains 10 to 20% conglomerate with light- to dark-gray quartzite granules and pebbles, lenses often occur in foreset-type beds up to 200 feet in length and sometimes show crude graded bedding; top 100 feet contains interbeds of medium-gray, red-stained mudstone in beds usually less than 5 feet thick; low-angle cross-stratification common, especially in basal 200 feet; contact with overlying Kaiparowits Formation is conformable and gradational	373
Mudstone, light grayish brown, contains a few thin beds of very fine-grained sandstone, nonresistant	12
Sandstone, white to light yellowish brown, fine-grained, quartzose with calcite cement, friable, low-angle cross-stratification throughout; some irregular dark reddish brown ferruginous concretions; forms sheer cliff in places	190
Mudstone, dark-gray, nodular, forms partly covered slope	57
Sandstone, light-brown, fine-grained, quartzose with calcite cement, evenly bedded with some mudstone in beds up to 12 feet thick at base, top part forms cliff	262
Mudstone, light to moderate olive gray, laminated; contains 20 to 30% fine- to very fine-grained, light-gray, friable sandstone in beds up to 20 feet thick; a 50-foot zone of sandy and silty micrite concretions occurs about 100 feet above base, most are septarian with yellow and white calcite spar, some contain bone fragments, ganoid fish scales, and plant debris; weathers to form slope	273
Sandstone, light-brown, fine- to medium-grained, quartzose with calcite cement, contains current ripple marks and low-angle cross-stratification, beds are lenticular and interfinger laterally with mudstone, unit thins westward to about 30 feet in 200 yards along strike, forms cliff	120
Mudstone, medium-gray, nodular, weathers to form partly covered slope	21
Sandstone, light-brown, fine-grained, quartzose with calcite cement, low-angle cross-stratification; unit is lenticular, thinning to 12 feet in 100 yards along strike; forms cliff	38
Mudstone, medium-gray, weathers to form partly covered slope; conformable with underlying Straight Cliffs Sandstone	18
Total thickness of Wahweap Sandstone	1364

Straight Cliffs Sandstone.

Fossils are rare in the Wahweap of the Tropic area, and generally consist of scattered bone fragments, reptile teeth, and silicified wood. In the southern part of the Kaiparowits Plateau, Peterson and Waldrop (1965, p. 66) reported the occurrence of gastropods, pelecypods, ostracodes, fish and reptile teeth, and bone fragments in the lower half of the Wahweap. They concluded that

> "the fossils strongly suggest nonmarine environments of deposition for the enclosing strata; indeed, marine fossils are entirely lacking in the collection. Fossils, lithology, and sedimentary structures suggest that the Wahweap Formation was deposited in flood-plain, fluvial, and possible lacustrine environments. Unfortunately, the fossils are not well enough known to give a closer age determination than Late Cretaceous. Cobban and Reeside (1952, pl. 1, col. 30) questionably correlate the Wahweap with the upper part of the Niobrara and Telegraph Creek Formations of Santonian age in their reference sequence for the Western Interior."

The Wahweap of the Tropic area appears to be similar to that described by Peterson and Waldrop (idem). No evidence was discovered during this study that would contradict their interpretation of depositional environments, or conclusions of Cobban and Reeside as to the age of the formation.

Kaiparowits Formation

The Kaiparowits Formation is the youngest stratigraphic unit of Cretaceous age in south-central Utah. It was named by Gregory and Moore (1931, p. 106-108) after Kaiparowits Peak, which is a few miles east of the Tropic area. One of the best exposures and thickest sections of the formation is found in the locality known as "The Blues" between the southern tip of Table Cliff Plateau and Highway 54 (fig. 6). Badland topography characterizes "The Blues," which derives its name from the drab bluish-gray aspect of the Kaiparowits where it has been exposed to weathering.

Sandstone is the dominant rock type in the Kaiparowits, but mudstone beds up to 10 feet thick are scattered throughout the formation. The sandstone is arkosic and has as its principal constituents quartz, biotite, feldspar, and undetermined dark ferromagnesian minerals, all of which are cemented with calcite. The feldspar commonly is kaolinized and is very light gray to white. This together with the dark ferromagnesian minerals gives the sandstone a "salt and pepper" appearance. Most of the sandstone is poorly cemented and friable, but some is well cemented and occurs in lenses that stand in relief where exposed to weathering. In badland areas such as "The Blues," the formation from a distance appears to consist mostly of shale with scattered lenses of sandstone. On close inspection, however, it is found that what appears to be shale is mostly friable sandstone.

An unconformity with angular discordance up to about 15^{o} separates the Kaiparowits from the overlying Claron Formation. This represents a Late Cretaceous and/or Early Tertiary interval during which beds of the Kaiparowits were folded and beveled by erosion. As a result, the Kaiparowits thins rapidly from east to west in the northeast part of the mapped area. In the vicinity of "The Blues," the formation has an estimated thickness of 2,000 to 2,500 feet. Near Pine Lake to the northeast, the estimated thickness is only about 200 feet. Post-Claron erosion has removed what remnants of the Kaiparowits Formation may have been present along the axis of the Johns Valley anticline. West of the anticline, the Claron lies unconformably on the lower part of the Wahweap, and the Kaiparowits is absent.

Fossils are rare in the Kaiparowits Formation, but a few fresh-water molluscs and fragments of turtle and dinosaur bone have been found. In a report on fossils collected outside the present study area, Reeside (in Gregory and Moore, 1931, p. 107, 108) concluded that they probably are not older than middle Montanan and may be as young as late Montanan. A similar age was indicated by Cobban and Reeside (1952, pl. 1, col. 30) when they questionably correlated the Kaiparowits with the upper part of the Pierre Shale and the Fox Hills Sandstone of Maestrichtian age. No further age data presently is available for the formation.

The Kaiparowits Formation appears to have been deposited principally by fluvial processes on a broad flood plain between the Mesocordilleran Highland to the west and a seaway that was retreating to the southeast.

Tertiary System

The Paunsaugunt and Table Cliff Plateaus adjacent to the Tropic area are capped with limestone and miscellaneous clastic sedimentary rocks of Early Tertiary age. These rocks have been referred to the Wasatch Formation by Gregory and Moore (1931, p. 114-116) and by many subsequent writers. Difference in lithology, at least partial difference in age, and difficulty in correlation between the Wasatch Formation of northern Utah and rocks that have been called Wasatch in central and southern Utah have caused other writers to question the use of the term in central and southern Utah. The "Wasatch problem" has been outlined by Spieker (1946, p. 137-139), who proposed the use of new terminology in central Utah. For similar reasons, Mackin (1954; 1960, p. 101) and Cook (1960, p. 32; 1965, p. 54) considered the name Claron to be preferable to Wasatch as a formation name in the southeastern part of the Great Basin and southwestern part of the Colorado Plateau. Claron Limestone is a name previously proposed by Leith and Harder (1908, p. 41-44) for a thick sequence of fluvial and lacustrine sedimentary rocks in the Iron Springs district west of Cedar City, Utah. As a formation name in the Tropic area, Claron is considered to be preferable to Wasatch because of differences between rocks of Tertiary age in the Tropic area and those of the type Wasatch, and because of similarities to rocks of the type Claron to the west. Furthermore, with different terminology now in common use in central Utah, there is a discontinuity in use of terminology if Wasatch is used in both northern and southern Utah.

Claron Formation

The Claron Formation is exposed in the spectacular "Pink Cliffs" on the west side of the Paunsaugunt fault. In places, intricate erosion has carved a fairyland of buttresses, columns, and minarets. This, coupled with a wide range of pastel colors, provides the basic scenic attraction of Bryce Canyon National Park. Similar exposures are found on the flanks of Table Cliff Plateau to the east (fig. 6). The formation has an estimated thickness of approximately 1,600 feet in the vicinity of Table Cliff Plateau, but no more than about 500 feet of section is exposed at any one locality within the mapped area.

On the basis of color, the Claron in most places can be subdivided into a lower pink member and an upper white member. The lower pink member is approximately 1,000 feet thick. Where it is exposed on cliff faces it is covered with a surficial red ferruginous stain, and from a distance appears to be of rather uniform composition. On close inspection, however, the lower member is found to have a markedly variable composition. Commonly the basal 20 to 50 feet, and in some places to as much as 300 feet, is highly conglomeratic. Pebble- to boulder-sized clasts consist mostly of quartzite and chert with minor amounts of carbonate rock set in a matrix of sand and mud. Above the basal conglomerate is an assortment of light to medium brownish gray, muddy and sandy limestone, light-gray, calcareous sandstone, medium reddish brown calcareous mudstone, and lenses of quartzite and chert pebble conglomerate. Pebbles in the higher conglomerates often form the nuclei of algal oncolites.

The upper white member is at least 600 feet thick and forms the rim rock of the Table Cliff Plateau. It consists mostly of relatively pure light-gray microcrystalline limestone that weathers almost white. Much of the limestone contains scattered vugs lined with small calcite crystals. In a few places the member contains interbedded lenses of conglomerate, sandstone, mudstone, and tuffaceous material, but these constituents are much less common than in the lower pink member.

The range in age of the Claron Formation has not been adequately determined. A few species of fresh-water gastropods from the middle part indicate an Eocene age. It is possible, however, that the basal part of the formation may be older than Eocene. The fossils, lithology, and primary sedimentary structures suggest deposition in fluvial and lacustrine environments.

Additional details concerning the rocks of this formation may be found in descriptions and discussions of the Wasatch Formation by Gregory and Moore (1931, p. 114-116) and Gregory (1951, p. 44-52).

Quaternary System

Strata of Quaternary age in the Tropic area consist principally of deposits on broad pediment surfaces and alluvium in the valleys. Thin layers of gravel associated with remnants of stream terraces occur near the mouth of Tropic Canyon, but these were not mapped.

Pediment Deposits

Some of the most prominent land forms in the Tropic area are broad gravel- to boulder-capped pediment surfaces that extend from elevations of 8,400 to 6,300 feet (fig. 7). They slope gently away from nearby uplands with gradients that range from one to four degrees. Underlying bedrock represents all formations from the Dakota to the Kaiparowits, and all rock types are beveled without respect to composition or structure. Generally the surface is smooth, but local channeling on the Tropic Shale with relief up to 10 feet has been observed.

Gregory and Moore (1931, p. 133-135) described several erosion surfaces in the Kaiparowits region, the most extensive in the Tropic area was named the Cannonville erosion surface. In at least one locality along the west side of Coal Bench in secs. 27 and 34, T. 36 S., R. 2 W., a second surface lies about 75 feet below the main Cannonville surface.

Originally, the pediment deposits must have been much more extensive than at present for numerous small remnants of pediment gravel cap hills and mounds in many localities. The map scale prevented representation of these small remnants and only a few relatively large areas of pediment deposits are shown. Widespread dissection by streams has reached depths as much as 500 feet below the surfaces of adjacent pediment deposits.

The pediment deposits generally consist of poorly sorted, unconsolidated or poorly cemented, clastic material that ranges in size from clay to boulders. All of the surfaces in the mapped area head toward the Pink Cliffs of either the Paunsaugunt Plateau, Table Cliff Plateau, or Canaan Mountain. Therefore, the deposits consist most commonly of products weathered from the Claron Formation, secondarily of products from the beveled underlying formations of Cretaceous age, and rarely of pebbles from younger volcanics. Clasts of gravel to boulder size usually are well rounded, and in order of abundance generally are composed of Claron limestone, dense quartzite derived from Claron conglomerate, brown sandstone mostly from various Cretaceous formations, and multicolored chert from Claron conglomerate. Sparse carbonate pebbles, some with Late Paleozoic fossils, also appear to have come most recently from Claron conglomerate. Boulders of Claron limestone and miscellaneous Cretaceous sandstone range up to four feet in diameter, some quartzite boulders range up to 15 inches in diameter, but most chert occurs in the pebble size range.

Thickness of the pediment deposits is remarkably uniform. Over much of their extent they average about 100 feet, but subsequent erosion has caused local thinning.

Only indirect evidence concerning the age of the pediment deposits presently is available. Similar deposits of Quaternary age have been described by Smith and others (1963, p. 42-53) in the Capitol Reef area about 50 miles northeast of the Tropic area. Evidence from detailed studies suggest that pediment deposits in the Capitol Reef area are of pre-Wisconsin age. It seems logical to assume that conditions favorable for pediment development existed simultaneously in the Tropic and Capitol Reef areas.

Alluvium

The alluvium consists of stream deposits that occur as fans and valley fill. Composition and texture differ markedly from one locality to another depending on the source and conditions at the time of erosion, transport, and deposition. In the broad flat valleys, particularly those carved on the Tropic Shale, alluvium tends to be better sorted and clasts range from clay to sand size. In other areas where source rocks are more resistant and stream gradients are higher it tends to be poorly sorted and clasts range from clay to boulder size.

Sections of alluvium can be observed at many localities where gullies up to 50 feet deep have been cut by recent stream erosion. This erosion undoubtedly is related to climatic conditions, farming, grazing, and timber removal, but no attempt to determine the relative importance of these factors was made during this study.

Much of the alluvium is post-Wisconsin in age, but some may be older.

STRUCTURE

The Tropic area which encompasses the northwestern part of the Kaiparowits Plateau, in turn part of the Colorado Plateau province, lies between the Paunsaugunt fault on the west and the Table Cliff syncline on the east. Between these major structures are relatively small flexures that include parts of the Johns Valley and Tropic anticlines and the intermediate Pasture Canyon syncline (pl. 1). Strata throughout most of the area have dips of less than 5 degrees, but some beds immediately adjacent to the Paunsaugunt fault and others on the west flank of the Table Cliff syncline have dips up to 45 degrees.

Faults

Paunsaugunt Fault

The Paunsaugunt fault is the easternmost of three master faults that trend north-south and separate major tectonic blocks in southern Utah. The Paunsaugunt fault separates the Kaiparowits Plateau on the east from the Paunsaugunt Plateau on the west. According

Figure 8. Paunsaugunt fault on north side of Tropic Canyon. Claron Formation on left is adjacent to Straight Cliffs Sandstone on right. Henderson coal zone is just above center at right.

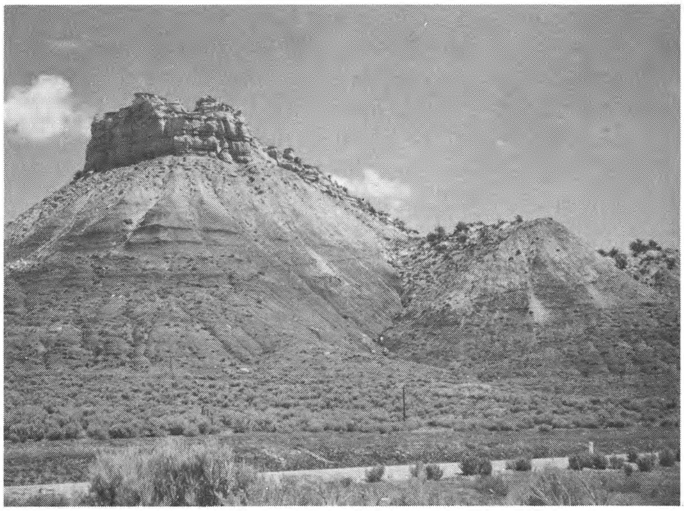

Figure 9. Toreva block on right formed by movement along small fault in Tropic Shale and thin cap of Straight Cliffs Sandstone. View is toward northeast with U-54 in foreground.

Figure 10. Drilling rig at Tidewater No. 41-27 Johns Valley site. Claron Formation is in foreground and on skyline with Straight Cliffs Sandstone exposed along axis of Johns Valley anticline.

to Gregory (1951, p. 77), it extends southward across the northern Kanab Plateau and may connect with faults at Big Springs and Ryan on the west side of the Kaibab Plateau. Maps that accompany numerous reports (e.g. Gregory and Moore, 1931, pl. 16; and Alexander and Clark, 1954, fig. 3) show the Paunsaugunt fault extending well north of the Tropic area of this report. Detailed field investigation, however, failed to substantiate those indications. As shown on plate 1, the major segment of the Paunsaugunt fault that passes through Bryce Canyon National Park terminates in either sec. 25 or 36, T. 35 S., R. 3 W., and no displacement of strata was observed to the north within the mapped area.

The Paunsaugunt fault is a normal fault with westward dips ranging between 70 and 90 degrees. Maximum throw in the Tropic area is at least 1,500 feet near Tropic Canyon where the lower part of the Claron Formation is in juxtaposition with the lower member of the Straight Cliffs Sandstone (fig. 8). The amount of displacement diminishes northward from Tropic Canyon where folding in places along the hanging wall has formed a series of step-like monoclinal folds with axial planes at approximately right angles to the plane of the fault (fig. 11). The foot wall has not been affected by comparable folding. One of the most prominent step-like flexures on the hanging wall is displayed on the south slope of Shakespeare Point where about 400 feet of relief is due to monoclinal folding.

Movement that formed the Paunsaugunt fault occurred after deposition of the Claron Formation. Post-fault erosion has profoundly modified the land forms in existence at the time of faulting. Because of headward erosion by tributaries of the Paria River, the surface of the upthrown block now is well below the surface of the downthrown block in the vicinity of Tropic. Possible stages in land form development in the Tropic area have been illustrated by Gregory (1951, fig. 42).

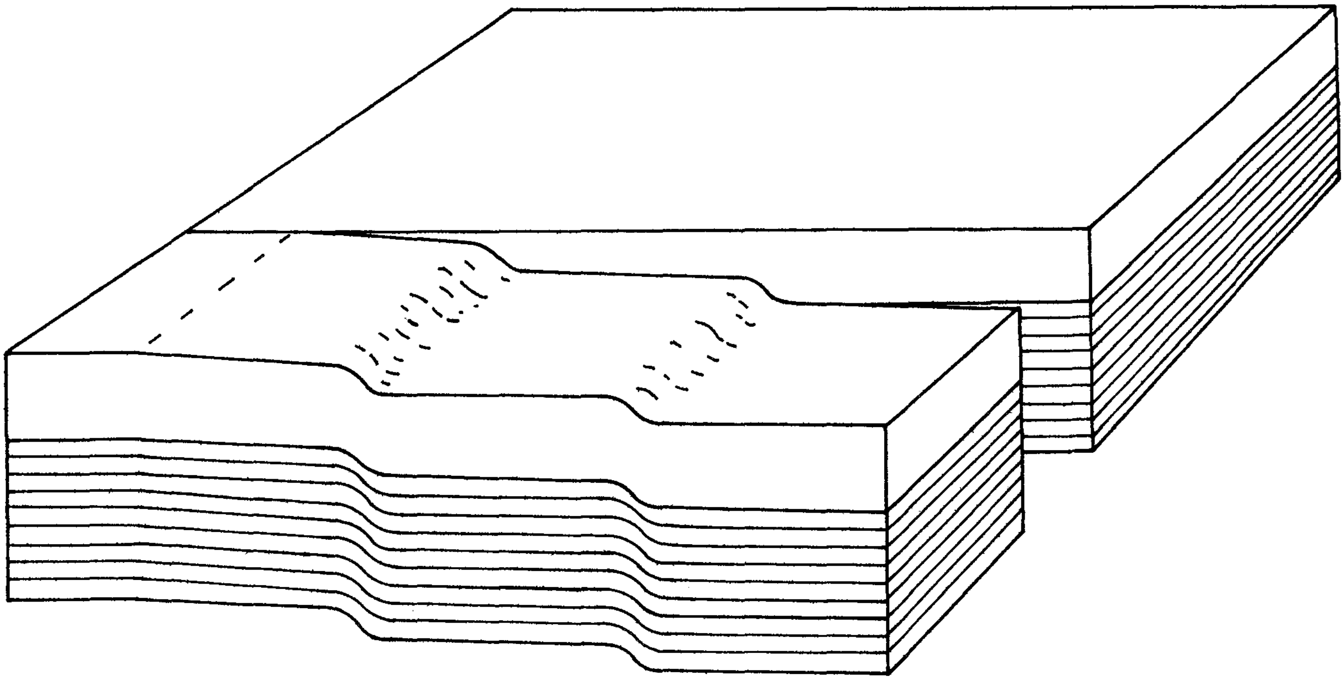

Figure 11. Diagram of the Paunsaugunt fault at its northern end showing step-like flexures on the hanging wall.

Minor Faults

A few minor faults of possible tectonic origin were observed in the Tropic area, but were not mapped because of their small size. Displacement in all instances was less than 10 feet, and none of the faults could be traced more than a few hundred feet.

Numerous minor faults of nontectonic origin have resulted in toreva-block landslides (fig. 9). They most commonly occur where weak beds of Tropic mudstone were eroded into steep slopes. Curved fractures then developed, especially where cap rock of Straight Cliffs Sandstone was present, and masses of rock rotated slightly as they slipped downslope. The toreva blocks range in volume from a few cubic feet to many thousands of cubic yards. Several blocks of rock from the Claron Formation also have slipped downslope. They range up to 200 feet in length, and most are located near the Paunsaugunt fault where cliffs have been formed by headward stream erosion. Because of map scale, it was practical to map only the largest of the nontectonic faults, which are in sec. 7, T. 37 S., R. 1 W. (pl. 1).

Folds

All of the folds discussed in this section appear to have been formed during one rather short interval in latest Cretaceous and/or earliest Tertiary time. This is suggested by the fact that a large remnant of the folded and eroded Kaiparowits Formation of Late Cretaceous age is preserved in the center of the Table Cliff syncline and is unconformably overlain by non-folded beds of the Claron Formation of Eocene age.

Johns Valley Anticline

The mapped area includes about two-thirds of the Johns Valley anticline, which extends beyond the northern border of the map (pl. 1). Its axis is about 10 miles in length and trends mostly north-northwest. The anticline is asymmetrical with dips up to 45° on the east flank and 7° on the west flank. According to Alexander and Clark (1954, p. 105), it has about 900 feet of surface closure. Three oil and gas tests and one core-hole for coal have been drilled on this anticline (fig. 10). Results of the drilling are discussed in the section on economic geology.

Tropic Anticline

The axis of the Tropic anticline extends about seven miles into the mapped area from the south (pl. 1). The axial trend is poorly defined, owing to the broad, flat crest, but appears to be nearly north-south with a slight hook toward the northwest at its northern tip. The anticline is asymmetrical with dips up to 10° on the east flank and 2° on the west flank. Neither its southern extent nor its closure were determined during this study. One unsuccessful oil and gas test has been drilled on the structure by Tenneco in sec. 15, T. 37 S., R. 2 W.

Pasture Canyon Syncline

A small syncline between the Johns Valley and Tropic anticlines is named here the Pasture Canyon syncline (pl. 1). Its axis trends northwest-southeast and has a length of five to six miles. The syncline is fairly symmetrical with flank dips that range up to four degrees. Courses of several small tributary streams appear to be aligned because of the structural influence of this syncline.

Table Cliff Syncline

The east limbs of the Johns Valley and Tropic anticlines form parts of the west limb of the Table Cliff syncline, which is a relatively large structure. As mapped by Gregory and Moore (1931, pl. 16), its axis is about 25 miles long, trends northwest-southeast, and underlies Table Cliff Plateau and Canaan Mountain. No part of the axial plane lies within the mapped area.

ECONOMIC GEOLOGY

Coal

Workable coal beds in the Tropic area occur only in the Straight Cliffs Sandstone, but thin lenticular beds also are present in the Dakota Formation. The Dakota represents deposition during part of the westward transgressive phase of a Cretaceous marine cycle and the Straight Cliffs represents deposition during part of the eastward regressive phase. The intermediate Tropic Shale lacks coal and represents deposition during an interval of maximum marine transgression.

Dakota Formation

The Dakota at any given locality commonly contains from one to several coal beds, but few are more than one foot thick. The beds are lenticular and most extend laterally less than a few hundred feet, and some extend only a few tens of feet. Coal beds may occur anywhere from the bottom to the top of the formation, and do not appear to be concentrated in persistent zones as in some other areas of southern Utah.

The only samples of Dakota coal analyzed for quality were collected a short distance outside the mapped area. These analyses (table 3, nos. 55 and 56) indicate a range of rank from lignite to subbituminous B, and moderate to high ash content. The samples came from an outcrop along the south bank of Heward Creek about 5½ miles west-southwest of Cannonville where 12 feet 3 inches of coal occurs in the following section:

Section of coal in SE¼ (?) sec. 31, T. 37 S., R. 3 W.

	Feet
Mudstone, medium-gray, weathers light-gray	3 plus
Coal, stained with jarosite	2.4
Claystone, medium-gray with black carbonaceous laminae, lenticular	0.3
Coal (sample 56, table 3)	5.9
Claystone, light-gray, chunky, numerous plant fragments	0.6
Coal (sample 55, table 3)	3.9
Claystone, dark-brown, slightly bentonitic	2 plus

The exact stratigraphic position of this coal section was not determined because of beveling of the Dakota by pediment erosion, but it does occur at least 50 feet below the truncated top of the formation. Apparently these coal beds wedge out before reaching the map area of this report, but may be continuous with one of the Dakota coal zones of the Kanab field to the southwest.

Owing to the poor quality and thin lenticular nature of the beds which preclude current economic interest in this coal, no attempt was made to determine coal reserves of the Dakota Formation in the Tropic area.

Straight Cliffs Sandstone

Most of the coal in the Straight Cliffs Sandstone of the Tropic area occurs in two persistent zones, the lower of which contains relatively little coal, and for convenience in this discussion is named the lower coal zone. The higher zone contains the only workable coal in the Tropic area, and in this report is named the Henderson coal zone after Henderson Canyon in the northeast part of the mapped area.

LOWER COAL ZONE

This zone ranges in thickness from about 5 to 20 feet, and its base ranges from about 60 to 130 feet above the base of the Straight Cliffs Sandstone. The lower coal zone commonly consists of a variety of brown, gray, and black carbonaceous siltstone, mudstone, and claystone with scattered thin, discontinuous coal beds. At many localities coal is not present, but the zone everywhere is characterized by dark carbonaceous lutites. Where coal is present, it is generally in lenticular beds only a few inches thick. The greatest thickness of coal observed at any outcrop occurs in the following section:

Section of coal along stream channel in SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 8, T. 36 S., R. 2 W.

	Feet
Siltstone, medium gray-brown, highly carbonaceous	4 plus
Coal	1.0
Claystone, light-gray	0.1
Coal	1.4
Claystone, medium gray-brown, highly carbonaceous	1.3
Coal, bony	0.8
Siltstone, light gray-brown, moderately carbonaceous	2 plus

Sample logs from the California Company No. 1 Johns Valley (Amstrat 191-R) and Tidewater No. 41-27 Johns Valley (Amstrat D-2389) drill holes indicate multiple coal beds up to 14 feet thick through a 55- to 100-foot interval at approximately the position of the lower coal zone. As mentioned previously, however, coal of comparable thickness and stratigraphic distribution was not observed in surface exposures.

The lower coal zone of the Tropic area occurs at approximately the same stratigraphic position as the lower coal zone of Peterson and Waldrop (1965) in the southern part of the Kaiparowits Plateau. Whether or not the zones are continuous beneath the Plateau is not known at this time.

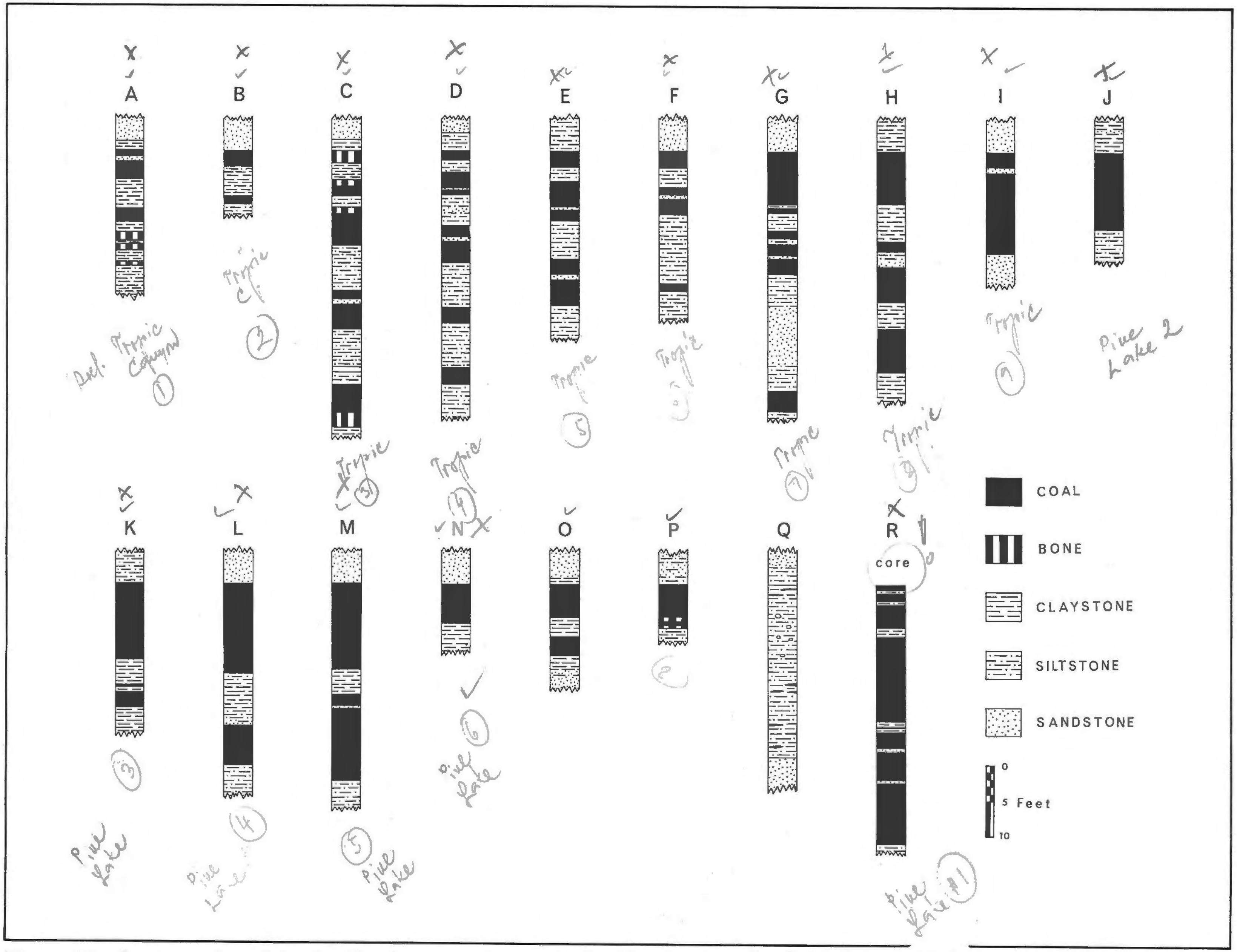

Figure 12. Sections of coal in the Henderson coal zone in the Tropic area, Garfield County, Utah (see plate 1 for locations).

HENDERSON COAL ZONE

Because of the economic potential of coal in the Henderson zone, its outcrop was mapped (pl. 1), and the base of the zone serves as a boundary between the lower and upper members of the Straight Cliffs Sandstone of this report. The base of the zone ranges from about 400 to 700 feet above the base of the Straight Cliffs. A factor that seems to have an important influence on the position of the zone is the rapid local thickening and thinning of a prominent unit of light-colored conglomeratic sandstone, which ranges in thickness from about 60 to 360 feet and occurs in an intermediate position between the lower coal zone and the Henderson coal zone.

The Henderson coal zone can be traced continuously in outcrop from the Paunsaugunt fault on the west to Henrieville Creek on the east, and probably underlies most of the northern half of the map area (pl. 1). At any one locality, coal generally occurs in multiple beds with a cumulative thickness that ranges up to 23.5 feet in outcrop (fig. 12, section M), and averages about 12 feet. Intercalated beds are characterized by a variety of clastic rocks with textures that range in size from clay to sand. Near Henrieville Creek all of the coal beds terminate rather abruptly and to the east the zone is represented only by a sequence of dark-colored carbonaceous mudstones.

Coal beds of the zone increase in cumulative thickness in the subsurface beneath the Johns Valley area. Sample logs from California Company (Amstrat 191-R) and Tidewater (Amstrat D-2389) drill holes indicate cumulative thicknesses of coal from about 20 to 75 feet. In 1960, however, the zone was cored at a point about midway between two California Company drill holes (see pl. 1), and was found to contain a cumulative thickness of 32 feet of coal (fig. 12, section R).

Sections of coal and associated rock in the Henderson coal zone at 18 localities in the Tropic area are shown on figure 12. Letters on the sections correspond to those on the geologic map (pl. 1). In general, the sections are arranged in a rough east to west order. Individual beds cannot be correlated from place to place with certainty, and could not be traced from section to section along the outcrop because of poor exposures.

RANK AND QUALITY OF COAL

Only coal from the Henderson coal zone has been analyzed for quality because this zone contains the only observed coal beds of workable thickness in the Tropic area. Eighteen analyses are listed on tables 3 and 4. Analyses on table 3 are of samples collected from various outcrops and mines. Those of table 4 are of samples from a core taken in the Johns Valley area (see pl. 1; and fig. 12, section R). The two groups of analyses are listed separately because of different factors used in calculation of percentages.

The rank of coal in the Henderson coal zone ranges from subbituminous C to perhaps high-volatile C bituminous, according to the standard classification of the American Society for Testing Materials (1954). Rank of coal in the thicker beds generally lies near the boundary line between subbituminous A and high-volatile C bituminous. Averitt (1962, p. 54) has pointed out that

> "the distinction between coals of these two particular ranks is somewhat difficult to make because the range of assigned heat values is the same for both ranks, and the final distinction is based on tests of weathering and agglomerating properties, which are applied less frequently than tests of composition and heat value. However, because the range of assigned heat values is the same for both ranks, the distinction is of less significance than the rank names suggest."

Table 3. Analyses of coal from outcrops and mines in the Tropic area and vicinity. Formation: SC = Straight Cliffs Sandstone, D = Dakota Formation. Source of analysis: USBM = U.S. Bureau of Mines (Aresco and others, 1957); BD-1 = Black & Deason, Assayers and Chemists, Salt Lake City (Robison, 1964); BD-2 = Black & Deason (new analysis, this report).

Formation and Sample number	Location	Coal section (Pl. 1)	Source of analysis	Kind of sample	Proximate analysis (percent): Moisture as-received coal	Proximate analysis (percent): Dry coal: Volatile matter	Proximate analysis (percent): Dry coal: Fixed carbon	Proximate analysis (percent): Dry coal: Ash	Proximate analysis (percent): Dry coal: Sulfur	Btu as-received basis	Btu dry basis
SC	NW¼NW¼ sec. 23, T. 36 S., R. 2 W. (Shakespear coal mine)	J	USBM	tipple	20.2	42.6	44.9	12.5	0.7	9,120	11,430
SC	ditto	J	USBM	tipple	20.9	42.6	45.3	12.1	1.0	8,910	11,270
SC	ditto	J	USBM	tipple	20.9	42.0	47.0	11.0	0.9	9,240	11,680
SC-29	SE¼SE¼ sec. 25, T. 36 S., R. 2 W.	M	BD-1	channel	19.2	46.6	44.5	8.9	1.0	9,260	11,475
SC-30	ditto	M	BD-1	channel	22.0	47.7	39.3	13.0	1.6	8,542	10,994
SC-31	ditto	M	BD-1	channel	16.3	48.3	41.4	10.3	1.0	9,506	11,342
SC-32	NE¼NE¼ sec. 36, T. 36 S., R. 2 W. (Davies coal mine)		BD-1	channel	11.0	46.1	44.1	9.5	1.0	10,126	11,363
SC-50	NW¼SE¼ sec. 26, T. 36 S., R. 2 W.	K	BD-2	channel	28.6	45.0	44.5	10.5	0.9	7,372	10,326
SC-51	NW¼SE¼ sec. 15, T. 36 S., R. 3 W.	A	BD-2	channel	26.7	40.5	36.2	23.3	0.6	6,468	8,826
SC-52	NE¼NE¼ sec. 12, T. 36 S., R. 3 W.	E	BD-2	channel	27.2	47.0	41.0	12.0	0.6	7,364	10,125
SC-54	ditto	E	BD-2	channel	28.7	42.5	44.2	13.3	0.9	7,121	9,986
SC-54	NE¼SE¼ sec. 6, T. 37 S., R. 1 W.	P	BD-2	channel	22.7	44.7	42.1	12.4	0.8	7,755	10,049
D-55	SE¼ (?) sec. 31, T. 37 S., R. 3 W.		BD-2	channel	21.6	36.5	37.8	25.7	0.7	6,307	8,085
D-56	ditto		BD-2	channel	21.7	40.7	43.5	15.8	0.8	7,620	9,723

COAL RESERVES

Reserves of coal in the Henderson zone are estimated and classified on a coal-zone basis according to standard procedures of the U. S. Geological Survey (Averitt, 1961) in view of the fact that individual beds in this zone could not be correlated.

Two categories of reserves--indicated and inferred--are considered. These categories are defined by Averitt (1961, p. 22) as follows:

> "Indicated reserves are reserves for which tonnage is computed partly from specific measurements and partly from projection of visible data for a reasonable distance on geologic evidence. In general, the points of observation are about 1 mile apart, but they may be as much as $1\frac{1}{2}$ miles apart for beds of known continuity.
>
> "Inferred reserves are reserves for which quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region and

Table 4. Analyses of coal from a core in SW¼NE¼ sec. 22, T. 35 S., R. 2 W. From an unpublished report by the Utah Engineering Experiment Station to Robert P. Kunkel and Stanley L. Thayne, 1960.

Sample number	1	2	3	4	5	6
Location in hole	289-292	292-298	298-304	304-307	310-317	318-324
Thickness in feet	3	6	6	3	7	6
Proximate analysis (percent) - as-received basis:						
Moisture	9.36	17.57	17.98	19.77	17.80	18.89
Volatile matter	32.39	34.36	38.26	37.23	37.81	36.71
Fixed carbon	28.31	26.37	33.15	35.12	30.58	35.96
Ash	29.94	21.70	10.61	7.88	13.81	8.44
Heating value (Btu)			9,740	10,130		10,300
Proximate analysis (percent) - dry, mineral-matter-free basis:						
Volatile matter	51.25	55.13	52.86	50.86	54.40	49.88
Fixed carbon	48.75	44.87	47.14	49.14	45.60	50.12
Heating value (Btu)			11,010	11,080		11,350
Rank: subbituminous A (non-agglomerating)						

for which few measurements of bed thickness are available. The estimates are based on an assumed continuity for which there is geologic evidence. In general, inferred coal lies more than 2 miles from the outcrop or from points of mining or drill hole information."

Estimated original reserves of coal in the Henderson coal zone of the Tropic area listed in table 5 total 957 million short tons, of which 470 are indicated and 487 are inferred.

Table 5. Estimated reserves of coal in the Henderson coal zone on a coal-zone basis.

Overburden (feet)	Reserves, in millions of short tons, in beds of thickness stated		
	Indicated	Inferred	Total
S½T. 35 S., R. 2 W.			
0-1000	136	99	235
1000-2000	-	171	171
2000-3000	-	57	57
Total	136	327	463
S½T. 35 S., R. 3 W.			
0-1000	1	-	1
1000-2000	3	-	3
2000-3000	1	-	1
Total	5	-	5
T. 36 S., R. 1 W.			
0-1000	22	-	22
1000-2000	43	58	101
2000-3000	8	71	79
Total	73	129	202
T. 36 S., R. 2 W.			
0-1000	183	8	191
1000-2000	27	19	46
2000-3000	-	4	4
Total	210	31	241
T. 36 S., R. 3 W.			
0-1000	38	-	38
Total	38	-	38
T. 37 S., R. 1 W.			
0-1000	6	-	6
1000-2000	2	-	2
Total	8	-	8
All townships			
0-1000	386	107	493
1000-2000	75	248	323
2000-3000	9	132	141
Grand total	470	487	957

Core hole information shows that the greatest observed cumulative thickness of coal beds in the Henderson zone is near the north boundary of the mapped area. Though it may be assumed that the Henderson zone continues northward, there is no current basis for estimation of these possible reserves.

COAL RESERVES IN STATE LANDS

State lands partly or wholly within the area underlain by the Henderson coal zone are listed below together with an estimate of the coal they may contain.

	Area in acres	Thickness of coal	Indicated reserves short tons
T. 36 S., R. 2 W., sec. 16	109	14	2,701,000
T. 36 S., R. 2 W., sec. 36	94	6	998,000
T. 36 S., R. 1 W., sec. 32	640	6	6,795,000
			10,494,000

PRODUCTION

Coal mining in the Tropic area has been sporadic and relatively insignificant. Since the first pioneer settlers arrived in 1875, a number of small mines have been opened and abandoned.

In 1931, Gregory and Moore (p. 152, 153) published descriptions of coal sections from two mines in the area. One, the Pollock mine, apparently was in SE$\frac{1}{4}$ sec. 25 T. 36 S., R. 2 W., and just across the canyon to the northwest from the Davies mine discussed below. The other, unnamed, was reported as being in sec. 5, T. 36 S., R. 2 W., but probably was at the same locality as coal section H (fig. 12) of this report in SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 9, T. 36 S., R. 2 W. Entries to both of these mines have been closed with slump material. Amount of production from the two mines is unknown, but presumably was minor.

The largest coal mine in the area is the Shakespear mine (also known as the Ray mine and the Tropic mine), located in NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 23, T. 36 S., R. 2 W. (fig. 13). It was last operated by Mr. Alton Shakespear during the winter of 1961-62. Coal was mined from several drifts and cross-cuts about 6 to 8 feet high. The backs and floors are composed of coal. Two men usually were employed while the mine was in operation, and daily production was reported to have been about 10 tons. Total production from the mine probably has been no more than a few tens of thousands of tons.

In 1952, Mr. Byron Davies opened a small mine in NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 36, T. 36 S., R. 2 W. It was operated only one winter and was abandoned. The mine consists of a single drift approximately 80 feet in length.

Total coal production from the Tropic area prior to 1966 is estimated to have been less than 50,000 short tons, nearly all consumed locally.

Oil and Gas

The first commercial oil discovery in the Kaiparowits region made in 1964, sparked considerable new interest in oil and gas possibilities of the region. This discovery was made by Tenneco Oil Company on the Upper Valley anticline where their Upper Valley No. 2 wildcat was successfully completed for 300 barrels of oil per day in the Kaibab Formation of Permian age. Significantly, the Upper Valley discovery is only a few miles east of the Tropic area.

Figure 13. Site of Shakespear coal mine in Straight Cliffs sandstone.

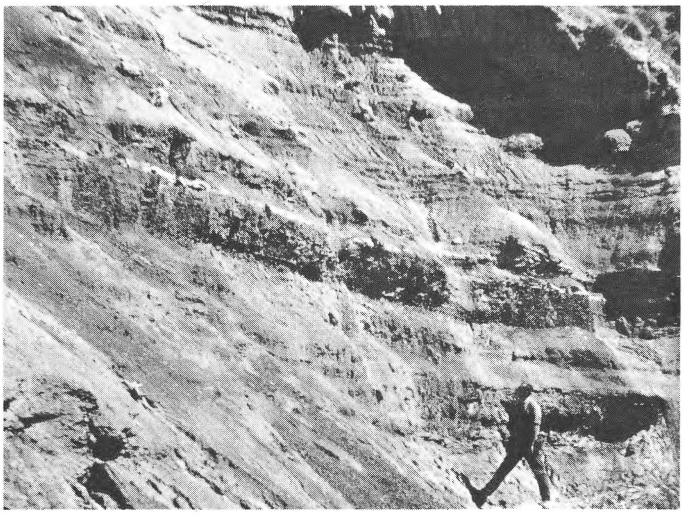

Figure 14. Outcrop of Henderson coal zone in SE¼ SE¼ sec. 25, T. 36 S., R. 2 W. (see section M, fig. 12).

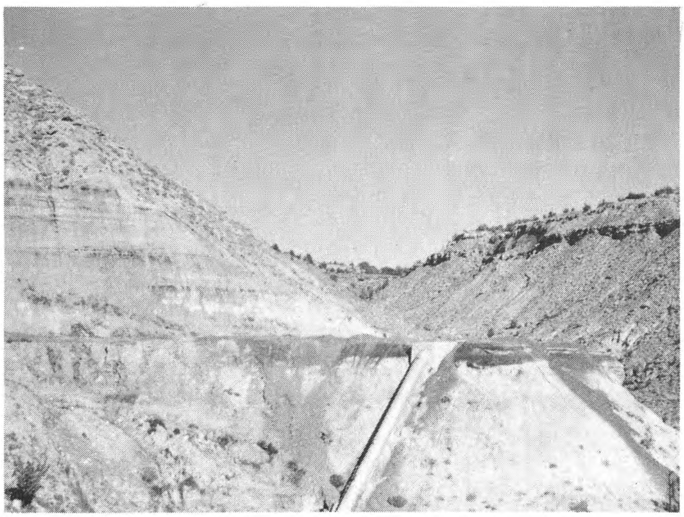

Figure 15. Site of American Mud and Chemical Company bentonite mine at base of Dakota Formation.

Four test wells for oil and gas have been drilled in the Tropic area (pl. 1). Promising shows of oil were found in all four wells, but none has produced oil in commercial quantities. Two California Company wells and one Tidewater well (fig. 10) penetrated the Johns Valley anticline and one Tenneco well penetrated the Tropic anticline. Table 6 summarizes data from these wells.

Oil and gas possibilities of the Kaiparowits region have been discussed by several writers. Especially pertinent are discussions by Heylmun (1958) and Kunkel (1965). A specific discussion of the two California Company drill tests in Johns Valley has been given by Alexander and Clark (1954).

The general consensus from reports on oil and gas possibilities of the Kaiparowits region is that most of the region of several thousand square miles with many large anticlines underlain by potentially oil-productive formations still has not been adequately tested. Kunkel (1965, p. 96) noted that shows of oil have been reported from eleven formations, but the majority of the shows have been found in only six formations. These are the Timpoweap Member of the Triassic Moenkopi, the Permian Kaibab, Toroweap, Queantoweap (= Cedar Mesa of some writers), and White Rim, and the Mississippian Redwall. Several of the anticlines have not been drilled, and most of those that have been drilled still have not been thoroughly tested.

Table 6. Wells drilled for oil and gas in the Tropic area. Data from Kunkel (1965) and American Stratigraphic Company logs 191-R, D-2195, and D-2389.

Company	Name	Location	Date completed	Deepest formation penetrated, and total depth	Remarks
California	No. 1 Johns Valley	NW¼ SE¼ sec. 22 T. 35 S., R. 2 W.	2-52	Mississippian "D" Zone 10,335'	Oil shows reported in Moenkopi, Kaibab, Cedar Mesa, Hermosa, and Molas.
California	No. 2 Johns Valley	SW¼ NE¼ sec. 22 T. 35 S., R. 2 W.	6-52	Kaibab 7,700'	Good oil shows in Timpoweap Member of Moenkopi.
Tenneco	No. 1 USA Tropic	NW¼ NW¼ sec. 15 T. 37 S., R. 2 W.	8-64	Cedar Mesa 6,836'	Oil shows reported in Moenkopi, Toroweap, and Cedar Mesa.
Tidewater	No. 41-27 Johns Valley	NE¼ NE¼ sec. 27 T. 35 S., R. 2 W.	9-65	Cedar Mesa 8,702'	Oil shows reported in Shinarump, Moenkopi, Kaibab, White Rim, Toroweap, Hermit, and Cedar Mesa. Swabbed 29.25 bbls. oil and 114.66 bbls. water in 13 hours from Shinarump at 6512-25 feet.

The two most prominent anticlines in the Tropic area have both been drilled, but the single test of the Tropic anticline is inadequate to thoroughly evaluate that structure. Promising shows of oil in all wells drilled to date, along with nearby commercial oil production from the Upper Valley anticline, suggest that the Tropic area still holds good possibilities for future oil production.

Bentonite

Extensive deposits of bentonite occur in the Dakota Formation and Tropic Shale. The beds of bentonite commonly are thickest near the base of each formation, but thickness of the beds generally fluctuates markedly along strike. Distribution of the Dakota and Tropic Formations in the Tropic area is shown on plate 1.

Of the three small mines that have produced bentonite in the Tropic area, the largest was that of the American Mud and Chemical Company, directed by Mr. Byron Davies of Cannonville. The mine is in sec. 13, T. 37 S., R. 3 W. where an 11-foot bed of bentonite at the base of the Dakota Formation was strip-mined (fig. 15). Olsen and Williams (1960, p. 5) reported that this bentonite produced from 80 to 105 barrels of gel per ton of ore. According to Mr. Davies (oral communication, 1965), most of the 4,000 tons of bentonite produced was utilized in the Glen Canyon Dam project. Mining operations subsequently were suspended and the mill has been dismantled.

A small underground mine in sec. 21, T. 37 S., R. 2 W. apparently also produced bentonite from a bed at the base of the Dakota. The mine portal now is closed by slump material, and no information is available concerning production.

Minor bentonite production also came from a strip-mine on Boat Mesa in sec. 25, T. 36 S., R. 3 W., but that operation too has been suspended. At that locality, the productive bentonite bed occurs near the top of the Tropic Shale.

Olsen and Williams (1960, p. 5) report that 2,200 acres in the vicinity of the American Mud and Chemical Company mine near Cannonville has an estimated producible reserve of 6,000 to 7,000 tons of bentonite per acre. At this time, no other data concerning bentonite reserves in the Tropic area are known to the writer.

Gravel

Large, well-sorted gravel deposits have not been observed in the Tropic area, but extensive poorly-sorted deposits are present. Several small gravel pits have been opened in the pediment deposits and at least two in alluvial deposits. One of the alluvial sources is in the creek bed of Campbell Canyon west of Tropic and the other is about one-half mile northeast of Henrieville. Most of the gravel has been used for road metal and concrete aggregate. Although of generally poor quality, gravel in the extensive pediment deposits (pl. 1) should provide ample reserves for any foreseeable needs in the area.

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PUBLISHED AND SOLD BY THE
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
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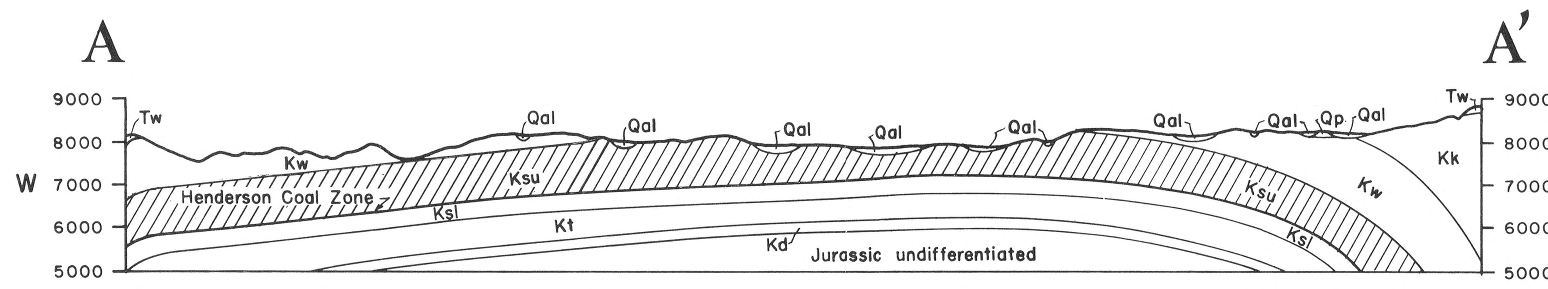

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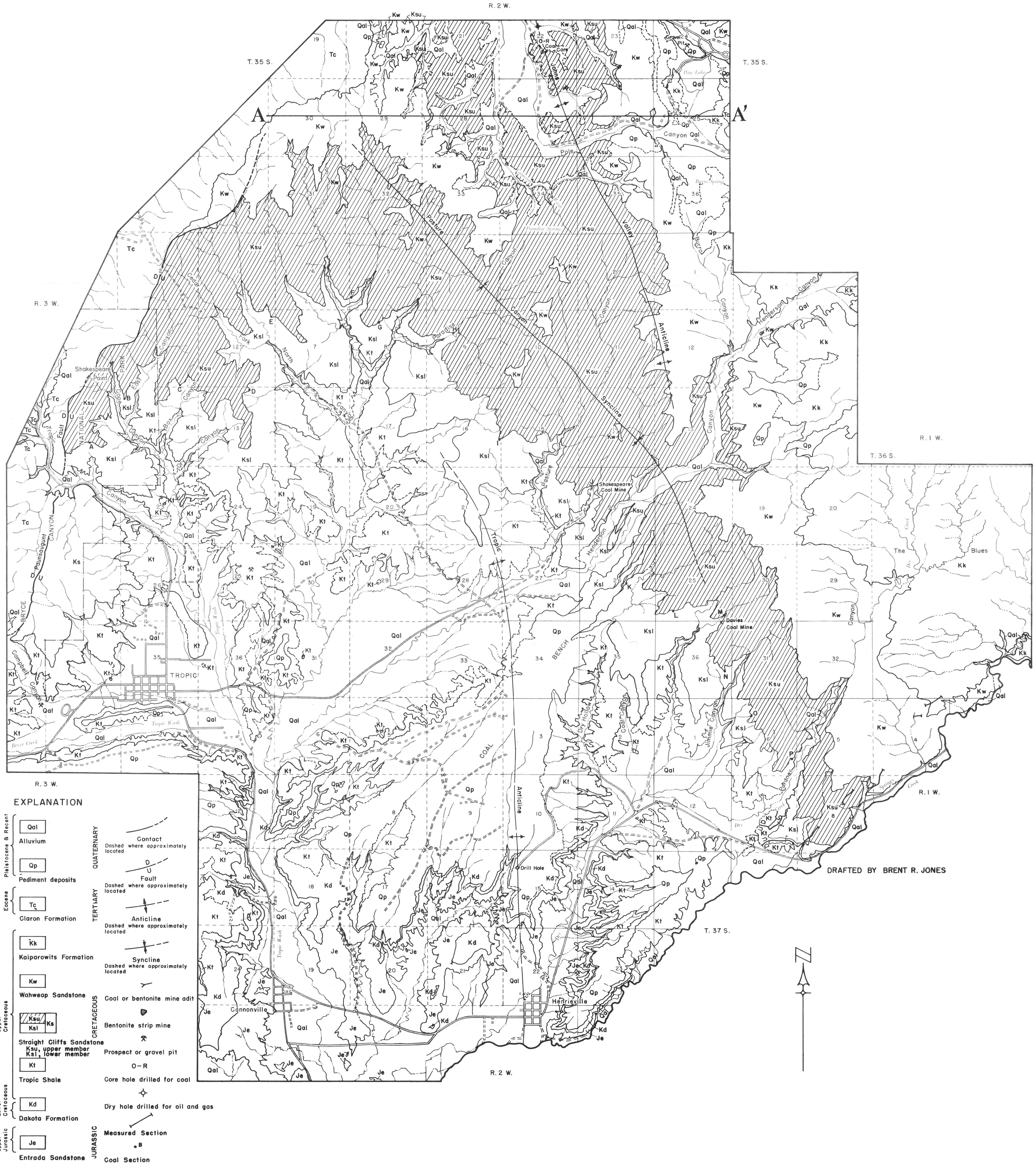

Plate 1 – GEOLOGIC MAP OF THE TROPIC AREA, GARFIELD COUNTY, UTAH

GEOLOGY MAPPED BY DR. RICHARD A. ROBISON

1966